S. George Philander
GENERAL EDITOR

ENCYCLOPEDIA OF Global Warming and Climate Change

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ENCYCLOPEDIA OF

Global Warming and Climate Change

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Encyclopedia of Global Warming and Climate Change

About the General Editor

S. George Philander, Ph.D.
Knox Taylor Professor of Geosciences, Princeton University
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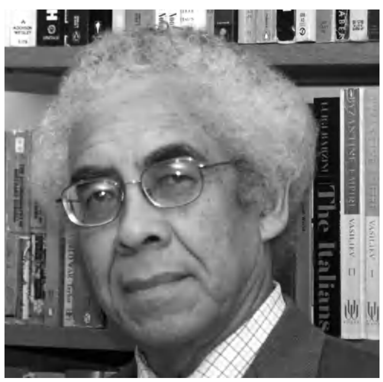
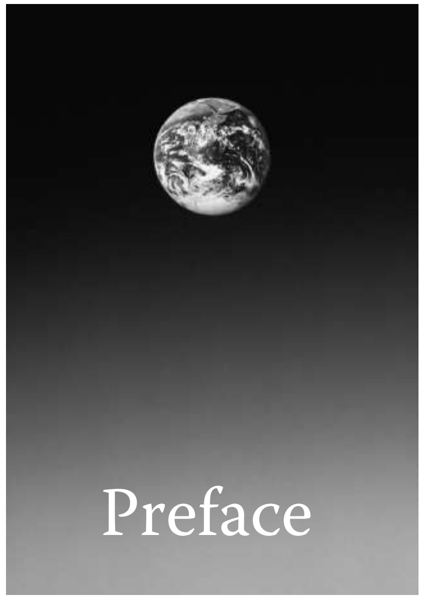


S. George Philander, Knox Taylor Professor of Geosciences at Princeton University, and Research Director of ACCESS (African Centre for Climate and Earth System Science) in Cape Town, South Africa, has a Bachelor of Science degree from the University of Cape Town, and a Ph.D. (Applied Mathematics) from Harvard University.

He is a member of the National Academy of Sciences, and a fellow of the American Academy of Arts and Sciences, the American Geophysical Union, and the American Meteorological Society. Philander's research interests include the oceanic circulation, interactions between the ocean and atmosphere that result in phenomena such as El Niño and La Niña, paleoclimates (including the recurrent Ice Ages of the past three million years), and future global climate changes. His two books for laypersons, *Is the Temperature Rising? The Uncertain Science of Global Warming*, and *Our Affair With El Niño: How We Transformed an Enchanting Peruvian Current Into a Global Climate Hazard* reflect his keen interest in improving communications between scientists and laymen.

The goal of the African climate center, which Philander is currently directing, is to give Africa its own voice on environmental issues such as global warming.



Preface

PLANET EARTH HAS become the concern of everyone. The activities of conservation biologists are now of interest to economists and political scientists who wish to find out whether certain environmental problems are best solved by regulations or market forces. Businesspeople, government officials, and politicians have become involved in science.

To be useful to such a diversity of people, the nearly 750 entries in this 3-volume encyclopedia cover a vast range of topics affecting global warming and climate change. The entries amount to more than a catalog of terms; they are all part of one story about global warming and how it is likely to affect our world.

Scientific objectivity have been the watchwords for the editors of this encyclopedia, yet different perspectives that various authors have on some of these issues are part of a conversation that citizens or students concerned about the environment ignore at their own risk. Even the title of the work, *Encyclopedia of Global Warming and Climate Change*, was carefully considered to include paleoclimatology in the discussion of weather, climate, and the current debate about global warming.

The authors of the entries include geographers, political scientists, chemists, anthropologists, medical practitioners, development experts, and sociologists. They are experts in their fields of specialty; many are researchers with extensive fieldwork experience; most of the entries on emerging techniques and technologies were written by innovators. As the volumes intend, it has become increasingly essential to bring the multiplying global warming issues, concepts, theories, examples, problems, and policies together in one place, with the goal of clearly explaining an emerging way of thinking about people and their planet.

Among the selection of articles, specific country entries are included, rather than climatic or environmental regions, to give the reader the opportunity to get information on the status of global warming—its causes and effects—by country, from Afghanistan to Zimbabwe. Also included are articles within specific categories, including: atmospheric sciences; climate; climate change effects; climate and society; climate feedbacks; climate models; institutions studying climate change; oceanography; paleoclimates; programs and conventions; and people studying climate change.

Pedagogical elements of this encyclopedia include the 4-color Introduction by General Editor Dr. S. George Philander, in which the reader can get a "bird's-eye view" of the sciences behind global warming. Also included in the work are a chronology of climate change, resource guide, glossary, and appendix of charts and table graphically presenting relevant data. Altogether, we hope the encyclopedia provides some groundwork for further discussion and spur possible action to curb global warming.

Reader's Guide

This list is provided to assist readers in finding articles related by category or theme.

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Anticyclones
Atmospheric Absorption of Solar Radiation
Atmospheric Boundary Layer
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Atmospheric Emission of Infrared Radiation
Atmospheric General Circulation Models
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Aerosols
Albedo

CLIMATE AND SOCIETY

CLIMATE CHANGE, EFFECTS

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COUNTRIES: EUROPE

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Liechtenstein
Lithuania
Luxembourg
Macedonia (FYROM)
Malta
Moldova
Monaco
Netherlands
Norway
Poland
Portugal
Romania
San Marino
Serbia and Montenegro
Slovakia
Slovenia
Spain
Sweden
Switzerland
United Kingdom

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Kiribati
Marshall Islands
Micronesia
Nauru
New Zealand
Palau
Papua New Guinea
Samoa
Solomon Islands
Tonga
Tuvalu
Vanuatu

GLACIOLOGY

Antarctic Ice Sheets
Drift Ice
Ice Ages
Little Ice Age
Sea Ice
Snowball Earth

GOVERNMENT AND INTERNATIONAL AGENCIES

Air Force, U.S.
Department of Defense, U.S.
Department of Energy, U.S.
Department of State, U.S.
Geophysical Fluid Dynamics Laboratory
Global Atmospheric Research Program (GARP)
Goddard Institute for Space Studies
National Aeronautics and Space Administration (NASA)
National Oceanic and Atmospheric Administration (NOAA)
National Science Foundation
Navy, U.S.
Office of Naval Research
United Nations
World Health Organization
World Meteorological Organization

INSTITUTIONS STUDYING CLIMATE CHANGE

Alaska Climate Research Center
Alliance to Save Energy
American Council for an Energy-Efficient Economy
American Electric Power
American Gas Association
American Geophysical Union
American Meteorological Society
Antarctic Meteorology Research Center
Applied Energy Services, Inc.
Atmosphere, Climate and Environment Information Programme (UK)
Atmospheric Research and Information Centre
BP
Canadian Association for Renewable Energies
Cantor Fitzgerald EBS
Center for Clean Air Policy
Center for Energy Efficiency
Center for International Climate and Environmental Research
Center for International Environmental Law
Center for Ocean-Atmospheric Prediction Studies
Center for Science and Environment (India)
Climate Action Network
Climate Change Knowledge Network
Climate Impacts LINK Project
Climatic Research Unit
Colorado Climate Center
Cooperative Institute for Arctic Research
Cornell University
David Suzuki Foundation
Department of Energy, U.S.
Desert Research Institute
Edison Electric Institute
Environmental and Societal Impacts Group
Environmental Defense

Environmental Development Action in the Third World
Environmental Financial Products, LLC
Environmental Protection Agency (EPA)
European Commission
FEEM (Italy)
Florida State University
Foundation for International Environmental Law and Development
Friends of the Earth
Geophysical Fluid Dynamics Laboratory
Global Atmospheric Research Program (GCRP)
Global Environment Facility (GEF)
Global Industrial and Social Progress Research Institute (GISPRI)
Greenpeace International
Harvard University
Heinz Center
Idaho State Climate Services
Indiana University
Institute of Energy Economics (Argentina)
Intergovernmental Panel on Climate Change (IPCC)
International Council of Scientific Unions (ICSU)
International Energy Agency (IEA)
International Institute for Sustainable Development (IISD)
International Research Institute for Climate Prediction
International Solar Energy Society (ISES)
International Union of Geodesy and Geophysics (IUGG)
Joint Institute for the Study of the Atmosphere and Ocean (JISAO)
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Marshal Institute
Midwestern Regional Climate Center
National Academy of Sciences, U.S.
National Association of Energy Service Companies (NAESCO)
National Center for Atmospheric Research (NCAR)
Natsource
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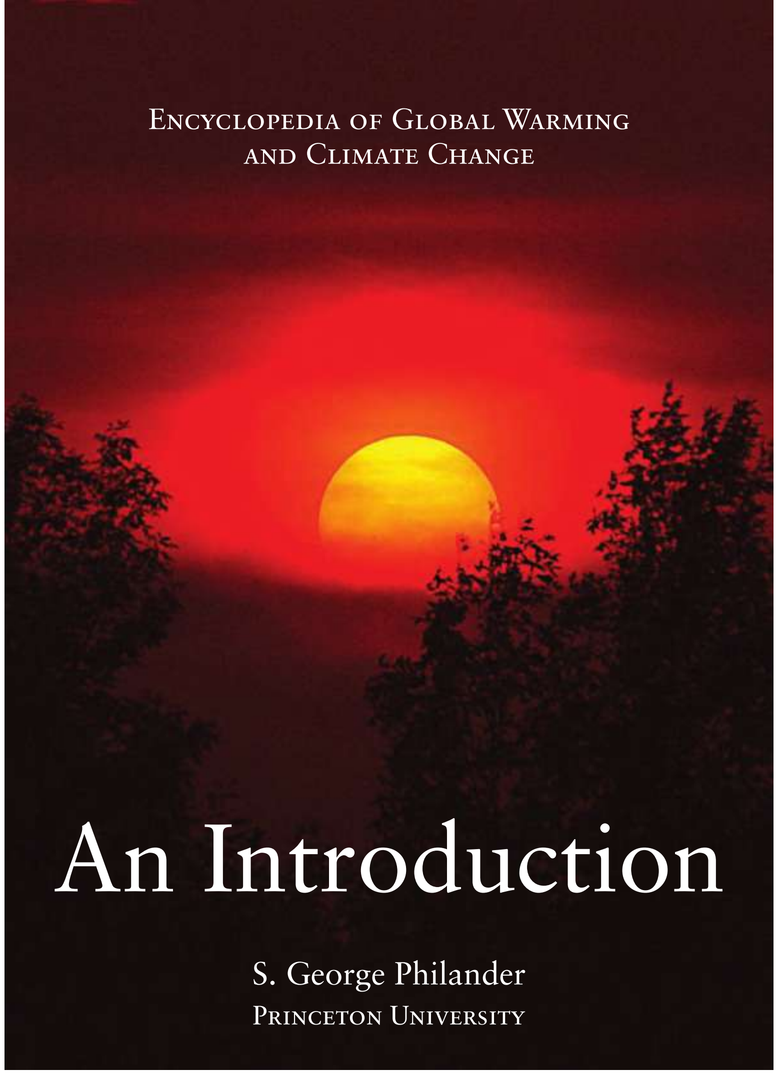
New Mexico Climate Center
OECD Annex I Expert Group on the UNFCCC
OECD Climate Change Documents
Ohio State University
Oregon Climate Service
Oregon State University
Organisation for Economic Co-operation and Development (OECD)
Penn State University
Pew Center on Global Climate Change
Renewable Energy Policy Project (REPP)
Resources for the Future (RFF)
Royal Dutch/Shell Group
Royal Meteorological Society
Scripps Institute of Oceanography
Solar Energy Industries Association (SEIA)
Stockholm Environment Institute (SEI)
Tata Energy Research Institute (TERI)
Trexler and Associates, Inc.
UN Conference on Trade and Development/Earth Council Institute: Carbon Market Program
United Nations Development Programme (UNDP)
United Nations Environment Programme (UNEP)
University Corporation for Atmospheric Research
University Corporation for Atmospheric Research Joint Office for Science Support
University of Arizona
University of Birmingham, Meteorology and Climatology Department
University of California
University of Colorado
University of Delaware, Center for Climatic Research
University of Florida
University of Hawaii, School of Ocean and Earth Science and Technology
University of Illinois, Department of Atmospheric Sciences
University of Kentucky, Agricultural Weather Center
University of Leeds, Institute for Atmospheric Science
University of Maine, Institute for Quaternary Studies
University of Maryland, Department of Meteorology
University of Miami
University of Michigan
University of New Hampshire
University of Oklahoma, Weather Radar
University of Reading, Department of Meteorology
University of Utah, Department of Meteorology
University of Washington, Atmospheric Science Department
Utah Climate Center
Weather World 2010 Project
Western Regional Climate Center
Woods Hole Oceanographic Institute
World Bank
World Business Council for Sustainable Development
World Meteorological Organization



An Introduction

S. George Philander
Princeton University

IN ITS 2007 report, the Intergovernmental Panel on Climate Change (IPCC), a large, international panel of scientists, all experts on the Earth's climate, concluded that human activities, specifically those that cause an increase in the atmospheric concentration of carbon dioxide, have started affecting the Earth's climate. The panel further predicted that far more significant climate changes are imminent. This report, and Al Gore's documentary *An Inconvenient Truth* are persuading a rapidly increasing number of people that human activities can lead to possibly disastrous global climate changes.

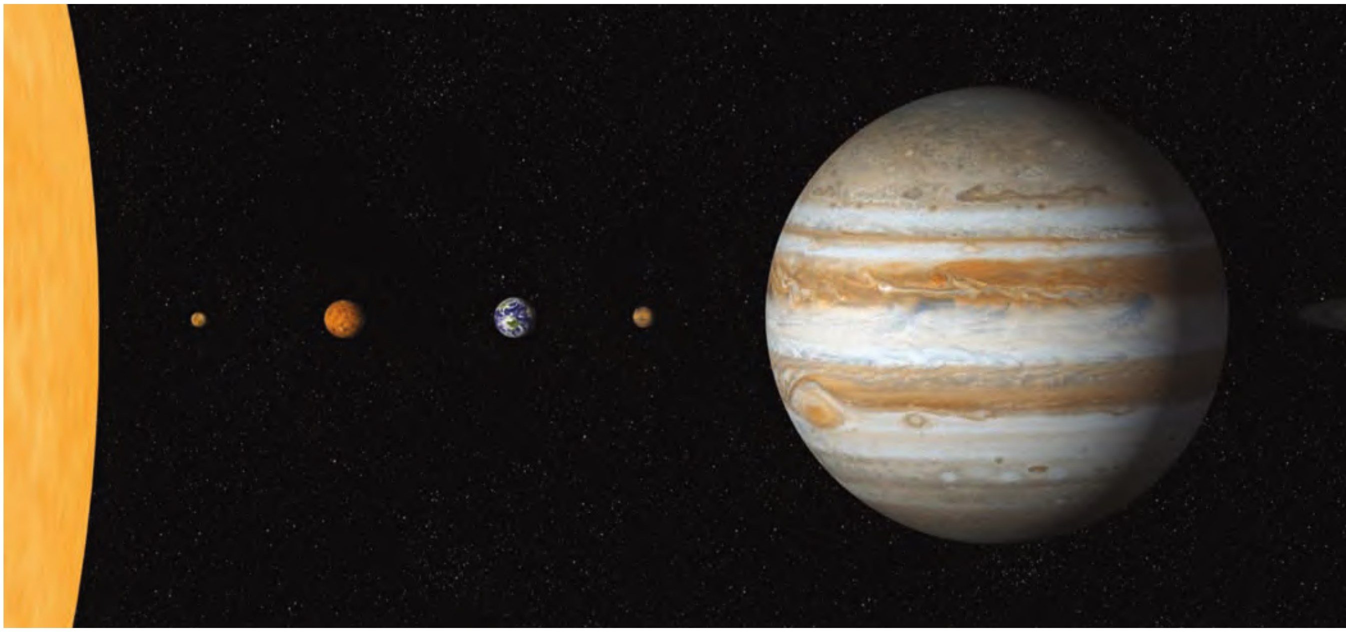
Those nonscientists are passionate about being wise and responsible stewards of the Earth, but at present they are handicapped because they take the words of the scientists on faith, and accept the reality of the threat of global warming without grasping the scientific reasons. This is most unfortunate, because our response to the threat of global warming is far more likely to be effective if it were motivated, not merely by the alarms scientists sound, but also by knowledge of how this very complex planet maintains the conditions that suit us so well. We need an awareness of how extremely fortunate we are to be the Earth's inhabitants at this moment in its long and eventful history, and an understanding of how our current activities are putting us at risk. The purpose of this encyclopedia is to help the reader learn about the intricate processes that make ours the only planet known to be habitable. This encyclopedia covers, in addition to the science of global warming, its social and political aspects that are of central importance to the ethical dilemmas that global warming poses: (1) How do we find a balance between regulations and freedom? (2) How do we find a balance between our responsibilities to future generations, and our obligations to the poor suffering today?

The first dilemma, which generates strong emotions, has caused an unfortunate polarization of a complex, multifaceted issue. The extremists who find regulations abhorrent assert that there is no evidence of global warming. (They are sometimes referred to as deniers or skeptics.) Their opponents, the believers, claim that global warming is underway, and is already causing environmental disasters. For believers, the second dilemma assumes global warming is already contributing to the suffering of the poor and therefore is an urgent priority for everyone. They refuse to accept that, for the many people who are so poor that they have nothing to lose, global warming is not an urgent issue. Dilemmas 1 and 2 call for compromises and hence for an objective assessment of the scientific results. The IPCC reports, which provide such an assessment, are explicit about uncertainties in the available results and hence favor neither the deniers nor the believers. The magnitudes of the uncertainties vary, depending on the time and region under consideration, and depending on whether we focus on temperature, the height of the ocean surface, rainfall or some other parameter.

Earth's temperatures fluctuate in a relatively narrow range; the Earth, unlike its neighbors Venus and Mars, is neither too warm nor too cold.

The following is a very brief synopsis—a bird's eye view—of the discussion of these topics in the numerous entries of this encyclopedia. This information hopefully

TINY FROM AFAR: In our solar system, Earth, third planet from the sun at left, is dwarfed by giants Jupiter and Saturn. The order of the planets starts with Mercury, which is closest to the Sun, then Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, and controversial Pluto.

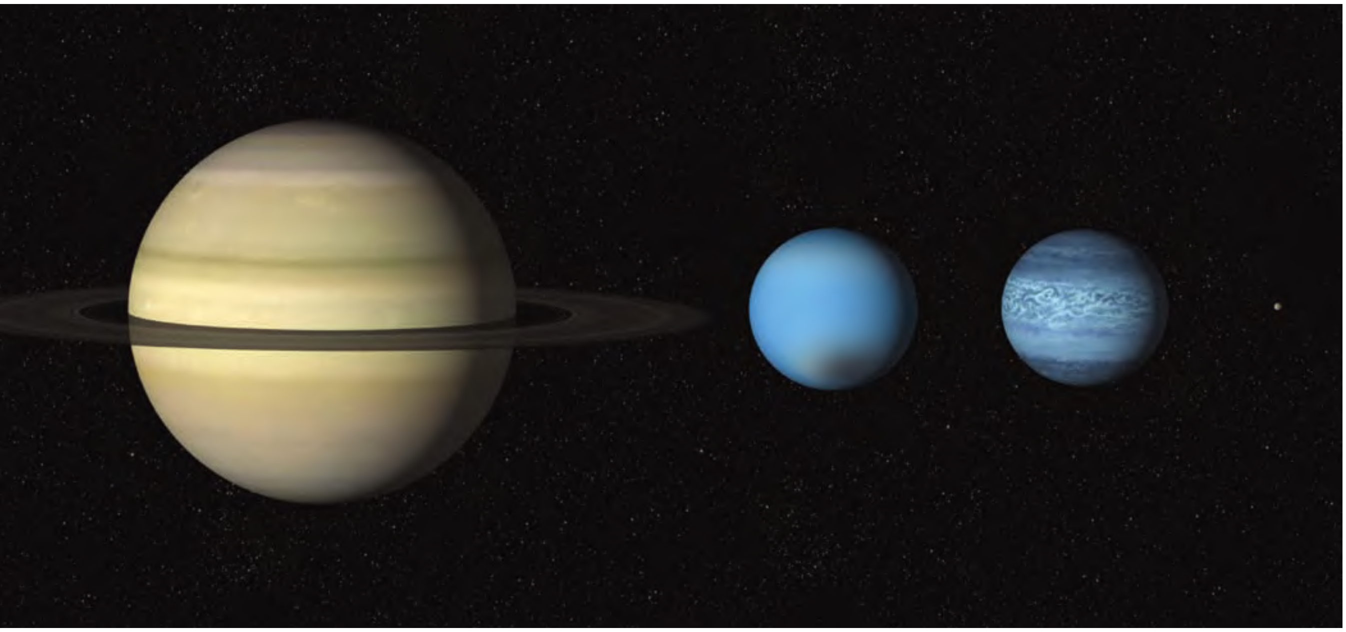


provides a basis for the development of an effective response to the threat of global warming.

Let us assume that we are aliens from another galaxy, in search of a habitable planet. On entering this particular solar system, our attention is at first drawn to the large, spectacular planets Jupiter and Saturn which are adorned with splendid rings and many moons. Earth, tiny by comparison, is a faint, blue dot from afar. Closer inspection shows that two of the Earth's main features are chaotically swirling white clouds, and vast oceans that cover nearly 70 percent of the surface. Both are vitally important to the Earth's most impressive feature of all: a great diversity of life forms that require water in liquid form. The abundance of liquid water means that, on the Earth, temperatures fluctuate in a relatively narrow range; the Earth, unlike its neighbors Venus and Mars, is neither too warm nor too cold.

The Earth's main source of energy is the sun, but this planet would be far too cold for most of its inhabitants were it not for its atmosphere, the thin veil of transparent gases that covers the globe. (If the Earth were an apple, its atmosphere would have the thickness of the peel.) This veil, by means of an intricate interplay between photons of light and molecules of air, serves as a shield that provides protection from dangerous ultraviolet rays in sunlight. The atmosphere serves as a parasol that reflects sunlight, thus keeping the planet cool; and as a blanket that traps heat from the Earth's surface, thus keeping us warm. The blanket is the greenhouse effect, which depends not on the two gases nitrogen and oxygen that are most abundant, but on trace gases that account for only a tiny part of the atmosphere, .035 percent in the case of carbon dioxide.

The most important greenhouse gas is water vapor, which is capable of engaging in escalating tit-for-tats (or positive feedbacks in engineering terms.) If atmospheric



SATELLITE VIEW: A photograph from space of a setting sun shows how thin the atmosphere is. If the Earth were an apple, its atmosphere would have the thickness of the peel.

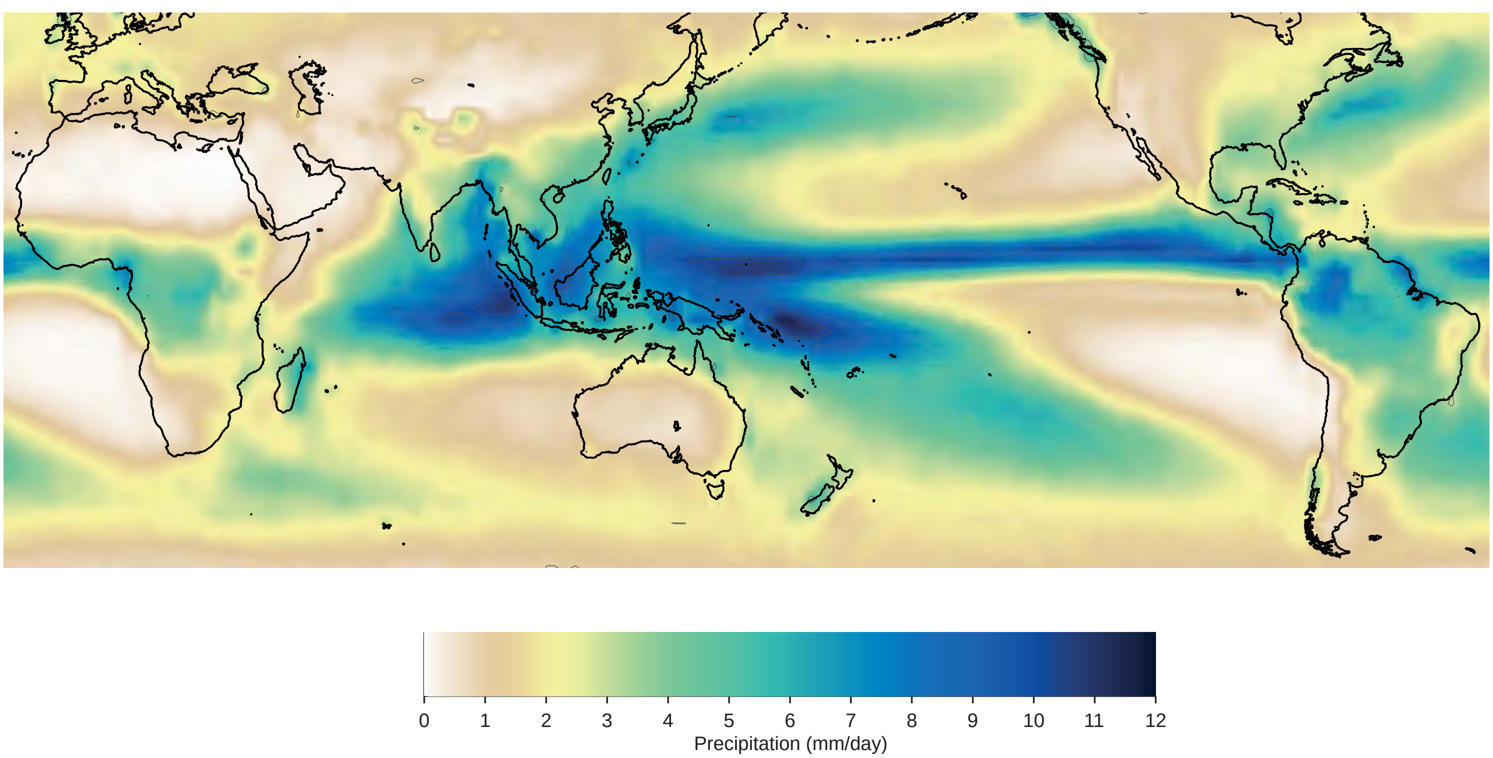
temperatures were to increase by a modest amount, then evaporation from the oceans will increase, thus increasing the concentration of water vapor in the atmosphere. The result is an enhanced greenhouse effect that increases temperatures further, causing more evaporation, even higher temperatures, and so on. The consequence could be a runaway greenhouse effect—this is thought to be the reason why Venus has no water today. The Earth was spared this fate because it is further from the sun than Venus, and is sufficiently cool for the air to become saturated with water vapor, in which case clouds form. Clouds present the following question: Is their net effect cooling, because of the sunlight they reflect, or warming because of their greenhouse effect? The answer depends on the type of cloud. Occasional glances at the sky reveal that there are many, many types. Uncertainties about future global warming stem mainly from uncertainties concerning the types of clouds that are likely in a warmer world. Simulating these fantastical, ephemeral objects is the biggest challenge for scientists trying to reproduce climate in computer models.

The westerly jet streams are so intense that some bands of latitude are known as the Roaring Forties and the Screaming Fifties.

If the atmosphere were static, we would be confined to a band of mid-latitudes, because the tropics would be too hot, the polar regions too cold. Fortunately, the atmosphere has winds that redistribute heat and also moisture, cooling off the lower latitudes, while warming up higher latitudes. The circulation that effects this redistribution includes surface winds that are easterly (westward) in the tropics, where they converge onto the regions of maximum surface temperature at the equator. There the air rises into tall cumulus towers that provide plentiful rain. Aloft, the air flows poleward, cools, and sinks over the subtropical deserts. Some of the air continues further poleward to join the westerly jet streams that are so intense that some bands of latitude are known as the Roaring Forties and the Screaming Fifties. This atmospheric circulation, despite its chaotic aspects that we refer to as weather, creates distinctive climatic zones—jungles and deserts, prairies and savannahs—that permit enormous biodiversity.

In the tropics, the atmospheric circulation, and hence the pattern of climatic zones, are strongly dependent on patterns of sea surface temperature that influence how much moisture the winds take (evaporate) from the ocean, and then deposit in rain-bearing clouds. The most surprising feature in the sea surface temperature patterns is the presence of very cold surface waters right at the equator in the eastern Pacific Ocean. (When he visited the Galapagos Islands, Charles Darwin commented on the curiously cold water at the equator where sunlight is most intense.) To explain this we need to explore the oceans, the thin film of water that covers much of the globe.

The average depth of the ocean, 3.1 miles or 5 kilometers, is negligible in comparison with the radius of the Earth, which is more than 3,700 miles or 6,000 kilometers. Both the atmosphere and ocean are very thin films of fluid, one air, the other water. Measurements made on expeditions from Antarctica to Alaska show that the ocean



PRECIPITATION MAP: There is a strong relationship between amount of precipitation and ocean temperature. Charles Darwin remarked on the surprisingly cold waters off the Galapagos Islands.

EARTH LIGHTS FROM SPACE: This map by NASA shows a composite image of lights on Earth, but both the landforms and lights appear brighter than would be visible to an unaided observer in space. Researchers were able to produce this map of lights showing urban surface activity.

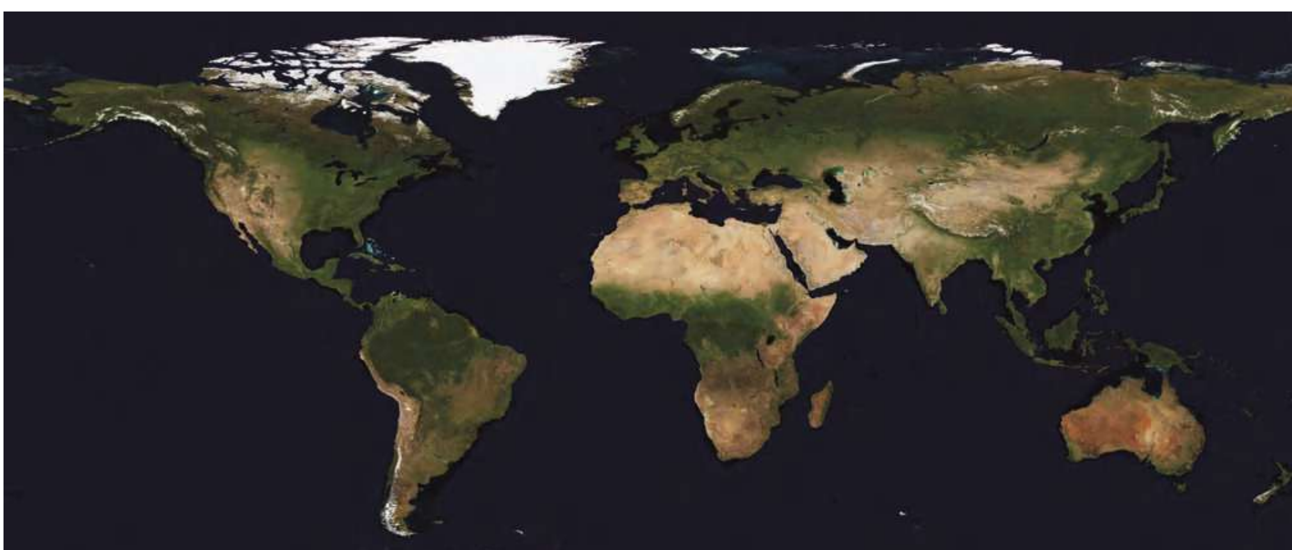
BRIGHT LIGHTS, BIG CITY: What becomes remarkably clear in this image is the energy usage in the United States, western Europe, and Japan, as compared to Africa and the rest of the world. The major national and regional contributors to greenhouse gas emissions are evident.

is composed of a very shallow layer of warm water that floats on a much colder, deep layer. So shallow is the warm layer that, at the equator near the dateline where the surface waters are warmest, the average temperature of a vertical column of water is barely above freezing. An important consequence is that the winds blowing in the right direction can easily expose cold water to the surface by driving oceanic currents in the right direction. The westward trade winds do this along the equator. They drive the warm surface water westward, causing cold water to appear near the Galapagos Islands. Winds parallel to the western coasts of Africa and the Americas, north and south, similarly drive currents that bring cold water to the surface.

Some of the oceanic currents are very slow and deep, others are swift and shallow and include the Gulf Stream and Kuroshio—narrow, rivers of warm water that flow poleward. These currents redistribute heat and chemicals, thus determining patterns of sea surface temperature and oceanic climatic zones that are evident in satellite photographs of the distribution of chlorophyll at the surface of the Earth. Chlorophyll is produced by phytoplankton, literally plants that wander. Those plants, and other life forms that depend on them, are most abundant near the ocean surface, because they need light that penetrates only tens of feet or meters below the ocean surface. When that living matter dies, it sinks and decomposes so that the cold, deep ocean is rich in nutrients.

It follows that ideal conditions for biological productivity—an abundance of light and nutrients—exists where the deep water rises to the surface. These are known as the oceanic upwelling zones, where surface waters are cold, such as off the western coasts of the Americas and Africa. The absence of a layer of warm surface waters around Antarctica makes the Southern Ocean another highly productive zone. Note that the subtropical ocean basins are in effect oceanic deserts with very few plants, because there is practically no exchange between the warm surface waters and the cold water at depth.

The plants on land and at sea, by means of photosynthesis, capture carbon dioxide from the atmosphere during their growing season, and return it when they die and

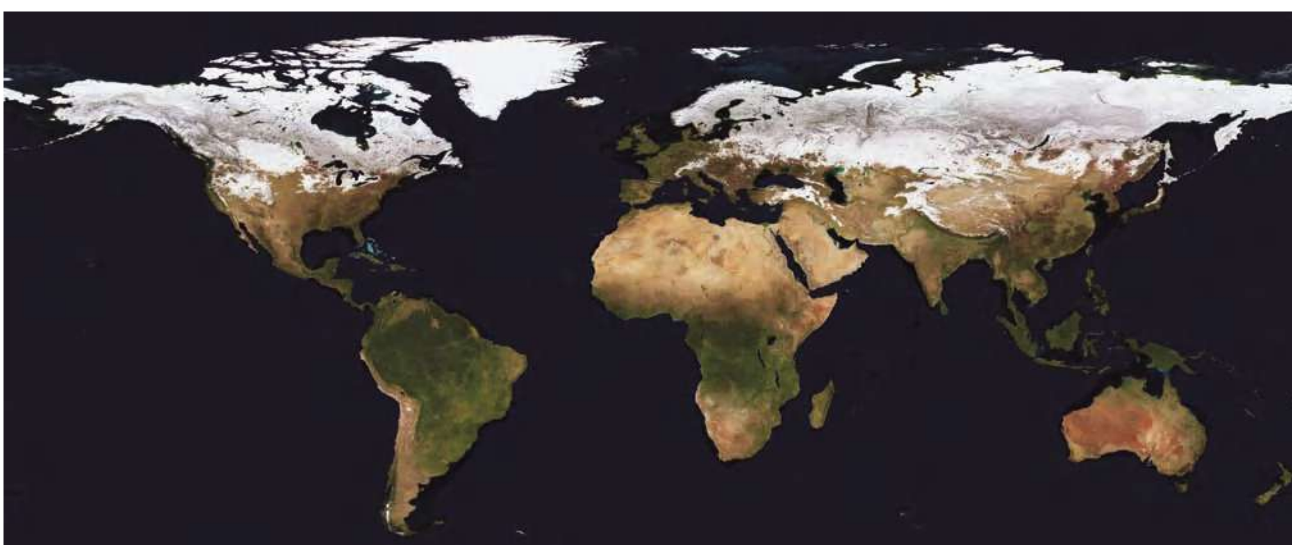


JULY AND JANUARY: True color composite satellite maps of the Earth's surface in July (above) and January 2004 (at right) from NASA illustrate the significance of seasonal snowfall.

decay. This continual flow of carbon between the ocean, atmosphere, and biosphere (the assemblage of all life on Earth) causes variations in the atmospheric concentration of carbon dioxide. Many people think of the composition of the atmosphere as fixed, in the way that water in a glass is composed of two parts hydrogen and one part oxygen. In reality the atmospheric composition changes continually because each constituent participates in a biogeochemical cycle. (The best known is the hydrological cycle, which is associated with continual changes in the atmospheric concentration of water vapor.) At present, we are interfering with the carbon cycle by burning fossil fuels, and thus emitting carbon into the atmosphere. The oceans and the plants absorb a large fraction, but much remains in the atmosphere so that the concentration there is rising rapidly.

A thousand years ago, the northern Atlantic was so warm that Greenland had a large enough population for the pope to send a bishop.

The ocean, atmosphere, and biosphere form a complex interacting system capable of generating fluctuations on its own. This is known as natural variability, in contrast to variability forced by daily and seasonal changes in sunlight, or by human-induced changes in the composition of the atmosphere. Daily changes in the weather, the best-known examples of natural variability, are as natural as the swings of a pendulum and would be present even if there were no variations in sunlight. Another natural fluctuation, with a much longer timescale of years rather than days, is the oscillation between El Niño and La Niña in the Pacific Ocean. From a strictly oceanic perspective, these phenomena are associated with changes in sea surface temperatures, in the currents, and so on, that are attributable to changes in the winds. Along the equator, those winds are intense during La Niña, weak during El Niño. Why do the winds change? From a meteorological perspective, the large

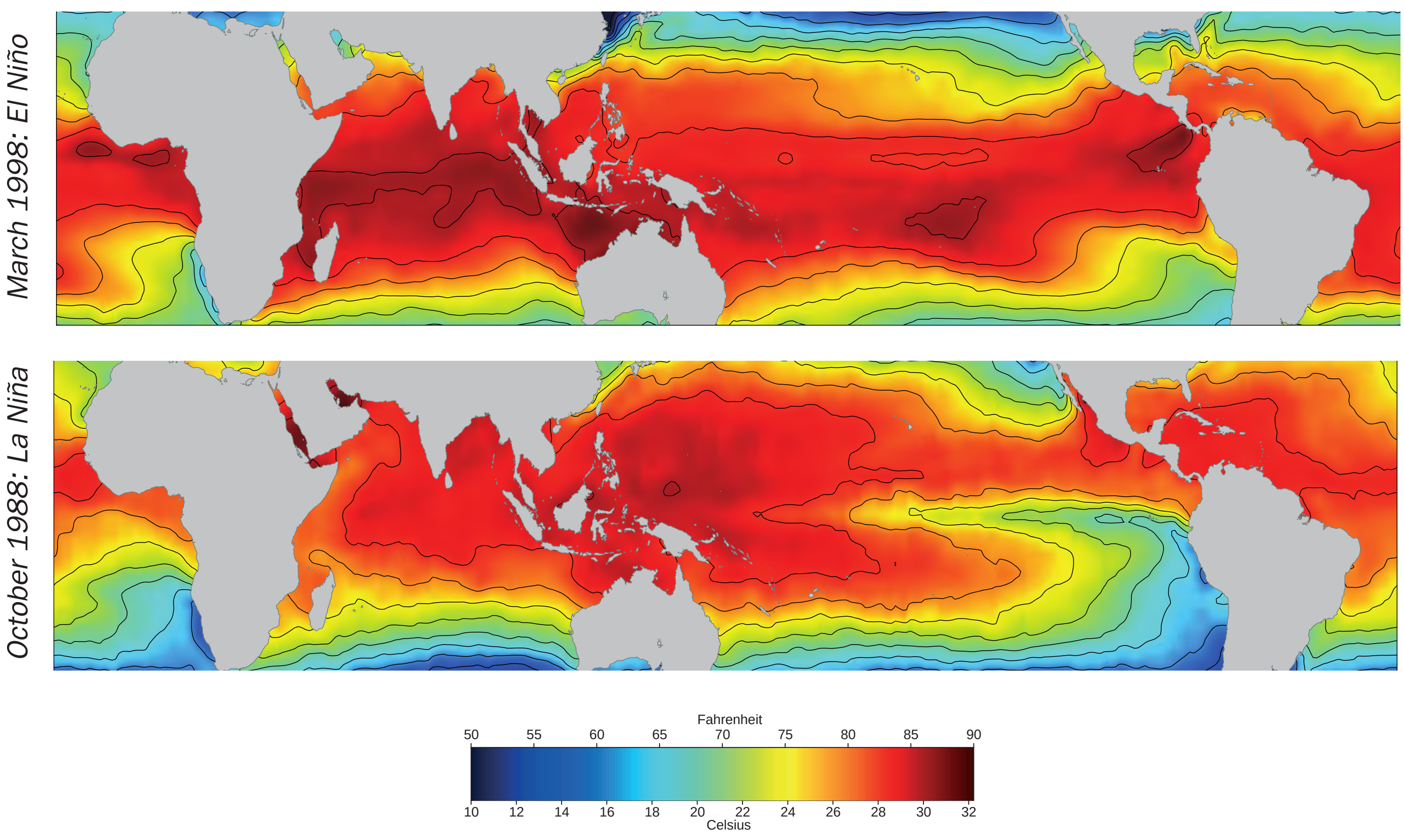


ALBEDO EFFECT: Snow-covered regions effectively cool the Earth by reflecting sunlight back into space, and hence changes in the range of snow cover can serve to amplify climate changes.

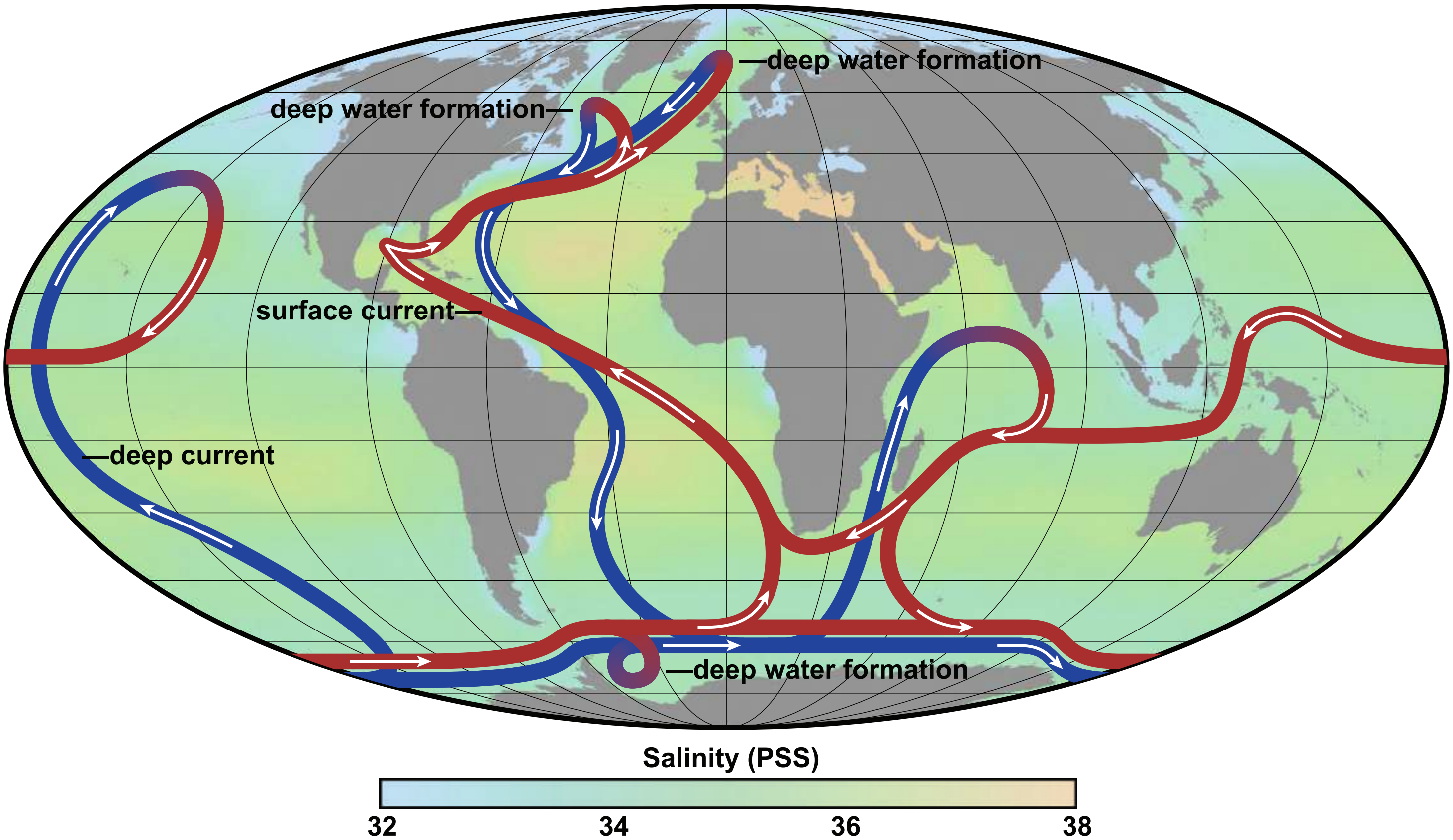
temperature contrast between the western and eastern equatorial Pacific during La Niña drives intense winds that weaken when the contrast weakens. This circular phenomenon—atmospheric changes are both the cause and consequence of oceanic changes—implies that El Niño and La Niña are consequences of interactions between the ocean and atmosphere.

We know a great deal about daily changes in weather because we have ample opportunities to study those changes. Over the past few decades, we learned a fair amount about El Niño, because that phenomenon occurred several times during that period. The past centuries and millennia were also characterized by naturally occurring fluctuations, but information about those climate fluctuations is scant, because of the lack of instrumental records. A thousand years ago, the northern Atlantic was so warm that Greenland had a large population, sufficiently large for the Pope to send a bishop.

That warm period was followed by the frigid Little Ice Age. Those changes were presumably aspects of natural variability, but as yet they are unexplained. Because we know very little about natural variability, it is not possible to determine whether a few unusually warm years, or a few intense hurricanes such as Katrina, or the unusually strong El Niño of 1997, indicate the onset of global warming. Scientists had to search carefully for distinctive patterns, for the "footprints" of global warming, before they could conclude in the 2007 IPCC report that humans activities are affecting the global climate.



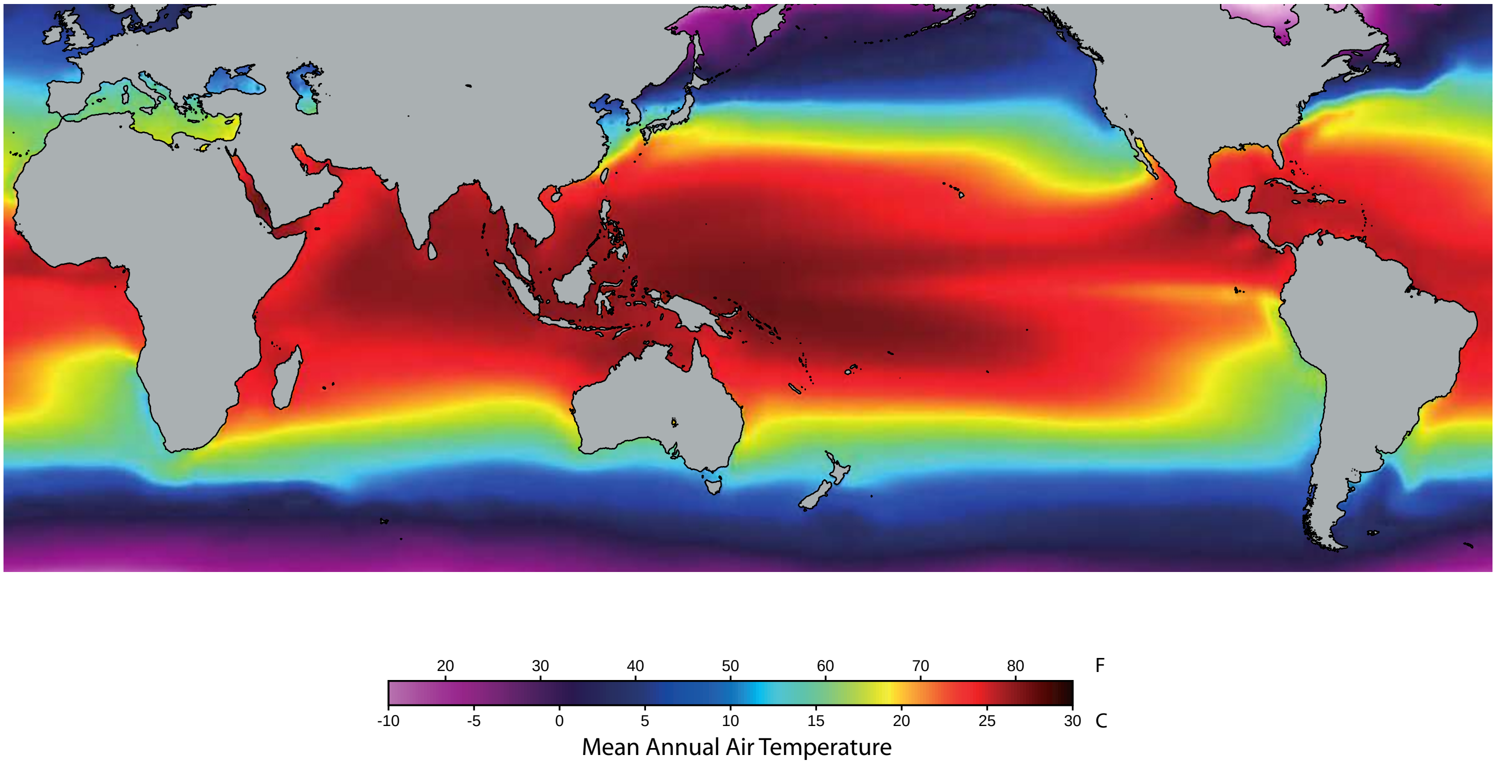
NATURAL FLUCTUATION: With a timescale of years rather than days, the oscillation between El Niño and La Niña in the Pacific Ocean governs weather patterns and storm activity.



OCEAN CURRENTS: The warm surface currents (red) intertwine with the deep cold currents (blue), creating climate patterns across the Earth. (Robert Simons/NASA)

The composition of the atmosphere, which strongly influences climate, depends on biogeochemical cycles involving not only the ocean, atmosphere and biosphere, but also the solid Earth. *Terra firma* is anything but firm; its surface is composed of several slowly moving, nearly rigid plates, on some of which the continents float. This is the surface manifestation of motion deep in the interior of the Earth, where temperatures are very high because of the decay of radioactive material. Earthquakes are common along the plate boundaries, which feature tall mountains where the plates collide, or deep trenches where one plate dives (subducts) beneath another. In regions of subduction, volcanoes are common; that is why the Pacific rim is known as a "ring of fire." When they erupt, volcanoes emit carbon dioxide into the atmosphere. That gas interacts with water vapor to form an acid that erodes rocks, causing the removal of carbon dioxide from the atmosphere. Hence, the building of mountains—the creation of extensive rock surfaces—promotes the removal of carbon dioxide from

> *Some 65 million years ago, the Earth was so warm that there was no ice on the planet. Palm trees and crocodiles flourished in polar regions.*



TEMPERATURE MAP: The areas in dark red with the highest temperatures correlate to the Precipitation Map—regions with the highest precipitation are also the warmest.

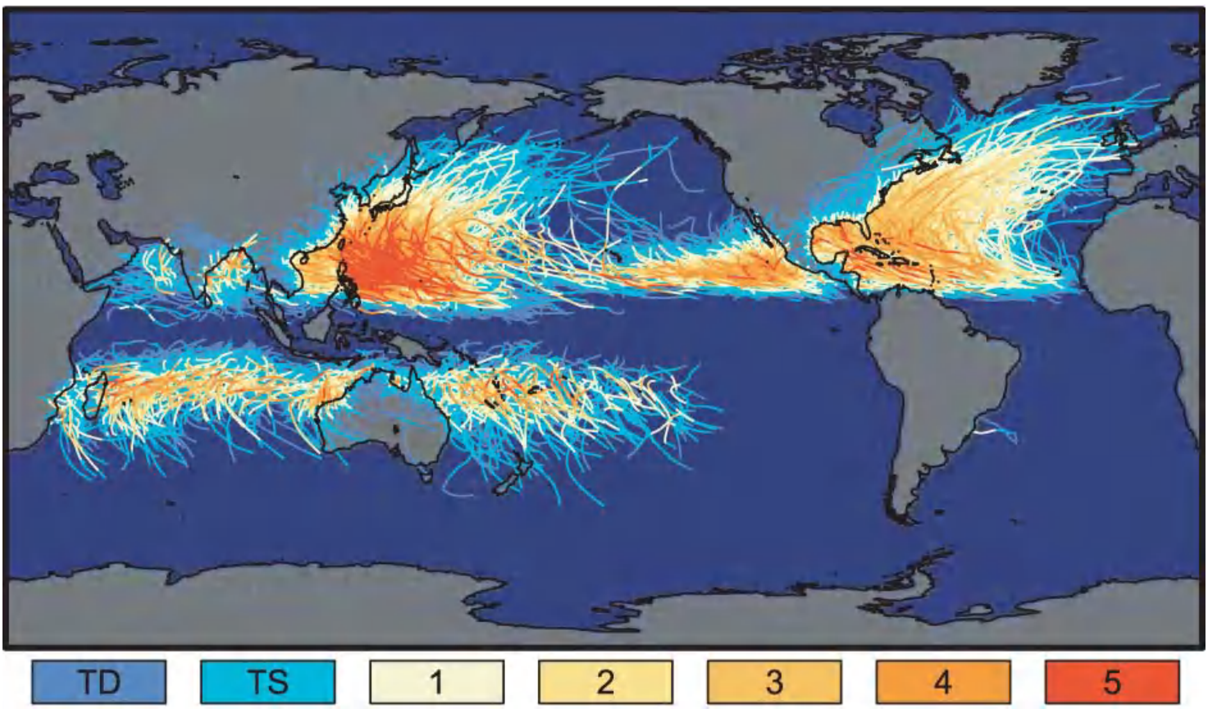
the atmosphere. Continental drift therefore affects the atmospheric composition by bringing into play processes that increase, and others that decrease, the concentration of carbon dioxide. Volcanic eruptions contribute to the increase, the building mountains to the decrease. Continental drift affects climate in a more direct manner by changing the distribution of continents. At one time all the continents were together and formed a supercontinent, Pangea, with a northern part known as Laurasia, and a southern Gondwanaland that included the Antarctic continent. With the breakup that started around 250 million years ago, Africa and South America separated to form the Atlantic Ocean. India traveled northward until it collided with Asia, and started creating the Himalayas.

For those interested in global warming, what happened after the demise of the dinosaurs some 65 million years ago is of special interest. At that time, the Earth was far warmer than it is today, so warm that there was no ice on the planet. Palm trees and crocodiles flourished in polar regions, in part because the atmospheric concentration of carbon dioxide was much higher than it is today. Subsequently, the continued drifting of the continents, accompanied by decreases in the atmospheric concentration of carbon dioxide, contributed to the global cooling. (This period is known as the Cenozoic, the age of new animals, specifically mammals.) What caused the Ice Ages? Why did they start 3 million years ago? The answers involve slight changes in sunlight. Sunlight varies daily and seasonally because the Earth rotates on its tilted axis once a day, while orbiting the sun once a year. Additional variations over

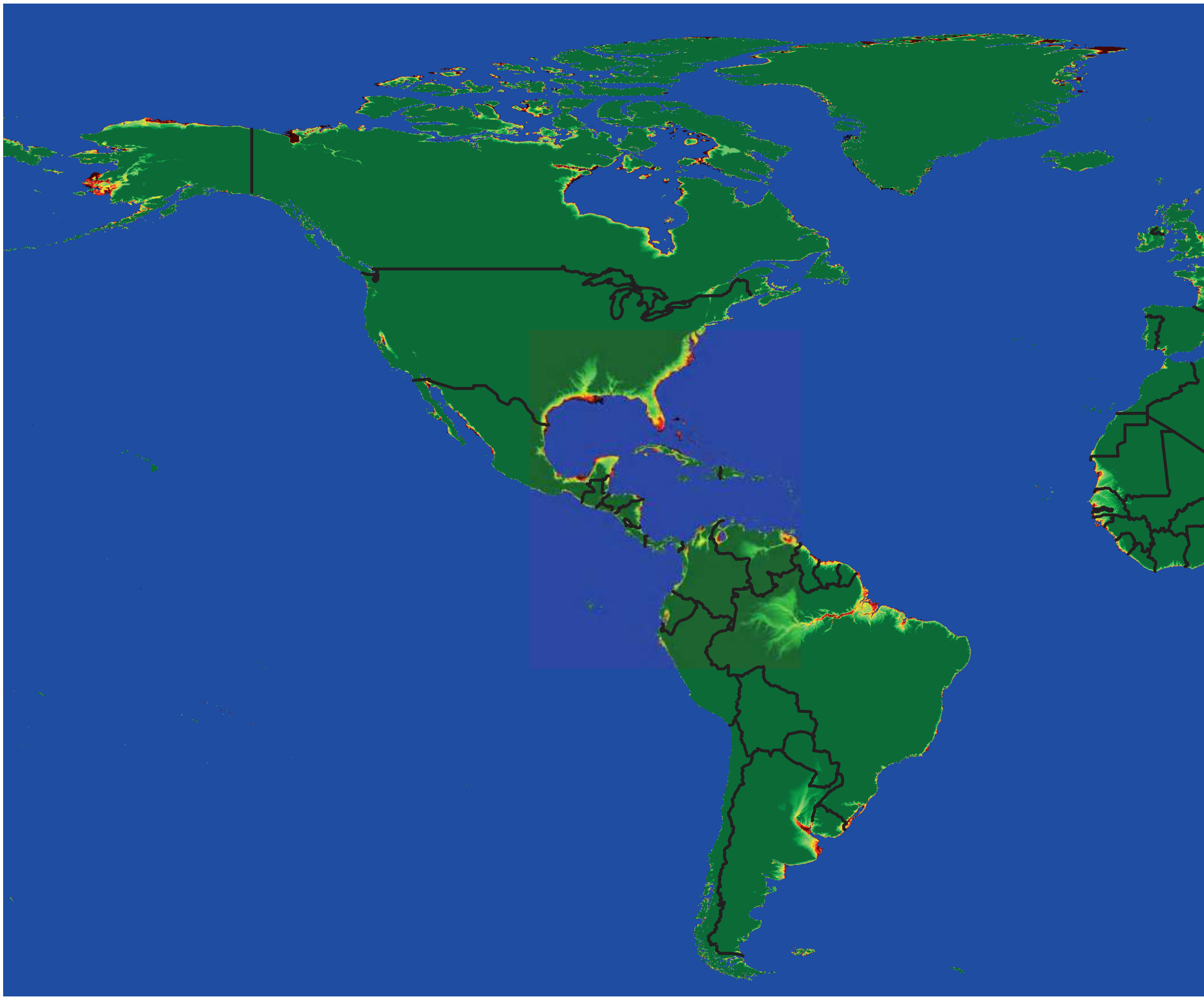
Glaciers, because they are white, reflect sunlight. This reflection deprives the Earth of heat, lowers temperatures, and promotes the growth of glaciers.

much longer periods of thousands of years are associated with slight oscillations of the tilt of the axis, which also precesses, while the orbit changes gradually, from a circle into an ellipse, and back to a circle. The moon and several planets cause these Milankovitch cycles, which have been present throughout the Earth's history. The climate fluctuations induced by these sunlight cycles were modest up to 3 million years ago, but then started amplifying. That amplification required positive feedbacks that translated the slight variations in sunlight into Ice Ages. The feedbacks were brought into play by the drifting of the continents. A complex and poorly understood interplay between the slow, erratic drifting of continents, and the regular variations in sunlight, caused the Ice Ages to be absent during some periods, and prominent during others, such as the present.

The global cooling associated with the drifting of the continents that started 60 million years ago inevitably led to the appearance of glaciers, first on Antarctica, then on northern continents around 3 million years ago. Glaciers, because they are white, reflect sunlight. This deprives the Earth of heat, lowers temperatures, and



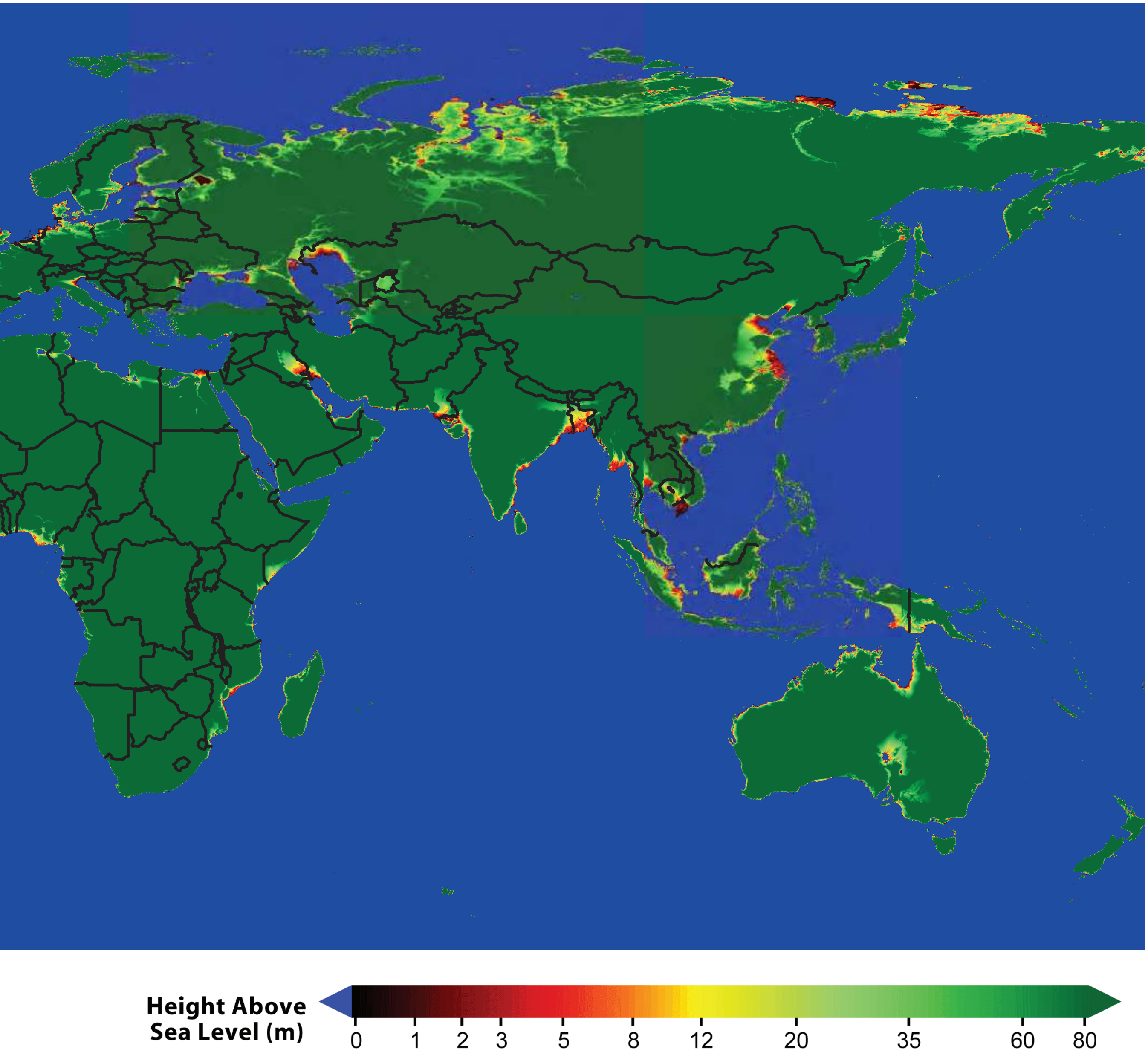
HURRICANE PATHS: A plot of the intensity and paths of hurricanes and typhoons. How global warming will affect the development and strength of storms is a subject of debate and study.



POTENTIAL FLOODING: This is a topographic map designed to emphasize regions near sea level that could potentially be vulnerable to sea level rise, though over centuries rather than decades.

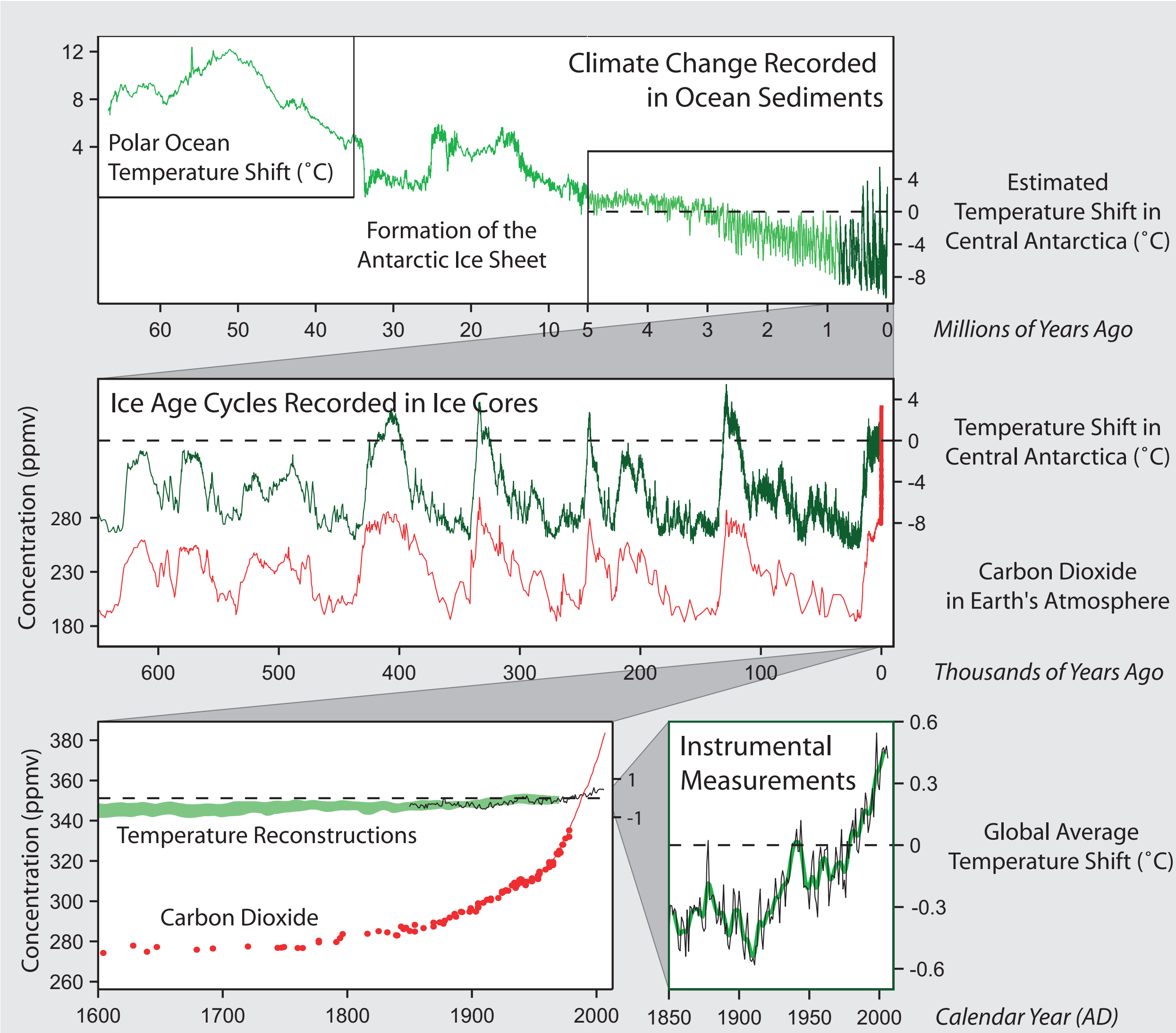
promotes the growth of glaciers. Hence, the appearance of continental glaciers was one of the feedbacks that amplified the response to Milankovitch variations in sunlight. Trapped in those glaciers are bubbles of air that tell us about past changes in the atmospheric composition, past variations in the atmospheric composition of carbon dioxide. As yet it is not known why the concentration varied, or to what degree the variations contributed to the temperature fluctuations.

Solving the puzzle of the Ice Ages will be a major contribution to our ability to anticipate future climate changes, because the solution will tell us a great deal about the sensitivity of the Earth's climate to changes in the atmospheric concentration of carbon dioxide. In the meanwhile, familiarity with the data can give us a valuable perspective on global warming by giving us a geological context for our activities over the past century. From a geological perspective, the present is a special moment



in the history of our planet for at least two reasons. The first is that the Earth is currently in an era of high sensitivity to small disturbances. Starting approximately 3 million years ago, the Earth's response to slight variations in sunlight, the Milankovitch cycles, have included enormous climate fluctuations associated with recurrent Ice Ages. Only some of the feedbacks that are involved have been identified. The second reason why the present is special is that we are currently enjoying the temperates of one of the brief interglacial periods that separate prolonged Ice Ages.

The previous interglacial was more than 100,000 years ago but, at that time, we humans were few in numbers, and had very limited capabilities. We were ready when the current interglacial started, some 10,000 years ago, and proceeded to advance with astonishing rapidity, inventing agricultures, domesticating certain animals, developing cultures, and building cities. We developed so rapidly that we are now



HISTORY OF CLIMATE CHANGE: A compound graphic depicts Earth's climate change across the millennia and centuries. Top: Global cooling over the past 60 million years. Middle: Recurrent Ice Ages over the past 600,000 years. Bottom: Rise in temperature and carbon dioxide over the past four centuries. The information in the top panel comes from cores drilled into the ocean floor, where sediments contain remains of primitive organisms that live near the ocean surface. The information in the middle panel comes from Antarctica, where the accumulated snowfall of hundreds of millennia created deep glaciers.

geologic agents, capable of interfering with the processes that make this a habitable planet. For more than a century, we have caused the atmospheric concentration of carbon dioxide to grow exponentially. This, surely, is a time for circumspection and caution.

MAPS AND PLOTS PREPARED BY ROBERT A. ROHDE
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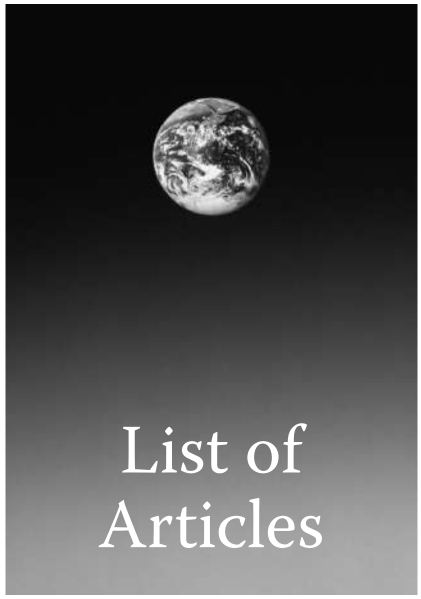

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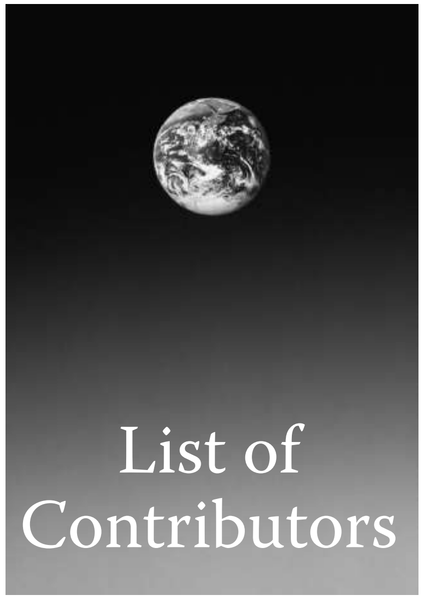

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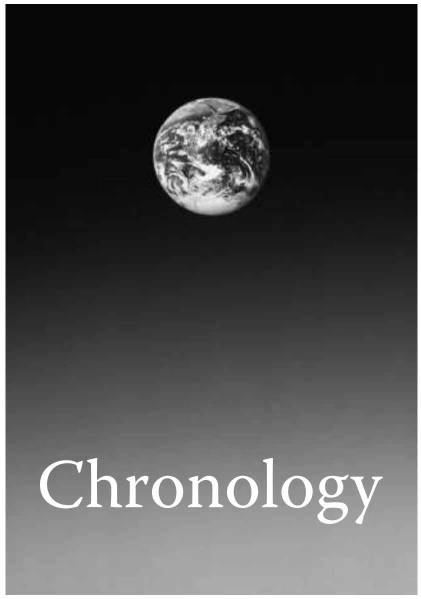

Chronology

4.5 billion years ago
The Earth, newly formed, had the hottest climate in the planet's long history. Temperatures were hot enough to liquefy rock. Radioactive elements in Earth's core generated heat and pressure as they decayed, pushing molten rock toward Earth's surface. Volcanoes also brought molten rock to the surface, liberating heat. Volcanoes spewed carbon dioxide into the atmosphere, causing the Greenhouse Effect.

3.8 billion years ago
As the mass of radioactive elements in Earth's core diminished, the climate cooled and the first rock formed. The cooling of the atmosphere liquefied water vapor, which fell to Earth as rain.

3.5 billion years ago to 3 billion years ago
The origin of life enhanced the cooling of the climate, for among the first life were single-celled photosynthetic algae. Like plants, these algae consumed carbon dioxide and exuded oxygen. The reduction of carbon dioxide in the atmosphere weakened the Greenhouse Effect. With the reduction in carbon dioxide, temperatures dropped below freezing, causing the planet's first ice age 3 billion years ago.

2.9 billion years ago
The retreat of the glaciers inaugurated a long period of warm climate. The sun, burning steadily brighter, bathed Earth in its heat. Warm inland seas covered Earth, moderating the climate. Ocean currents circled the globe, spreading warm water from the equator to the poles.

800 million years ago to 550 million years ago
Glaciers covered the oceans as well as the land, killing photosynthetic algae that lived in the ocean. With algae in small numbers they were able to remove only a fraction of carbon dioxide from the atmosphere. With no check on its accumulation, carbon dioxide increased in the atmosphere, causing the Greenhouse Effect. The Greenhouse Effect ended the Late Proterozoic Ice Age roughly 550 million years ago, inaugurating a new warm period.

350 million years ago to 280 million years ago
The lush plant growth of the Carboniferous Era confirmed that the climate was warm and that carbon dioxide, essential for plant growth, was abundant.

230 million years ago
The continents gathered into a single landmass called Pangea. Because it was near the equator, Pangea's climate was tropical.

135 million years ago to 65 million years ago
Temperatures soared 20 degrees Fahrenheit warmer than today's temperatures during the Cretaceous Era.

Forests covered Antarctica. Ocean currents again carried warm water to the poles.

65 million years ago
An enormous meteor impacted Earth, ejecting a gigantic cloud of debris and dust. It ignited widespread fires, which pumped ash into the atmosphere. The debris, dust, and ash blocked out much of the sun's light, chilling the climate. So severe was the reversal in climate that the dinosaurs and a large number of marine species, unable to cope with the new conditions, perished.

55 million years ago to 35 million years ago
Temperatures declined 20 degrees F (11 degrees C). Glaciers formed on Antarctica.

130,000 years ago
The climate was again warmer than it is today. The water from melting glaciers flowed to the oceans, raising the sea level 60 ft. (18 m.) higher than it is today.

100,000 years ago
The climate cooled yet again and glaciers once more spread across the continents, plunging Earth into its most recent ice age.

16,000 to 13,000 years ago
The glaciers were in retreat, temperatures rose nearly 15 degrees Fahrenheit.

12,900 and 11,500 years ago
Temperatures during the Younger Dryas fell 50 degrees Fahrenheit in only a decade

7,000 years ago
Temperatures peaked at 2–3 degrees F (1–1.5 degrees C) above current temperatures. The climate remained warm and wet for another 3,000 years.

1,000 to 1,300 C.E.
The Medieval Warm Period rewarded peasants with bountiful crops. With food in surplus, human population increased.

1400 to 1840
The Little Ice Age covered the globe with record cold, large glaciers, and snow. This massive climate change triggered disease, famine, and death. Today, many scientists around the world believe that global warming caused by the Greenhouse Effect will be the fastest warming of the Earth since the termination of the Little Ice Age.

1824
French mathematician and physicist Jean Baptiste Joseph Fourier established that a buildup of carbon dioxide in Earth's atmosphere warms the climate.

1859
Irish scientist John Tyndall discovered that some gases block infrared radiation. He suggested that changes in the concentration of the gases could bring climate change.

1863
Tyndall announced that water vapor is a greenhouse gas.

1875
British scientist James Croll established that ice and snow reflect sunlight into space and cool the Earth.

1896
Swedish scientist and Nobel laureate Svente Arrhenius coined the phrase *Greenhouse Effect* and predicted that the Earth's climate is slowly warming. Arrhenius published the first calculation of global warming from human-induced emissions of carbon dioxide.

1897
British scientist Thomas C. Chamberlin established the link between ice ages and low concentrations of carbon dioxide and between warm climates and high concentrations of carbon dioxide.

1920 to 1925
The opening of Texas and Persian Gulf oil fields inaugurated an era of cheap energy. The burning of petroleum releases greenhouse gases into the atmosphere, warming the climate.

1924
German climatologist and geologist Alfred Wegener posited that the continents move slowly across Earth. When they are near the equator their climate is warm, while near the poles their climate is cold.

1930
Serbian geophysicist Milutin Milankovitch proposed that changes in the eccentricity of Earth's orbit cause climate change, including ice ages.

1932
Meteorologist W.J. Humphreys elaborated the conditions for a return to an ice age. He believed that an increase in debris in the atmosphere and the reflection of sunlight by ice and snow might return Earth to an ice age.

1933 to 1935
The drought of the 1930s created dust storms on the Plains. The worst dust storm of the Dust Bowl gripped the Plains on what later becomes known as Black Sunday. President Franklin Roosevelt established the Soil Erosion Service in response to the devastation of the Dust Bowl and as a part of his New Deal programs to create jobs. The Soil Erosion Service was the predecessor of the Soil Conservation Service established in 1935, which is known today as the Natural Resources Conservation Service (NCRS).

1937
Royal Meteorological Society president George Simpson posited that an increase in solar radiation might cause an ice age. By warming the poles more than high altitudes, the increase in solar radiation would intensify the circulation of the atmosphere, carrying moisture to high latitudes, where it would fall as snow. If enough snow accumulated, a new ice age would ensue.

1938
Amateur scientist G.S. Callendar recorded an increase in temperatures in the Artic and posited the Greenhouse Effect as the cause.

1939
Simpson announced that the atmosphere seems to keep the climate nearly constant by regulating the amount of clouds. The more clouds, the lower the temperature, and the fewer clouds, the warmer the temperature.

1940
Many scientists dismissed Callendar's claims. However, in response to his theory scientists began to develop new ways to measure the history of and current conditions of Earth's climate.

1945
The U.S. Office of Naval Research began generous funding of many fields of science, some of them useful for understanding climate change.

1950
American scientist Charles F. Brooks announced that Artic ice might be melting and that, once started, the melting might shrink the ice to a vestige of its former size and raise sea levels.

1950s
The development of new technology led to an increased awareness of global warming and the Greenhouse Effect. Researchers began to show that the level of carbon dioxide in the atmosphere was rising each year and people became concerned about pollution.

1956
American scientists Maurice Ewing and William Donn posited that the last ice age had rapidly descended on Earth when the North Pole wandered into the Arctic Ocean, triggering the accumulation of snow and ice in this region. American scientist Norman Phillips produces a somewhat realistic computer model of the global atmosphere. Canadian physicist Gilbert Plass calculated that adding carbon dioxide to the atmosphere would affect the radiation balance.

1957
Launch of Soviet Sputnik satellite. Cold War concerns support the 1957–58 International Geophysical Year, bringing new funding and coordination to climate studies. U.S. oceanographer Roger Revelle warned that humanity is conducting a "large-scale geophysical experiment" on the planet by releasing greenhouse gases.

1958
Astronomers identified the Greenhouse Effect on Venus, where temperatures are far above the boiling point of water.

1960
A report found that global temperatures had declined since the early 1940s. American scientist Charles David Keeling set up the first continuous monitoring of carbon dioxide levels in the atmosphere. Keeling soon finds a regular rise in temperatures.

1961
Soviet meteorologist Mikhail Budyko warned that the burning of fossil fuels, and the attendant accumulation of greenhouse gases in the atmosphere, would warm the planet.

1963
Fritz Moller calculated that a doubling of carbon dioxide in the atmosphere might increase temperatures 50 degrees Fahrenheit.

1965
Climatologists gather in Boulder, Colorado, to discuss climate change. Edward Lorenz and others point out the chaotic nature of the climate system and the possibility of sudden shifts.

1966
Italian scientist Cesare Emiliani's analysis of deep-sea cores showed that the timing of ice ages was set by small orbital shifts, suggesting that the climate system is sensitive to small changes.

1967
The International Global Atmospheric Research Program was established, mainly to gather data for better short-range weather prediction. Computer modelers Syukuro Manabe and Richard Wetherald predicted that an increase in the number of clouds might hold heat in the atmosphere and so increase temperatures.

1968
Mikhail Budyko derived two mathematical models. One predicted an increase in temperatures due to the Greenhouse Effect. The other predicted the return of the ice age. Budyko favored the first model. Other models were also contradictory. Studies suggested that the Antarctic ice sheets might collapse, raising sea levels catastrophically.

1969
American climatologist William Sellers predicted that a 2 percent decrease in solar radiation, whether from a fluctuation in solar output or the result of debris in the air, might plunge Earth into a new ice age. Like Budyko, Sellers feared that the burning of fossil fuels might warm Earth. Nimbus III satellite begins to provide comprehensive global atmospheric temperature measurements.

1970
The First Earth Day. The environmental movement attains strong influence, spreading concern about global degradation. The creation of the U.S. National Oceanic and Atmospheric Administration was the world's leading funder of climate research. Aerosols from human activity were increasing in the atmosphere. American scientist Reid Bryson claimed they counteracted global warming and may actually cool the Earth.

1971
The Study of Man's Impact on Climate (SMIC), a conference of leading scientists, reported a danger of rapid and serious global change caused by humans and called for an organized research effort. The American Mariner 9 spacecraft found a great dust storm warming the atmosphere of Mars along with indications of a radically different climate in the planet's past.

1972
Budyko predicted that a 50 percent increase in greenhouse gases in the atmosphere might raise temperatures enough to melt all the ice on Earth, whereas a 50 percent reduction might plunge Earth into an ice age. Budyko favored the first scenario and predicted that temperatures might rise enough to melt all the ice by 2050. Ice cores and other evidence showed that the climate changed in the past in the space of 1,000 years or so, especially around 11,000 years ago.

1972 to 1974
Serious droughts and other unusual weather since 1972 increased scientific and public concern about climate change, with cooling from aerosols suspected to be as likely as warming. Journalists wrote about ice ages.

1975
Concern about the environmental effects of airplanes led to investigations of trace gases in the stratosphere and the discovery of danger to the ozone layer. Manabe and collaborators produced complex but plausible, computer models, which predicted an increase of several degrees Fahrenheit for a doubling of carbon dioxide.

1975 to 1976
Studies showed that chlorofluorocarbons (CFCs) (1975) and also methane and ozone (1976) contribute to the Greenhouse Effect. Deep-sea cores show a dominating influence from 100,000-years ago. Milankovitch's prediction of orbital changes emphasized the role of feedbacks. Deforestation and other ecosystem changes were recognized as major factors in the future of the climate. American meteorologist Amos Eddy showed that the absence of sunspots in past centuries corresponded with cold periods.

1977
Scientific opinion tended to converge on global warming, not cooling, as the chief climatic risk in next century.

1978
Attempts to coordinate climate research in United States ended with an inadequate National Climate Program Act, accompanied by rapid, but temporary, growth in funding. American scientist James Hansen predicted that the accumulation of aerosol particles in the atmosphere might reflect sunlight back into space and so reduce temperatures.

1979
The second oil energy crisis. A strengthened environmental movement encouraged the development of renewable energy sources and the reduction of technologies that burn fossil fuels. The U.S. National Academy of Sciences estimated that a doubling of carbon dioxide might increase temperatures 35 to 40 degrees Fahrenheit. The World Climate Research Program was launched to coordinate international research on climate change.

1980
The election of President Ronald Reagan caused a backlash against the environmental movement. Political conservatism is linked to skepticism about global warming. Some scientists predicted greenhouse warming should be measurable by about the year 2000.

1982
Greenland ice cores revealed temperature oscillations over a single century in the distant past. Strong global warming since the mid-1970s was reported, with 1981 the warmest year on record.

1983
Reports from U.S. National Academy of Sciences and Environmental Protection Agency spark conflict, as greenhouse warming becomes prominent in mainstream politics.

1984
Theories about global warming and the Greenhouse Effect became more prevalent, gaining attention from the mass media. However, many people believe the threat is not imminent and some doubt that global climate change is a danger.

1985
The Center for Atmospheric Science Director Veerabhadran Ramanathan and collaborators announced that methane and other trace gases together could bring as much global warming as carbon dioxide itself. The Villach conference in Indonesia declared consensus among experts that some global warming seems inevitable and called on governments to consider international agreements to restrict emissions of greenhouse gases. Antarctic ice cores show that carbon dioxide and temperature went up and down together through past ice ages, pointing to powerful biological and geochemical feedbacks. American scientist Wallace Broecker speculated that a reorganization of North Atlantic Ocean circulation could bring swift and radical climate change.

1987
This was the warmest year since humans began to keep records. The 1980s were the hottest decade on record, with seven of the eight warmest years recorded up to 1990. Even the coldest years in the 1980s were warmer than the warmest years of the 1880s. The Montreal Protocol of the Vienna Convention imposed international restrictions on the emission of ozone-destroying gases.

1988
Global warming attracts worldwide headlines after scientists at Congressional hearings in Washington, D.C., blamed the U.S. drought on its influence. A meeting of climate scientists in Toronto subsequently called for 20 percent cuts in global carbon dioxide emissions by 2005. The United Nations set up the Intergovernmental Panel on Climate Change (IPCC) to analyze and report on scientific findings. News media coverage of global warming leapt upward following record heat and droughts. The Toronto conference called for strict, specific limits on greenhouse gas emissions. British Prime Minister Margaret Thatcher is the first major leader to call for action. Ice-core and biology studies confirmed that living ecosystems give climate feedback by way of methane, which could accelerate global warming. The level of carbon dioxide in the atmosphere reached 350 parts per million.

1989
Fossil-fuel suppliers and other industries formed the Global Climate Coalition in the United States to lobby politicians and convince the media and public that climate science is too uncertain to justify action.

1990
American meteorologist Richard Lindzen predicted that an increase in carbon dioxide in the atmosphere might not cause a concomitant increase in water vapor. Consequently, the Greenhouse Effect might be less severe than some were forecasting. The first IPCC report stated that the world has been warming and continued warming seems likely in the future. Industry lobbyists and some scientists disputed the tentative conclusions.

1991
Mount Pinatubo erupted. Hansen predicted that the eruption would cool Earth, verifying (by 1995) computer models of aerosol effects. Global warming skeptics emphasized research indicating that a significant part of 20th-century temperature change was due to solar influences. Studies from 55 million years ago show the possibility of the eruption of methane from the seabed causing enormous warming.

1992
A conference in Rio de Janeiro produced the United Nations Framework Convention on Climate Change, but the United States blocked calls for serious action. The study of ancient climates revealed climate sensitivity in the same range as predicted by computer models.

1993
Greenland ice cores suggested that great climate changes (at least on a regional scale) could occur in the timespan of a single decade.

1995
The second IPCC report detected the "signature" of human-caused Greenhouse Effect warming, declaring that serious warming is likely in the coming century. Reports of the breaking up of the Antarctic ice sheets and other signs of current warming in polar regions began to affect public opinion.

1997
Japanese automobile manufacturer Toyota introduces the Prius in Japan, the first mass-marketed electric hybrid car. Engineers progressed in the design of large wind turbines and other energy alternatives. An international conference in Japan produced the Kyoto Protocol, setting targets to reduce greenhouse gas emissions—if enough nations would approve and sign the treaty.

1998
The warmest year on record globally averaged (1995, 1997, and 2001-2006 were near the same level). Borehole data confirmed extraordinary warming trend. Qualms about arbitrariness in computer models diminish as teams model ice-age climate and dispense with special adjustments to reproduce current climate.

1999
A National Academy Panel dismissed criticism that satellite measurements showed no warming. V. Ramanathan detected massive "brown cloud" of aerosols from South Asia.

2000
The Global Climate Coalition dissolved as many corporations grappled with the threat of warming, but the oil lobby convinced the U.S. administration to deny the problem. Various studies emphasized variability and the importance of biological feedbacks in the carbon cycle that are liable to accelerate warming.

2001
The Third IPCC report stated that global warming, unprecedented since the end of last ice age, is "very likely," with possible severe surprises. The National Academy panel marked a "paradigm shift" in scientific recognition of the risk of abrupt climate change (decade-scale). Warming is observed in ocean basins. These observations match computer models, giving a clear signature of Greenhouse Effect.

2002
Studies found surprisingly strong "global dimming," due to pollution. This factor had retarded greenhouse warming, but dimming is now decreasing.

2003
Numerous observations raised concern that the collapse of ice sheets (West Antarctica, Greenland) might raise sea levels faster than most had believed. A deadly summer heat wave in Europe deepens divergence between European and U.S. public opinion.

2004
In a controversy over temperature data covering the past millennium, most scientists concluded that climate variations were substantial, but not comparable to post-1980 warming. The first major books, movies and artwork feature global warming.

2005
The Kyoto Treaty, signed, by all major industrial nations except the United States, took effect. Work to retard greenhouse emissions accelerated in Japan, Western Europe, U.S. regional governments, and corporations. Hurricane Katrina and other major tropical storms spurred debate over the impact of global warming on storm intensity.

2006
An Inconvenient Truth premiered at the 2006 Sundance Film Festival and opened in New York and Los Angeles on May 24, 2006, earning $49 million.

2007
The fourth IPCC report warned that serious effects of warming have become evident. The cost of reducing emissions would be far less than the damage they will cause. Al Gore shared the Nobel Peace Prize for his efforts to spread knowledge about global warming. The level of carbon dioxide in the atmosphere reaches 382 parts per million.

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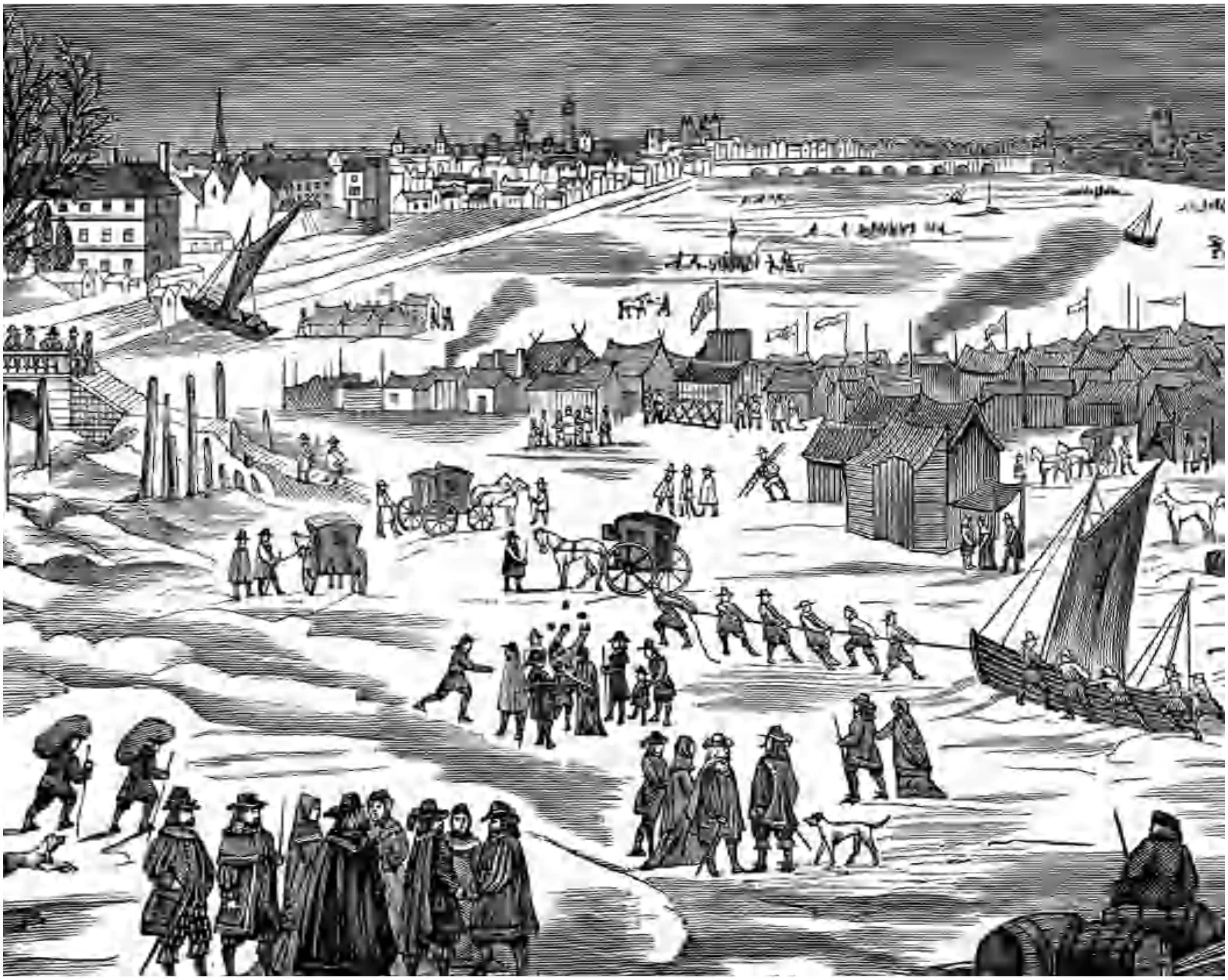
Abrupt Climate Changes

THROUGHOUT RECORDED HISTORY, and in studies of geological and other records from much earlier periods of the Earth's history, there have been a number of abrupt climate changes. These significant and widespread shifts in climate heavily impacted many parts of the world. Current studies of these changes draw from details revealed from ice core samples, especially from Greenland and northern Canada, and also from records compiled showing signs of geological changes. More recent information has emerged from examinations of the fluctuations in the size of tree rings, and also from historical accounts.

The quantity of these abrupt climate changes has led some academics, often labelled climate change skeptics, to explain the current global warming in terms of these trends. They suggest or state that the current changes are, or could be, merely a part of a cycle of global warming and cooling, similar to those that have occurred over hundreds of thousands of years.

Explaining global warming in the 1990s and 2000s by studying these abrupt climate changes gained much publicity around the world through the article "A Pervasive Millennial-Scale Cycle in North Atlantic Holocene and Glacial Climates," which was written by ten leading scientists, Drs. G. Bond, W. Showers, M. Chesby, R. Lotti, P. Alamsi, P. de Menocal, P. Priore, H. Cullen, I. Hajdas, and G. Bonani, and published in the journal *Science* in November 1997. This article, and related work, led to a substantial body of research on abrupt climate changes—when the Earth's temperature has either significantly increased or decreased over a short period of time—and also the possible causes of these changes.

A development of this theory came from two other scientists associated with those skeptical of global warming, S. Fred Singer of the University of Virginia, and Dennis Avery of the Hudson Institute in New York. They raised the possibility of a 1,500-year climate cycle, especially in the North Atlantic region, with hot temperatures every 1,500 years, The present global warming could be a part of this cycle. Certainly a part of this theory clearly rests on the extreme weather patterns experienced around the world during the years 535–36 C.E. They are recorded by the Byzantine historian Procopius, and also in Irish annals, as well as in records kept in China—all showing that the climate change occurred across a large number of areas.



The Little Ice Age, which lowered world temperatures from about 1600 to 1750, froze large rivers and canals in Europe. This engraving depicts a fair held on the ice of the frozen River Thames in London in 1683.

These historical accounts are confirmed by a tree ring analysis undertaken by the dendrochronologist Mike Baillie from Queen's University of Belfast, Northern Ireland, which showned little growth in Irish oak trees during this period. Similar data emerging from a study of tree ring samples conducted on trees from Scandinavia, California, and Chile. The rise in temperature during these years seems to have led to a widespread series of famines around the world, and the collapse or destruction of a number of empires including that of the Persians, and the Mesoamerican city of Teotihuacan.

There is no accepted cause of this instance of abrupt climate change, although there has been the suggestion that it could have been caused by the large-scale eruption of a volcano, such as Krakatoa, off the coast of Java (modern-day Indonesia); this idea formed a central part of the work of David Keys in his book *Catastrophe: A Quest for the Origins of the Modern World* (1999). It should, however, be noted that other scientists have been critical of these conclusions.

HISTORY

Going back further in history, there was a prolonged drought in the 22nd century B.C.E., which had a dramatic effect on the Old Kingdom of Egypt. It led to about 40 years of famines and social dislocation, which produced the emergence of the unified Kingdom of Egypt as a new political identity capable of financing irrigation projects and the like to overcome these problems. There have also been more recent changes in temperature, with suggestions that the collapse of the Mayan Empire in Mexico in the 8th and 9th centuries was possibly caused by a regional abrupt climate change, although others have pointed to the greater likelihood that this stemmed from overpopulation, foreign invasions, epidemics, and internal insurgencies. The idea of localized problems is reinforced by the fact that there is little evidence of an abrupt climate change elsewhere in the world at that time.

There have also been studies of what has been deemed the Little Ice Age, which took place from about 1600 until about 1750, with the freezing of rivers such as the River Thames in England, of canals in the Netherlands (shown in contemporaneous paintings), and the southern section of the Bosphorus in 1622. As the process seems to have been gradual, it might also have been responsible for the end of the Viking colonies in Greenland during the 15th century.

Certainly the concept of abrupt climate change goes back far further than recorded history. The last Ice Age in the Pleistocene period, which ended in about 10,000 B.C.E., ended a period of cold weather that is believed to have started with a long glacial advance from about 70,000 B.C.E., reaching a peak in 18,000 B.C.E., when most of northern Europe and considerable portions of modern-day Canada were covered with glaciers.

THE DEBATE

As a result of these studies, there are scientists who argue that global warming is just a phenomenon that has taken place before, and will take place again. They believe that global warming is not caused by the emission of increasing amounts of carbon dioxide and other greenhouse gases. There are also many who suggest that while warming is a regular phenomenon, it has been exacerbated by increasing greenhouse gas emissions.

Although abrupt climate changes have happened throughout history, scientists who argue that global warming is extremely serious, point to the rapidity of recent climate changes, and that they are occurring at an increasing rate throughout the world. In contrast to the changes that have been studied, measured, examined, and analyzed over the last 20 years, events such as the Little Ice Age took place gradually over at least 120 years, if not longer. Some date the start of the period back to 1250, when the Atlantic Pack Ice started to grow, and suggest it was a cause of the Great Famine of 1315–17, with the serious glacial expansion taking place only since 1550, and the first significant climatic changes in non-Arctic Europe beginning in the early 17th century.

By contrast, similar fluctuations in temperature (rising now, instead of falling as in the 1600s) in recent decades, have happened over a very short time, and the loss of large amounts of Antarctic ice have been evident over a 10-year period. The ability to track many of these changes from satellites has allowed geographers and scientists to identify other problems, such as the "Ozone Hole." .

The theory of abrupt climate change clearly indicates that there are many forces that contribute to global warming around the world, in addition to human-caused carbon dioxide and other emissions. However, researchers have been increasingly able to monitor these changes since the early 1990s, and the fact that the symptoms of climate change and global warming are currently being recorded around the planet, and are accelerating, has led many scientists to suggest global warming cannot be solely explained by the theory of abrupt climate change. It has further led to the theory that these man-made causes might be coinciding with a cyclical period of abrupt climate change, leading to a worsening of problems being faced by people in most parts of the world.

SEE ALSO: Attribution of Global Warming; Climate Change, Effects; Climatic Data, Historical Records; Climatic Data, Ice Observations; Climatic Data, Nature of the Data; Climatic Data, Tree Ring Records; Global Warming; Little Ice Age.

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Adaptation

ADAPTATION IN SOCIAL, cultural, and economic contexts is also an important component of thinking about societal response to climate change. As such, adaptation is defined in many ways. It can be defined as a process that enables people to minimize the adverse effects of climate on their health and well-being. It also refers to the capacity of people or societies to take advantage of the changes that the climate might provide. Adaptation can also mean the adjustments in behavior and economic structures that will reduce societal vulnerability to climate change impacts.

This can include changes to social and cultural structures or mores within society, so that vulnerability to climate variability and potential extreme events is reduced. The Intergovernmental Panel for Climate Change (IPCC) defines adaptability as "the degree to which adjustments are possible in practices, processes, or structures of systems to projected or actual changes of climate," and notes, "adaptation can be spontaneous or planned, and can be carried out in response to or in anticipation of a change in conditions."

Of great interest to policymakers, however, is the ability of societies to implement adaptations. The IPCC reiterates that adaptation is more than just finding a technical "fix," but should incorporate a combination of strategic and technical options. This is generally discussed in the literature as *adaptive capacity*. The IPCC report (2001) on adaptive capacity notes that the capacity to adapt, as with vulnerability, is a result of the integration of wealth, scientific and technical knowledge, information, skills, infrastructure, institutions, and equity. This report also states that adaptations will be more beneficial if they are incorporated into existing strategies such as coastal zone management, disaster mitigation, land use planning, and sustainable development programs, a process referred to elsewhere in the literature as mainstreaming.

TYPES OF ADAPTATION

Adaptation can take many forms. It can work from the bottom up or top down. It can be reactive to changes or impacts, or it can be predictive, as in responding in advance to anticipated impacts. Adaptations can also be differentiated by whether or not they are autonomous or planned, occur in natural or socioeconomic systems, are anticipatory or reactive, and take technological, institutional, or behavioral forms. Adaptation can also be structural, such as the building of dykes or levees to combat flooding or sea level rise associated with climate change. Adaptation can also take the form of policy measures or approaches such as integrated coastal zone management.

An example of adaptation in practice is the adaptive management of sea-level rise. The six most important bio-geophysical (or natural system) effects of sea-level rise are: increasing flood-frequency probabilities, erosion, inundation, rising water tables, saltwater intrusion, and biological effects. Without adaptation, the consequences of global warming and sea-level rise would be disastrous, a point reiterated by the IPCC in its Fourth Assessment Report, 2007.

There are a number of technical options designed to respond to sea-level rise: retreat, accommodate, or protect. Retreat involves the removal of all artificial structures from the potentially affected area, providing the shoreline with space to move. Accommodation is where coastal developments try to adapt to sea-level rise by doing things such as introducing building standards, and only allowing removable homes to be built in high risk areas.

Protection, also called defense, includes not only the erection of coastal defense structures such as seawalls and dikes, but also leaving all existing structures in potentially affected areas, and even encouraging more development to be built. However, there are environmental, social, and economic aspects of all three options that have to be considered carefully before approving or discarding any of them.

In 2001, the United Nations Environment Programme (UNEP) adopted a seven-step adaptation framework for addressing the problems of sea-level rise and climate change: define the problem, select the method, test the method, select scenarios, assess the bio-geophysical and socioeconomic impacts, assess the autonomous adjustments, and evaluate adaptation strategies. While the UNEP specifically outlines a suite of strategic responses to sea-level rise, it cautions that before applying these strategies, policymakers must decide if their adaptation is to be autonomous or planned, and reactive or pro-active.

Policy makers can also use adaptive measures to manage climate change. One adaptive strategy is known as the no-regret or win-win approach. This approach allows policy makers to implement strategies that benefit all parties, and are politically feasible because of minimal risk. Another strategy is the precautionary strategy, where adaptation becomes part of ongoing management planning, thus ensuring that any future impact of climate change is anticipated. For example, local governments might factor in requirements for development applications to plan for climate change, even before the predicted effects of climate change occur in that region.

RESEARCH AND ADAPTATION

Some researchers interpret adaptation by examining the relationship between human and organizational behavior and adaptation strategies. For example, research based on nine case studies of companies in the United Kingdom showed that adaptation processes have many synergies with organizational learning. Researchers demonstrate that business adaptation techniques that affect organizational adaptive behavior provide lessons to policymakers for implementing climate change actions. Suggested business adaptation techniques include: changes to the firm's commercial strategy (commercial adaptation), changes to technologies used to provide products or services (technological adaptation), changes in financial management systems (financial adaptation), changes in data-gathering and monitoring trends, and information and monitoring of climate stimuli and search processes for adaptation measures.

Some policy makers construct adaptation as a space, providing the opportunity to implement well-established adaptation options, as well as options that are novel and not yet fully explored. The adaptation space is conceptualized as dynamic, growing, and evolving as new options are generated. Within the adaptation space, four alternative climate adaptation strategies can be identified. These include the wait and see approach, which is a strategy of deferral, based on skepticism or uncertainty about the possible impact of climate change and the benefits of adaptation.

Risk assessment and options appraisal is another strategy designed to evaluate options in preparation for adaptation of organizational routines. Bearing and managing risks is a strategy of handling risks and opportunities arising from climate impacts employing organizational resources and capabilities. The fourth strategy is one of sharing and shifting risks, a process of seeking to externalize risks associated with climate impacts through insurance and collaboration.

ADAPTATION AND UNCERTAINTY

Implementing adaptation strategies for climate change requires decision makers to incorporate and deal with the issue of uncertainty. Uncertainty is one of the key difficulties for policy makers in assessing both how climate change will manifest and the resulting extent, diversity, regularity, distribution, and magnitude of its impacts. Uncertainty arises from insufficient, inaccurate, or unavailable data; external developments and cross-boundary issues; and the unpredictability of human behavior. Part of the solution to dealing with uncertainty lies in ensuring that adaptation policy is robust, and anticipates future impacts based on a wide array of predictions. By building social and economic capacity to respond to diverse sets of circumstances, it is possible to incorporate uncertainty in planning frameworks. Adaptation strategies are, thus, a very important part of climate change management.

A protective approach to the adaptive management of sea-level rise retains old structures and even backs more development.

ADAPTIVE MANAGEMENT

Building on the notions of adaptation and adaptive capacity is the concept of adaptive management. It is a process that embeds greater fluidity and flexibility within conventional environmental management systems. Adaptive management is based on the assumption that as circumstances change, so must management strategies. It is a technique that provides a framework for continually improving management practice and delivering environmental outcomes within socioeconomic contexts.

Adaptive management also builds on environmental assessment techniques to deal with uncertainty, and access information sets on partially-known processes, making it ideal for climate change management. The fluid nature of adaptive management also suits the dynamics of working with the changing quality of environmental processes. Adaptive management means management that is flexible and based on the principle of continuous improvement. Employing adaptive management techniques enables policy makers to focus on variation over time within policy, rather than the more conventional spatial variation. For example, within local government, planners can use adaptive management techniques to review their planning schemes periodically, and ensure that they deal with variations over time. Adaptive management can be viewed as a process with consecutive stages including: information collection, systems analysis and vision, plan making, implementation of management actions, and monitoring and reviewing.

ADAPTATION ASSESSMENT

In planning for what types of adaptation to use at any given time, decision makers must consider these aspects: adaptation to what, who or what adapts, and how adaptation occurs. Decision makers must also determine the attributes for differentiating adaptations, such as purposefulness, timing, temporal and spatial scope, effects, form, and performance. In this context there is a distinction between two types of adaptation assessment: positive and normative. Positive assessment is predictive; the likelihood of adaptations that will be required is based on the assessment of likely impact scenarios. Normative assessment builds on the positive approach by evaluating likely adaptation options, and enables input into policy recommendations.

Many techniques can be applied to determine which adaptation type to implement. For example, adaptation trials in Egypt show that multi-criteria analysis and decision-matrix approaches based on questionnaire surveys to determine adaptation priorities and options, are useful tools. Other studies use participatory vulnerability assessment (PVA) tools to identify the adaptation strategies most appropriate for communities that will allow incorporation of political, cultural, economic, institutional, and technological factors. PVA also facilitates a dynamic interplay among various exposures, sensitivities, and adaptive capacities over time, because what is vulnerable in one period is not necessarily vulnerable (or vulnerable in the same way) in the next.

The choice and implementation of different adaptive measures is also contingent on the decision processes that frame them. Decision-making processes must ensure that adaptation and knowledge of climate impacts are both considered. Also, it is important that adaptation decisions are not impractical or prohibitively expensive. For example, in low-lying areas subject to flooding as a result of sea-level rise, the cost of adaptation could amount to at least 5 to 10 percent of Gross Domestic Product. The appropriate mechanism for implementation of adaptation strategies also depends on the particular response. One response within the United Kingdom to sea-level rise has been to develop shoreline management plans (SMP). The English coastline is divided into 11 cells, which are divided further into sub-cells. The divisions are made according to the transport of sand and other sediments. For each sub-cell a SMP has been defined. Each SMP is designed to take a strategic view of shoreline defenses and is based on a decision to pursue one or a combination of the following adaptation options: do nothing, advance the line, hold the line, or retreat the line. In Bangladesh, soft adaptation measures have been tried, such as the planting of mangroves along vulnerable coasts, beach nourishment, and coral transplanting. Hard measures include the building of seawalls and coastal dykes, such as in Japan or the Netherlands.

Ensuring the most appropriate adaptation in each case is the key. For example, in some places beach nourishment is implemented as a short-term, flexible strategy as an alternative to building sea walls. In cases where saline water intrusion threatens groundwater supplies, longer-term adaptation strategies, such as demand reduction initiatives like the improved maintenance of water reticulation systems to prevent and remedy leaks, conservation education, and plumbing, might be more appropriate.

LESSONS LEARNED FROM ADAPTATION

Climate change adaptation strategies have been tried worldwide. A number of key lessons have been learned that will help future decision makers when planning for, and adapting to, climate change. These lessons include: adaptation should build on previous experiences in relation to disaster management; adaptation can be autonomous or planned, reactive or proactive; adaptation takes time and, therefore, should not be postponed; there is a need to build diverse information/knowledge bases that will support adaptation processes; social vulnerability needs to be canvassed; adaptation technologies need to be developed and applied; institutional arrangements must support adaptation; and priority should be given to adaptation in catchments where the water is close to full utilization.

SEE ALSO: Climate Change, Effects; Impacts of Global Warming; Intergovernmental Panel on Climate Change (IPCC); Sea Level, Rising.

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Aerosols

AEROSOLS ARE SOLID or liquid particles that are small enough to remain suspended in the atmosphere for hours to days. They are created by both natural and human-caused processes, and are either directly emitted from sources or are formed in the atmosphere from the condensation of gases. Aerosols can perturb climate either directly, by the scattering or absorption of radiation, or indirectly, through the modification of clouds and precipitation. The effects of aerosols on climate represent the single largest source of uncertainty in the understanding of global warming. While the magnitude of the effect is unclear, most observations and models agree that the impact of aerosols is to cool the earth.

Typically, particles that comprise aerosols range in size from the length of a large molecule (one nanometer) to one-tenth the width of a human hair .0004 in. (10 microns). The number of these particles in a cubic centimeter of air at the Earth's surface is highly variable in time and space, and ranges from 100 to 100,000. "Primary aerosols" are formed directly at the source, examples of which include mineral dust, sea salt, and combustion products such as soot and black carbon. "Secondary aerosols" are those formed in the atmosphere from reacted gases, and are often complex mixtures of oxygen, hydrogen, sulfur, nitrogen, and carbon. Most aerosols contain a mix of primary and secondary constituents. Aerosols are the major part of smog, and, in addition, contribute to many environmental and human problems such as acid rain and human respiratory ailments.

The impact of aerosols on climate has been classified in two ways. The direct radiative effect describes the scattering and absorption of sunlight and the earth's radiated heat energy by aerosols. Indirect radiative effects include the suite of possible impacts of aerosols on climate through the modification of cloud properties.

Scientists quantify the impact of an external agent such as aerosols on climate by its radiative forcing, expressed in units of Watts per square meter (W m-2). A positive radiative forcing tends, on average, to warm the Earth's climate, whereas a negative forcing tends to cool the Earth.

The direct radiative effect of aerosols is closely related to "global dimming," which is the observed reduction of sunlight received at the surface of the Earth in areas where pollution aerosols play a role. Recent assessments of the direct effect have benefited greatly from improvements in satellite and surface-based observations, which provide near-global coverage of aerosol optical properties. These observations have been matched by improvements in, and are often integrated into, global atmospheric computer models that can provide estimates of direct radiative forcing of aerosols. The most recent estimate places the value of direct effect radiative forcing between minus 0.9 and minus 0.1 W m2.

The indirect effect highlights a key role that aerosols play in the atmosphere as the seeds upon which water vapor condenses to form clouds. Variations in the number of these seed particles, known as cloud condensation nuclei (CCN), result in changes in the radiative properties, amounts, and lifetime of clouds. The effectiveness of an aerosol to act as a CCN is a function of its size, composition, shape, and surrounding environment. These details are known best about liquid water clouds, whereas knowledge of ice clouds is limited.

Several types of indirect effects have been identified. The first is the albedo effect, also known as the Twomey or 1st indirect effect. Albedo is a measure of the reflectivity of a cloud, and the albedo effect refers to an increase in the number of CCN, which leads to the formation of more numerous, but smaller, cloud droplets. This leads to an increase in cloud reflectivity, resulting in a negative radiative forcing estimated to be between minus 0.3 and minus 1.8 W m2.

The cloud lifetime effect or 2nd indirect effect, describes how increased CCN can modify the hydrological cycle and cause feedbacks that ultimately affect the earth's climate. Examples include drizzle suppression, increased cloud height, and increased cloud lifetime. Drizzle suppression, for example, can result in increases in wind-blown dust, which would lead to increased aerosol concentrations that would directly and indirectly impact climate. A third classification, the semi-direct effect, refers to certain types of aerosols, such as black carbon, that absorb sunlight and heat the atmosphere, which suppresses cloud formation. There are no estimates available for the impact of these other indirect effects.

The overall impact of aerosols on climate includes direct, semi-direct, and indirect effects. All model simulations agree that the total effect is greater over the Northern Hemisphere than the Southern Hemisphere. Direct and semi-direct effects in models are generally smaller compared to indirect effects. The average overall forcing ranges from minus 0.2 to minus 2.3 W m2, and the resulting effect on precipitation ranges from 0 to minus .05 in. (1.3 mm.) day-1. No climate simulation accounts for all aerosol-cloud interactions, therefore the net aerosol effect on clouds deduced by models is inconclusive.

SEE ALSO: Biogeochemical Feedbacks; Climate Forcing; Cloud Feedback; Intergovernmental Panel on Climate Change (IPCC); Pollution, Air.

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Afforestation

AFFORESTATION INVOLVES TAKING action to plant trees in an area that has never been a forest area or to restore a deforested area. The trees may be planted from seeds or from seedlings. Legally, afforestation includes the setting aside of forest land, or land to be reforested by law. Many national forests have been created in the last century. These forest

On some land, such as this farm in Israel, afforestation will not occur naturally and requires mass planting programs.

areas may be designated as wilderness areas or as forest areas. In the case of the latter, they are usually multiuse areas. Some of the area in the forest will be used for recreation or for hunting, and other areas for timber operations.

The 18th and 19th centuries were times of enormous expansion of farming operations. In North America and in many places around the world, vast forests were cut down to create farms. In many areas of the eastern United States, the deforestation was extensive. In Vermont, for example, by 1900 about 80 percent of the land was being used for agricultural production, in particular for sheep herding. However, by 2000, farming had been greatly reduced and the state was over 80 percent forested. Some of the afforestation was due to the movement of people away from farming and into urban or town life.

Reforestation of Palestine began with the return of the first Jewish settlers in the late 1880s. After the creation of the state of Israel, a major tree-planting program began. The Kingdom of Jordan has also engaged in a widespread tree-planting effort. The deforestation there occurred under the Ottoman Empire because the Turks needed wood for their railroad steam engines. In Jordan, afforestation programs often encounter human resistance, as poor people see the forest as a resource for fuel and food for their goats. In Israel, Jordan, and other countries, afforestation cannot occur naturally as it can in an already well-watered area such as Vermont or the eastern half of the United States and Canada, generally. Deforestation in some places devastates the land because the removal of trees that held in moisture are no longer present, so the soil dries out so much that it is difficult for trees to re-establish themselves naturally. In tropical areas, the loss of forest cover may cause the soil to become so hard that water cannot penetrate it.

In some regions, deforestation, either followed by, or accompanied by, overgrazing, has led to desertification. In other areas, forests cannot be replanted because of the presence of people using the land for other purposes. Often, these uses are not as economical there as they would be if relocated. In Canada, Russia, and Iceland, afforestation programs have been used to replace the boreal forests.

It has been suggested that afforestation is a solution to global warming. However, there are a number of challenges to this claim. One challenge is that people, especially in third world countries, have little incentive to protect forests from destruction in order to save the planet from global warming. A second challenge is that, while forests lock up huge quantities of carbon dioxide, carbon dioxide emissions from many industrial sources are choking them. A third challenge is that while planting boreal forests will soak up vast quantities of carbon dioxide, the forests will also add to the heat of the planet because they absorb and retain energy.

SEE ALSO: Deforestation; Desertification; Forests.

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Afghanistan

LOCATED IN CENTRAL Asia, with no maritime borders, Afghanistan covers a land area of 251,772 sq. mi. (647,500 sq. km.) and has a population of 31,889,923. It has a population density of 119 people per sq. mi. (46 per sq. km.). About 12 percent of the country is arable land, with 46 percent of the land area being used as meadow or pasture. Only three percent of the country is forested. Officially some 80 percent of the population make a living from agriculture.

At war since the late 1970s, there are numerous environmental problems facing Afghanistan, especially involving unexploded ordnance and a poor infrastructure. Parts of Afghanistan have faced severe shortages of food, alleviated by foreign aid, initially from the Soviet Union, later from parts of the Islamic world, and from the West, which supports the government of President Hamid Karzai. There have also been campaigns to eradicate the production of opium poppy and cannabis, with attempts to substitute the planting of food crops.

The arid countryside and resulting low level of agricultural production has been highlighted as a serious problem for Afghanistan, with the rising global temperature likely to lead to further declines in farming. Since fighting began in 1978, Afghanistan has lost over 70 percent of its forests, leading to soil erosion, a decline in soil fertility, and a rise in salinization. In addition, a dramatic fall in water tables has affected the electricity production in the country, 64 percent of which comes from hydropower, with the remaining 36 percent from fossil fuels. One important hydroelectric plant is located at Sarobi on the Kabul River, and provides much of the power for the capital. Prior to the use of hydropower, there was heavy reliance on wind power, with "horizontal" windmills located on the tops of buildings between Herat and the Iranian frontier from as early as the 7th century C.E. These windmills were primarily used to grind grain. The sulfur industry operates around the city of Maimana in the northwest of the country, and a small oil industry exists near Herat in the west of Afghanistan.

In 2001, Afghanistan recorded the warmest winter on record, with crop production decreasing. The Afghan refugee crisis, created by the war, continues, with many people unable to subsist in their villages. Because the country is so underdeveloped, it has one of the lowest carbon dioxide emissions per capita in the world, with 0.2 metric tons per capita in 1990 falling to negligible levels in 1997, and in 2007 was estimated to be 0.03 metric tons per capita, with only Chad and Somalia recording lower levels.

The Afghan government took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, which took place less than a month after the overthrow of the pro-Russian president, Mohammad Najibullah. Under the Taliban government, there was little participation in any of the international forums, and the government of President Hamid Karzai has not expressed an opinion on the Kyoto Protocol to the UN Framework Convention on Climate Change.

SEE ALSO: Agriculture; Deforestation; Desertification; Developing Countries.

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Agriculture

FARMERS PRODUCE MUCH of the human food supply; raw inputs such as cotton, leather, and wool for textiles; and an array of fibers, chemicals, and pharmaceuticals that serve myriad manufacturing processes. Agriculture is a complex system of human activity that is intertwined in the economic, environmental, and social processes on the Earth.

The importance of agriculture to human well-being explains why influential national and international government and nonprofit agencies have focused so much attention on the impact of climate change on agriculture. There is a clear recognition on the part of agencies such as the United States Department of Agriculture (USDA), the International Panel on Climate Change (IPCC), the United Nations Food and Agricultural Organization (FAO), and the World Bank clearly recognize that climate change could have profound effects on the future. Global climate change may have some positive impacts on agriculture. On the other hand, there may be deeply negative impacts if climate change triggers droughts or other catastrophic events that hurt the global food supply. Resource scarcity could, in turn, cause famines and geopolitical conflicts with grave humanitarian consequences.

AGRICULTURAL IMPACTS OF CLIMATE CHANGE

Given that crops and livestock thrive in a relatively narrow set of environmental parameters, it makes sense to explore how climate change will affect agricultural productivity. Factors considered include the impacts of rising temperatures, increased production of carbon dioxide and other greenhouse gases, water supply fluctuations, soil quality variations, sea-level increases, and the introduction of new pests, diseases, and weeds, which could hurt agricultural output. These

One of the ways agriculture contributes to greenhouse gases is by shipping produce hundreds of miles to markets.

changes can have different impacts depending on the geographic scale of analysis. Climatic change will have different manifestations at local, regional, and global scales. Impacts will also vary according to the agricultural products under consideration. Some plant or animal species may be very resilient to environmental changes. Others may not adapt so well to change.

Temperature increases will affect crop and livestock production in various ways. A warming climate will extend the frost-free growing season at higher latitudes. Regions that are too cold to support commercial agriculture in northern Canada, Alaska, Scandinavia, and Russia, may become viable agricultural areas if temperatures increase. On the other hand, temperature-sensitive crops may no longer be commercially viable in regions that become too hot or dry. Also, rising temperatures could increase the heat stress on livestock.

Climatic change models predict that regional temperature variations may alter precipitation patterns and the supply of water for agriculture. Areas that are currently too dry may receive more moisture in the future. Areas that are productive now without irrigation may suffer as temperatures increase, because of increased plant evapo-transpiration. Farmers will have to find ways to offset the rising temperatures and corresponding moisture loss if they are to survive. Furthermore, many meteorologists suggest that weather events such as thunderstorms, tornados, and hurricanes may become more intense and occur with greater frequency. This may bring more rain to some regions. On the other hand, severe storms cause strong winds and flooding, which could cause large-scale crop damage.

Many regions of the world, such as the Indian Subcontinent, the Andes region of South America, Kazakhstan, California, and the American High Plains, rely on melt water from glaciers and heavy winter snows to feed streams and rivers that provide water for irrigation. These high altitude water sources have traditionally been viewed as renewable resources that can be depended upon to provide moisture during the growing season and are then replenished by snow falls during the frigid winters. However, rising temperatures have caused glaciers to shrink or disappear and have been linked to reduced snow pack at high altitudes.

A related problem is that many of the most productive rivers to fuel hydroelectricity are fed from the melt water of high altitude glaciers and snow pack. The Yangtze River in China is important for agriculture, and with the Three Gorges hydroelectric power plant, it is also an important energy producer. However, the Yangtze River, like the Colorado River in the United States and the Ganges River in India, is replenished by melt water from glaciers and snowmelt. This shows the complex impacts of rising temperatures that will reduce water for agriculture, but also produce a renewable form of energy to offset carbon dioxide production from fossil fuels. Melting glaciers may also increase sea levels, which could jeopardize agriculture by flooding and accelerated soil erosion in many low-lying areas around the world.

Global warming is caused by increased concentrations of carbon dioxide, nitrous oxides, methane, and other gases produced by the combustion of fossil fuels. The impact of having more carbon dioxide in the atmosphere is difficult to gauge with certainty. Plants consume carbon dioxide in the production of oxygen through photosynthesis. Theoretically, increased levels of carbon dioxide could spur plant growth because increased atmospheric concentrations of carbon dioxide mean that there is more available for plants to use during photosynthesis. In addition, there is a synergistic relationship between carbon dioxide and water uptake. Plants are more efficient users of water as ambient concentrations of carbon dioxide increase.

Unfortunately, there are many factors that could offset the potential productivity gains to agriculture from increased carbon dioxide concentrations. The conditions that increase the growth of commercial crops also increase the growth of traditional weeds and could accelerate the growth of new invasive plant species. Also, increased temperatures will prompt the growth of plant diseases and insects. In order to reduce the impact of pests and pathogens, farmers will have to apply more pesticides, herbicides, and other chemicals, many of which are manufactured from petrochemicals.

Soil dynamics will also be affected by changing temperature regimes. Rising temperatures will increase the rate at which organic material decomposes and possibly decrease the level of moisture in soils. This will lower soil productivity, thus prompting the increased use of fertilizers. This might be mitigated, though, by the growing presence of nitrogen oxides that are also increasing as a result of fossil fuel combustion. Increased temperatures might also accelerate soil erosion in agricultural areas, rising temperatures increase the severity of thunderstorms. Without appropriate adaptation by producers, soil erosion could accelerate as the increased flow and force of water droplets dislodge soil. This is a problem because soil erosion is itself a cause of carbon dioxide release into the atmosphere.

CONTRIBUTIONS TO CLIMATE CHANGE

While agriculture is affected by climate change, agricultural processes also contribute directly and indirectly to global warming. This occurs for many reasons. A direct contribution is agriculture's reliance on the combustion of fossil fuels such as gasoline, diesel, and propane to power farm equipment, including tractors, combines, grain elevators, grain dryers, and transport trucks for shipping feed and livestock. Agriculture also relies on petrochemicals in the form of herbicides and pesticides. Estimates suggest that agriculture uses 8 percent of all energy consumed in the United States.

In order for farming to occur, land must be cleared of trees and other vegetation. The problem is that forests represent a "sink" or reservoir of carbon that would otherwise be part of the earth's atmosphere. The process of deforestation releases the sequestered carbon back into the atmosphere as the fallen trees decompose. This process is often accelerated as farmers burn the wood. In rainforest areas, traditional cultures use a farming process called "slash and burn" or swidden agriculture, whereby farmland is carved from the rainforest by cutting down trees. The trees are set on fire and the resulting ash nourishes the soil. After a couple of years, the nutrients are leached out of the soils because of the heavy precipitation in the rainforest. Farmers then move to a new site and repeat the process.

However, the impact of swidden agriculture is small compared to the destruction of tropical and temperate rainforests for the purposes of agriculture and timber production. Brazil is effectively competing with the United States in soybean production by turning its forests into fields. By turning its rainforests into cropland, Brazil is increasing greenhouse gases through deforestation. It also contributes to greenhouse gases because it has heavily invested in the American model of industrial agriculture, which relies on the consumption of fossil fuels to power farm equipment and to manufacture fertilizers, pesticides, and herbicides. While it is easy to blame tropical countries for cutting down their forests to make way for farming, temperate countries in North America and Europe have also plowed under biodiverse prairies and cut down broadleaf forests to make way for agriculture. The United States has the most productive agricultural system in the world. This productivity comes at a cost to the environment.

Agriculture accounts for about 7.4 percent of all carbon dioxide emissions in the United States. In addition to carbon dioxide, agricultural operations contribute more methane and nitrogen oxides to the atmosphere than any other economic sector. Enteric fermentation generates most of the methane released. In simpler terms, this refers to the flatulence released from ruminant livestock, such as cattle, as they digest feed grains. The production of rice also creates enormous amounts of methane. When the rice paddies are flooded, the organic material in the water-covered soils decomposes, anaerobically releasing methane in the process. The fact that rice is a staple crop for hundreds of millions of people around the world explains why it contributes so much methane to the atmosphere.

Nitrous oxides are an important input to industrial agriculture. Crop production depletes the nutrients in the field. Prior to the industrial revolution, farmers managed soil nutrients by rotating their crops. Different crops use different soil nutrients at different rates. Hence, crop rotation from year to year reduced the overall rate at which nutrients were depleted. Farmers also periodically left fields fallow. The nutrients in these fields were replenished as organic material on the soil surface decomposed.

In modern industrial agriculture, crop rotations play a moderate or minor role in the management of soil fertility. Farmers survive on low profit-margins. Hence, they tend to specialize in only one or two crops to achieve economies of scale in production. In the American Midwest, the crops tend to be corn or soybeans. Farmers are not likely to rotate beyond these two crops, nor are they likely to leave fields fallow. This means that farmers must maintain soil productivity through the application of nitrogen to the soils. Nitrogen oxides form when the nitrogen designed to work below the soil comes in contact and binds with oxygen molecules. Farmers also use animal waste as a way to increase nutrients in the soils. Hence, animal waste management practices also contribute to nitrogen oxides in the atmosphere.

Finally, agriculture contributes greenhouse gases because of the national agricultural system and a global agricultural market that depends on shipping commodities hundreds and even thousands of miles to markets. This requires the combustion of gasoline and diesel to operate trucks and refrigerated storage facilities.

AGRICULTURAL SOLUTIONS TO CLIMATE CHANGE

There are many strategies that farmers, businesses, and consumers can adopt to reduce greenhouse gases related to agriculture. First, farmers can replace fossil fuels such as gasoline and diesel with biofuels such as ethanol or biodiesel. Ethanol is a fuel alcohol that is produced by a fermentation process that uses yeast to convert the sugars found in plants into a combustible alcohol fuel. Ethanol can offset varying amounts of fossil fuel–generated carbon dioxide depending on the material used to produce the ethanol. For example, Brazil, located in a tropical climate, can efficiently grow sugarcane. Sugarcane is an excellent source material for ethanol because the sugars in sugarcane can be easily converted into alcohol. In the United States, corn is the primary feedstock for ethanol. It is more costly to convert corn into sugar because the sugars are bound up in long starch molecules. These carbohydrates must be broken down in order to free up the sugars to be converted into alcohol. Therefore, researchers in the United States are working hard to discover ways to lower the costs of producing corn-based ethanol.

Researchers are also studying how to use other plant materials to produce fuel. Cellulosic ethanol is not yet a commercially-viable strategy, but many predict that it will be in the near future. Cellulose is the fibrous or "woody" part of many plants. For example, high concentrations of cellulose are found in the stock and leaves of corn. It would be beneficial to use this part of the corn for ethanol production because it is usually considered a waste product. Cellulosic ethanol would allow the corn kernel to be used for food rather than as a source material for ethanol. The challenge is that the sugars in the cellulose are tightly bound to starch molecules. Consequently a more expensive, enzyme-driven process must be used to convert the sugars into alcohol. Therefore, cellulosic ethanol is not commercially viable now, but many countries, including the United States, are spending hundreds of millions of dollars to discover how it could become a commercially viable fuel.

In addition to ethanol, research is being conducted on other plant-based alcohol fuels such as methanol and butanol. These fuels can also be produced from organic materials including grains and wood fibers. They are currently not commercially viable, but some researchers claim that they may be even better than ethanol as an alternative fuel. Diesel produced from plant material can also reduce greenhouse gases. Crops known as oilseeds, such as cottonseed, sunflower, soybeans, and canola, can serve as the source material to produce a diesel product that has performance characteristics similar to petroleum-derived diesel, without emitting the same volume of greenhouse gases.

Farmers can also modify their management practices so that farmland can serve as a sink to sequester carbon dioxide. For example, farmers can create buffers comprised of trees, shrubs, and natural grasses along rivers to prevent soil erosion and the loss of nutrients due to runoff. The Conservation Reserve Program in the United States pays farmers to take marginal cropland out of production as a way to reduce soil erosion.

Farmers can also create windbreaks near farmhouses and outbuildings. Windbreaks can create a microclimate that can moderate temperature extremes by blocking cold winds or providing shade on hot summer days. This can lower energy use and costs on farms. Windbreaks can also serve as carbon sinks, whereby trees and other plants absorb carbon dioxide. Farmers can also adopt conservation tillage strategies that leave part of the organic residue on the field after the harvest. This material slows runoff, thereby reducing soil erosion and nutrient loss. The decomposing material also replenishes the nutrients in the soil. All of these practices can reduce the energy used, and greenhouse gases produced, on the farm.

Livestock producers can reduce the impact of their operations by changing how they manage animal waste such as methane and manure. Some farmers are experimenting with anaerobic digesters that convert manure into more manageable waste solids that can be used as an organic fertilizer. The digester also creates methane as a byproduct, which can be captured and used as a renewable fuel.

Finally, some writers argue for a move away from large-scale industrial agriculture to place more emphasis on so-called civic agriculture as a way to slow global warming. Civic agriculture includes local food systems and organic foods. Local food systems reduce greenhouse gases by reducing transportation costs. Traditional food supply chains can stretch thousands of miles from the point of production to the place of consumption. Local food advocates suggest that food could be grown and consumed locally. Organic agriculture reduces the use of greenhouse gases because organic farmers cannot use petroleum-based herbicides or pesticides.

SEE ALSO: Alternative Energy, Ethanol; Food Production; Methane Cycle.

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Agulhas Current

THE AGULHAS CURRENT is the major western boundary current of the Southern Hemisphere. It completes the anti-cyclonic gyre of the South Indian Ocean, and because the African continent terminates at a relatively modest latitude, it becomes a mechanism for the climatologically important inter-ocean exchange between the Indian and Atlantic Oceans. The southwestward flowing Agulhas Current only becomes fully constituted along the east coast of southern Africa at a latitude somewhere between Durban (South Africa) and Maputo (Mozambique). It increases in speed and volume flux downstream.

On average, its volume flux is 70 × 106 m.3/s, with only small temporal changes. Its depth, by contrast, can vary from 6561 ft. (2,000 m.) to the sea floor at 9,842 ft. (3,000 m.) over a period of months. It is underlain by an opposing undercurrent at a depth of 3,937 (1,200 m.), with a maximum velocity of about 0.2 m./s and carrying about 4 × 106 m.3/s equatorward. An offshore profile of the surface speed of the current shows a peak of about 1.5 m./s close inshore, slowly tapering off to about 0.2 m./s at a distance of roughly 62 mi. (100 km.) offshore. The temperature of its surface waters is about 11 degrees F (6 degrees C) higher than ambient waters and decreases from 80 to 71 degrees F (27 degrees C to 22 degrees C) from summer to winter.

Using its flow characteristics, the Agulhas Current can be clearly divided into northern and a southern parts. The northern part follows the continental shelf edge very closely, meandering less than 9 mi. (15 km.)

to either side. Downstream of Port Elizabeth, in its southern part, it starts meandering with increasing distances to either side of its mean trajectory, producing large shear edge eddies and plumes on its landward side in the process. The path stability of the northern Agulhas Current is interrupted at irregular intervals by a major perturbation, called the Natal Pulse, which is triggered just upstream of Durban. Triggering is thought to come about when offshore eddies interact with the current. This singular meander grows as it travels downstream at a rate of about 12 mi. (20 km.) per day. It has an embedded cyclone on its landward side. Natal Pulses have been perceived to play an important role in inter-ocean exchange.

Once the southern Agulhas Current overshoots the tip of the continental shelf south of Africa, it retroflects, with most of its water heading zonally eastward as the Agulhas Return Current, more or less parallel to the Subtropical Convergence. The Agulhas Return Current is largely steered by the bathymetry and exhibits large meridional meanders. The retroflection loop itself is unstable, and at irregular intervals it occludes, forming a large ring 155 mi. (or 250 km. diameter) of warm Agulhas Current water. These rings may extend to the sea floor. After such an event the newly-formed retroflection loop starts prograding into the South Atlantic Ocean once more. There is evidence that nearly all ring shedding events are set off by the arrival of a Natal Pulse from farther upstream.

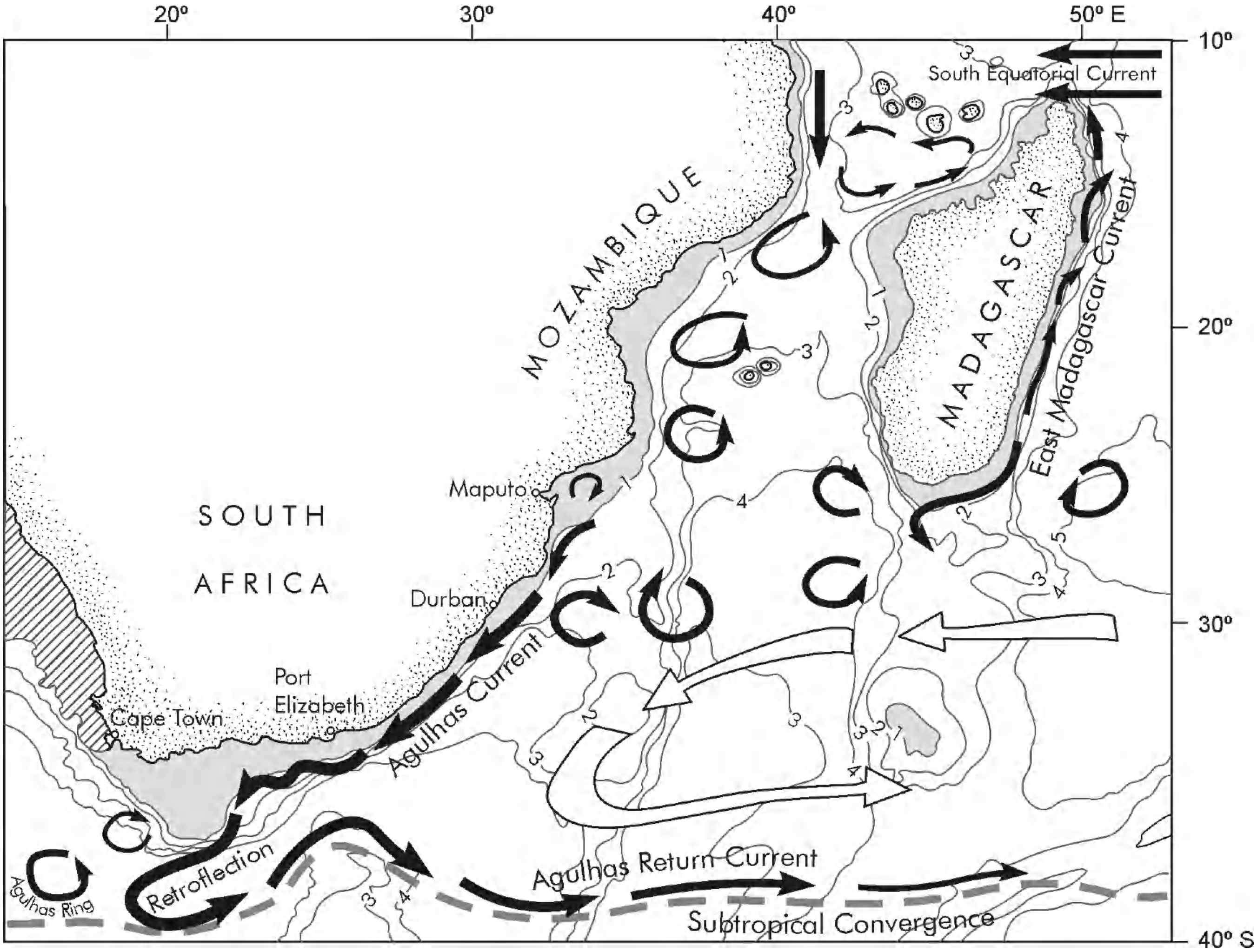
Having formed, most rings dissipate in the mixing cauldron of the Cape Basin northwest of Cape Town. Here, Agulhas rings have to contend with previously-formed rings, as well as Cape Basin cyclones. The few that survive this interaction move northwestward across the South Atlantic Ocean, slowly shedding their anomalous heat, salt, and vorticity to the ambient waters. The inter-ocean fluxes brought about by the ring-shedding process have been estimated to lie between 5 and 20 × 106 m.3/s. By this process and others, the Agulhas Current becomes a profound factor in local weather and in global climate.

It has been demonstrated that the presence of the Agulhas Current enhances coastal rainfall along South Africa's east coast. Wherever the current is further offshore, this enhancement is reduced. The enormous ocean-to-atmosphere heat fluxes at the Agulhas retroflection and from Agulhas rings and Agulhas eddies; the latter shed across the Subtropical Convergence by the Agulhas Return Current, directly affect the overlying atmosphere and, thus, local weather.

Even more important climatologically, is the role the Agulhas Current plays in the global thermohaline circulation. The westward heat and salt flux south of Africa is a crucial link in this chain of currents and fluxes. The Atlantic Ocean is the only ocean basin where there is a net heat flux northward across the equator; this has been assumed by some to be the result of the net westward heat flux south of Africa. Modelling studies have shown that a forced decrease in this flux is linearly related to a decrease in the meridional overturning of the whole Atlantic Ocean. Studies of temporal changes of inter-ocean fluxes, such as changes in the bottom sediments, have shown substantial variation in the penetration of Agulhas Current water into the South Atlantic over the past 500,000 years, which has never shut off completely. Furthermore, analyses of bottom sediments have demonstrated conclusively big surges of Agulhas Current water into the South Atlantic at the end of each glacial period.

Understanding significant changes in the inter-ocean exchanges requires a look at how the Indian Ocean controls Agulhas ring shedding. The main factor controlling the horizontal circulation system in the ocean gyres to either side of South Africa is the wind stress pattern. The succession of trade winds and westerlies drives a subtropical ocean gyre system both in the South Indian and Atlantic Oceans. This subtropical circulation is connected south of Africa, largely by the Agulhas rings. Meridional shifts of the wind pattern or variations in their strength lead to variations in this connection. Modelling studies suggest that a large southward shift opens the Agulhas valve and results in a supergyre that flows unobstructed through both oceans. Similarly, the wind patterns shifting northward, reduces the flux from the Indian to Atlantic Ocean. Data from the paleo record indicate that such fluctuations of the inter-ocean exchange have occurred.

Less dramatic variations of the exchange have been observed over the past decades. They seem to be controlled by the tropical and subtropical climate modes over the Indian Ocean. Associated wind variations force anomalies over the central and eastern Indian Ocean that propagate as planetary waves from east to west across the Indian Ocean. On encountering the



Agulhas rings that reach the South Atlantic Ocean and shed their heat, salt, and vorticity to the ambient waters are part of what makes the Agulhas Current a profound factor in both local weather and the global climate.

island of Madagascar, the anomalies interact with the background current system, involving swift boundary currents along the east coast of Madagascar and jets that separate from both the northern and southern tips of the island. This leads to instabilities in the flow, with mesoscale eddies formed both in the Mozambique Channel and south of Madagascar. The resulting eddy trains propagate to the African coast where they either trigger the formation of Natal Pulses or move into the Agulhas retroflection region. In both cases, they seem to regulate the frequency of Agulhas ring shedding. The rate of eddy formation around Madagascar has been observed to vary with the appearance and strength of the Indian Ocean (sub)tropical climate modes. The whole chain of events takes several years to propagate from the tropical and subtropical region to the Agulhas retroflection.

SEE ALSO: Anticyclones; Indian Ocean; Meridional Overturning Circulation; South Africa; Thermohaline Circulation; Western Boundary Currents.

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Air Force, U.S.

THE U.S. AIR Force began as the Aeronautical Division of the U.S. Army Signal Corps. This division was established on August 1, 1907, to manage air machines, military ballooning, and other military matters of the air. Since then, the Air Force has become an institution independent of the U.S. Army, and with its vast increase in size and fuel usage has a considerable effect on the environment. The U.S. Air Force is conscious of greenhouse gas emissions and their potential link to global warming. For example, the Air Force voluntarily purchased over one billion kilowatt-hours of green energy in 2006: 39 percent biomass, 38 percent wind, 16 percent geothermal, and 7 percent other. The power was purchased from several sources, including American Electric Power, Rocky Mountain Generation Cooperative, and Sterling Planet.

The estimated quantity of emissions spared via the green energy is equal to the emissions of just over 250,000 cars annually. This purchase led the U.S. Environmental Protection Agency (EPA) to name the Air Force the leading green energy purchaser in the United States in 2006. By July 2007, the Air Force had fallen to the number five position, behind PepsiCo, Wells Fargo & Company, Whole Foods Market, and The Pepsi Bottling Group, Inc. The Air Force had purchased nearly .5 billion kilowatt-hours of green energy, which supplied only 4 percent of its total electricity needs. Other renewable purchases and on-base renewable energy generation raised that percentage to nearly 10 percent. The Air Force is also on the Environmental Protection Agency's Top Ten Federal Government Green Power Partners list, in the highest position for three years in a row: 2005, 2006, and 2007.

Another facet of environmental protection pivotal to the Air Force is cleaning and restoring the environment surrounding Air Force Bases, especially during closings or realignments. A special office that helps to manage these issues is the U.S. Air Force Center for Environmental Excellence (AFCEE). The AFCEE is headquartered at Brooks City-Base, San Antonio, Texas. It is an Air Force Civil Engineer field-operating agency, created in 1991 in response to a need for assistance to Air Force commanders when establishing environmental or construction programs. Several rearrangements of the organization and offices have taken place since 1991; however, the vision and purpose of the AFCEE has remained the same. According to its mission statement, "AFCEE provides a complete range of technical and professional services in environmental and installation planning and engineering, and military housing construction and privatization." Within one year, the AFCEE base was managing numerous environmental clean-ups, specifically those needed after a sweep of closures and realignments of many bases.

Because there are many leading environmental engineers and green construction experts who are not in the Air Force, the AFCEE employs both civilians and military personnel in dealing with the environment and construction management. As of 2007, approximately 300 civilians and 50 military personnel belonged to the AFCEE. These members included contractors around the nation. A civilian director, assisted by an executive director, manages the AFCEE. The civilian director is a member of the senior executive service, while the executive director is a colonel in the Air Force. In addition, the executive director acts as commander of the military personnel at the AFCEE. Four support directorates assist the AFCEE in the spectra of Contracting, Mission Support, Operations & Development, and Staff Judge Advocate (Legal). Additionally, AFCEE directors manage four business line directorates: Installation and Support Worldwide, Installation and Support for Air Force-related Matters, Housing, and Base Conversion. Finally, there is a technical directorate and three regional offices for the environment. These offices are located in Atlanta, Georgia; Dallas, Texas; and San Francisco, California.

An additional step made by the Air Force to reduce fuel usage is the purchase of flight simulators to reduce the fuel requirements of training. Novel technology is also being used to better align fuel (and thus weight) carried with fuel needed per flight. Streamlining fuel weight to just the amount needed will reduce fuel usage overall, as a lighter plane uses less fuel per unit of distance and speed. While these changes were for the sole purpose of saving money on fuel and, thus, using tax dollars more efficiently, the reduced burning of fuel also has a positive impact on the environment.

SEE ALSO: Aviation; Environmental Protection Agency; Navy, U.S.

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ALABAMA IS 52,237 sq. mi. (135,293 sq. km.) wide, with inland water making up 962 sq. mi. (2,491 sq. km.), and coastal water 519 sq. mi. (1,344 sq. km.) Alabama's average elevation is 500 ft. (152 m.) above sea level, with a range in elevation from sea level on the Gulf of Mexico to 2,405 ft. (733 m.) at Cheaha Mountain. Alabama's varied topography includes plateaus, uplands (northeastern section of the state), forested ridges, rolling prairie, and fertile valleys. Most drainage flows to the Gulf of Mexico, or, as in the case of the Tennessee River, drains into the Ohio River, then drains into the Mississippi River. The bodies of water in Alabama are mostly reservoirs. Alabama's coastline on the Gulf of Mexico is only 53 mi. (85 km.) long; Mobile Bay, an inlet 35 mi. (56 km.) long at the mouth of the Mobile River, along with smaller bays and inlets, creates a much longer shoreline. Barrier islands block part of the entrance to Mobile Bay. Other islands extend along Alabama's western coast.

Alabama's temperate subtropical climate means its long summers are hot and humid, while winters are mild. Temperature extremes are unusual, though the highest temperature recorded in the state was 112 degrees F (44 degrees C) on September 5, 1925, and the lowest temperature recorded in the state was minus 27 degrees F (minus 33 degrees C) on January 30, 1966.

In winter, mild humid air masses from the Gulf alternate with cold air masses from the north. Snow occasionally falls in the north. The average annual precipitation is 56 in. (1.4 m.); most rainfall occurs in winter and spring with droughts common from August through October. River overflow and flooding occurs one time per year on average. Tornadoes occur November to May, and March to April is the most frequent storm season. Hurricanes occur between July and November.

Fossil fuel is important to Alabama's economy, with coal mining (in the north-central region, especially near Birmingham), natural gas, and petroleum, along with thousands of acres offshore leased for oil and gas. Agriculture is also important. A variety of crops (cotton, corn, and hay) are grown, though in some places the soil requires fertilization. In 1980, Alabama instituted a conservation program of forest management and replanted 22 million acres of forest for logging. Alabama is already experiencing the effects of higher temperatures and rising sea levels (9 in. in the last century) and hurricane and other major storms have increased in intensity and duration by about 50 percent since the 1970s, noted in the devastation from Hurricane Katrina in 2005.

While climate models vary, temperature increases for Alabama, from 1–4 degrees F (0.5–2 degrees C) in winter and summer, from 1–5 degrees F (0.5–2.7 degrees C) in spring, and from 2–7 degrees F (1–4 degrees C) in fall, are predicted by the end of the century. Potential risks include anticipated rising sea levels of an additional 20 in. (51 cm.) (causing flooding, loss of coastal wetlands, beach erosion, saltwater contamination of drinking water, and damage/decreasing stability of low-lying property and infrastructure), possible increase in frequency and intensity of summer thunderstorms, decreased water supplies, population (both human and animal) displacement, changes in agriculture (cotton yield unaffected, but rising corn and hay yields), and forest loss with persistent drought, as well as loss of trees unsuited to higher temperatures.

Human health risks include contracting certain infectious diseases from water contamination or disease-carrying vectors such as mosquitoes, ticks, and rodents. Warmer temperatures increase the incidence of heat-related illnesses and lead to higher concentrations of ground-level ozone pollution, which could cause respiratory illnesses (diminished lung function, asthma, and respiratory inflammation), especially in Birmingham, which sometimes already exceeds the national standard for ozone.

Based on energy consumption data from EIA's State Energy Consumption, Price, and Expenditure Estimates (SEDS) released June 1, 2007, Alabama's total CO_2 emissions from fossil fuel combustion in million metric tons CO_2 for 2004 was 140.48, including contributions from: commercial 2.08, industrial 24.57, residential 3.1, transportation 34.89, and electric power 75.84. Alabama joined the Climate Registry in 2007, and by doing so agreed to develop and manage a greenhouse gas emissions reporting system as well as provide an accurate assessment of greenhouse gas emissions.

The Geological Survey of Alabama is taking part in the Southeastern Regional Carbon Sequestration Partnership (SECARB) investigating the potential for using coal as a sink for carbon dioxide. They will perform field-testing and monitoring in the Black Warrior basin; an assessment indicated more than 5.9 trillion cu. ft. of CO_2 could be sequestered in established coal bed methane fields. Air quality water, and land protection and conservation in the state falls under the Department of Conservation and Natural Resources. However, in terms of climate change initiatives, more is being done on the local level and in the private sector.

The Alabama Power Company and the Tennessee Valley Authority (TVA) are working to improve greenhouse gas emissions. The Alabama Power Company is updating technology for reducing CO_2 discharges. TVA must meet federal and other environmental statutes and regulations for air and water quality, as well as managing the disposal of wastes (including hazardous materials). These regulations are becoming more stringent with clean air requirements and reducing greenhouse gas emissions.

SEE ALSO: Carbon Sequestration; Coal.

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Alaska

THE LARGEST AND the coldest of the 50 American states, Alaska is already experiencing the effects of climate change. The state, which is located in the extreme northwestern portion of the North American continent, normally experiences temperatures ranging from minus 60 degrees F (minus 51 degrees C) in the winter to more than 90 degrees F (32 degrees C) in interior areas during summer months. Over the last three decades, Alaska's average temperature has risen 5 degrees F (2.7 degrees C). Around the world, glaciers are melting at unprecedented levels, threatening animal and plant ecosystems. In Alaska, warmer temperatures are causing the breaking up of portions of Porter Glacier. Alaska shares an eastern border with Canada and is surrounded on three sides by the waters of the Gulf of Alaska, the Beaufort Sea, the Bering Sea, the Bering Strait, and the Chuckchi Sea, all of which are also filled with ecosystems that are vulnerable to changing temperatures.

Sea levels are rising around the world, and Alaska is seeing the effects of these changes to varying degrees. The most significant changes have been along the coasts of the Bering Sea, the Chuckchi Sea, and the Beaufort Sea. The coastal communities of Kivalina, Shishmaref, and Newtok are in the process of relocating because of erosion and flooding. According to the U.S. Army Corps of Engineers, more than 160 other rural communities in Alaska are vulnerable to coastal erosion. Alaska has over 100 acres of state parks and forests, and scientists have observed decreased tree growth in interior areas as a result of climate change. The state also has a large mammal population whose survival depends on preserving existing ecosystems. Alaska has experienced an increase in the number of forest fires in the state in response to warmer temperatures, and spruce bark beetles are destroying forests.

In much of Alaska, permafrost causes the ground to remain frozen year-round. Some 85 percent of Alaska is built on foundations of permafrost. When events occur to disrupt the thermal balance, the permafrost melts and the ground above it collapses in a process known as thermokarst slumping. Maintenance costs are already increasing for roads, pipelines, and other facilities built on permafrost. Two Alaskan scientists, who have identified holes as deep as 200 ft. (61 m.) in some areas, report that the permafrost south of the Yukon River is nearing thawing point. Another scientist has observed that permafrost in the far north remains relatively stable, but acknowledges that considerable warming has occurred since the 1990s. If permafrost melts, it may lead to slumping roads, slanting floors, forest sinkholes, disappearing trees, and the presence of new lakes.

Although the state government has acknowledged the need to respond to changes that are taking place in Alaska, there is still controversy over whether or not climate changes are due to global warming, and on defining specific actions that are necessary to deal with the issue. In the spring of 2007, three groups of Alaska Natives, the Inter-Tribal Council, the Council of Athabascan Tribal Governments, and Resisting Environmental Destruction on Indigenous Lands, filed an *amicus curiae* (friend of the court) brief in a global warming lawsuit filed by 10 states, three cities, and a number of citizen advocacy groups, in an effort to force the U.S. Environmental Protection Agency (EPA) to regulate greenhouse gases and identify them as contributors to global warming and climate change. The state government of Alaska has joined 10 other states and industries in formally protesting the suit, arguing that forcing the EPA to reduce carbon dioxide (CO_2) emissions from new vehicles would not solve the overall problems of global warming.

When compared with other states, Alaska produces 0.3 percent of the nation's alternative fuels and 0.1 percent of ethanol. The state produces 0.2 percent of total CO_2 and 0.4 percent of nitrogen oxide emissions. Alaska does not produce significant amounts of sulfur dioxide. Alaska has the 14th lowest level of CO_2 emissions in the United States; but because of Alaska's sparse and widely distributed population and its dependency on coal-generated power, the level of CO_2 produced per person is the highest in the nation and six times that generated by the state of New York, which has a population approximately 29 times the size of Alaska's. Because the land area of Alaska is 570,374 sq. mi. (917,928 sq. km.), residents spend much time traveling by air, and Anchorage, the largest city in the state, ranks second in air cargo traffic in the United States.

ENERGY PRODUCTION

Alaska ranks second in oil production in the United States, outranked only by Texas. A total of 14 of the largest American oil fields and two of the largest natural gas fields are found on the Alaska North Slope. Prudhoe Bay yields around 400,000 barrels a day, and the Trans-Alaska Pipeline is capable of pumping 2.1 million barrels of crude oil daily. The Alaskan ecosystems are still not completely recovered from the oil spill that occurred in 1989 when the *Valdez*, an oil tanker owned by Exxon, inadvertently spilled 260,000 barrels of oil into Prince William Sound. Because Alaska does not use all of the natural gas that is produced during oil production and there is no viable means of piping it into the American mainland, much of it is pumped back into the ground. In order to make use of this cheap and readily available natural gas, a number of petrochemical industries, which produce ammonia and urea fertilizer, have located in Alaska.

Some 50 hydroelectric plants supply the most heavily populated areas of Alaska with power. Around three-fifths of Alaska's energy is fueled by natural gas. Two-tenths of the energy requirement is met by petroleum and coal. In many isolated areas, diesel-fueled electric generators supply power. Renewable energy is replacing fossil fuels in some areas, and a geothermal plant has been built in Chena Hot Springs. Small wind farms have been set up in the rural areas of Healy and Kotzebue. Anchorage is home to one of the largest fuel cell systems in the United States.

ENVIRONMENTAL PROGRAMS

The Alaska Department of Environmental Conservation (DEC) is chiefly responsible for responding to environmental issues that affect global warming and climate change in Alaska. The Division of Air Quality, the Division of Environmental Health, the Division of Information and Administrative Services, the Division of Spill Prevention and Response, and the Division of Water are all sub-branches of ADEC. The Department of Fish and Game and the Department of Natural Resources also have environmental obligations.

In the fall of 2007, Governor Sarah Palin created the Climate Change Sub-Cabinet by executive order and charged the group with consolidating existing knowledge on climate change and making recommendations for policy and initiatives designed to reverse climate change trends that are already evident in Alaska. Three workgroups have been set up to pursue the goals of the Sub-Cabinet: Immediate Action, Alternative Energy Conservation, and Research Needs. The Sub-Cabinet is made up of department commissioners from Commerce, Community and

Economic Development, Natural Resources, Fish and Game, Transportation and Public Facilities, and Environmental Conservation.

The group was requested to work with the University of Alaska to investigate the development of renewable energies, including geothermal, wind, hydroelectric, and tidal resources. The Climate Change Sub-Cabinet cooperates with the Joint Alaska Climate Impact Assessment Commission set up by the legislature, Arctic Climate Impact Assessment (ACIA), and the University of Alaska's Alaska Center for Climate Assessment and Policy. Alaska has observer status at the Western Climate Initiative, which the governors of Arizona, California, New Mexico, Oregon, and Washington established in February 2007, to develop regional responses to climate change.

Because the population of Alaska is widely scattered and travel is often difficult, the needs of rural Alaskans are different from those of larger, more populated areas. A number of programs, such as RurAL CAP, have been established to meet these distinct needs. Alaska Environmental Resource Hub Online serves as an interactive environmental educational tool and provides a forum for addressing issues that include compliance, solid waste management, air quality, environmental justice, and health. RurAL CAP works closely with the local Indian General Assistance Program. The Alaska Village Indoor Air Quality Program provides education on environmental issues in rural communities and advises Alaskans on reducing exposure to domestic hazardous waste, installing carbon monoxide alarm systems, and using non-toxic green cleaning kits. RurAL CAP and RAVEN AmeriCorps members use the Savin Raven Game to teach children about environmental issues.

There are a number of other programs designed to protect Alaska's environment and slow the progress of climate change in the state. For instance, the Alaska Environmental Monitoring and Assessment Program samples coastal and fresh waters to maintain clean water and protect vulnerable ecosystems. The Environmental Quality Incentives Program serves the Alaskan agricultural sector by promoting voluntary conservation and offering financial and technical help to enable farmers to meet national guidelines for responsible agricultural practices.

Grassroots groups are also an essential element in pursing environmental policies designed to mitigate the effects of global warming and climate change. Citizens' groups include Alaska Action Center, Alaska Boreal Forest Council, Alaska Center for the Environment, Alaska Clean Water Alliance, Alaska Community Action on Toxics, Alaska Conservation Foundation, Alaska Forum for Environmental Responsibility, Alaska Friends of the Earth, Alaska Marine Conservation Council, Alaska Natural Heritage Program, Alaska Rainforest Campaign, and Alaska Wilderness League.

SEE ALSO: Alaska Climate Research Center; Arctic Ocean; Oil, Production of.

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Alaska Climate Research Center

THE ALASKA CLIMATE Research Center is a research and service organization at the Geophysical Institute at the University of Alaska, Fairbanks. Established and funded by the State of Alaska, the center conducts research focusing on the climate of Alaska and other polar regions. It also houses an archive of Alaska climate data. The primary concern of the center is to supply information concerning the meteorology and climatology of Alaska to public, private, and government agencies. It also assists researchers around the world.

Most of the climate data available for Alaska have been accumulated in Fairbanks and by the state climatologist in Anchorage at the Alaska State Climate Center. The Alaska Climate Research Center archives digital climate records, develops climate statistics, compiles monthly weather summaries, and conducts research on a number of high latitude meteorological and climate issues.

The center found itself in the spotlight of national debates over global warming in 2002, when a *New York Times* editorial praised Californian legislation that set stricter standards for CO_2 emissions from automakers. The article cited a report by journalist

Timothy Egan about Alaska, claiming that a dramatic 7-degree increase in average temperatures over the past 30 years has led to “melting permafrost, sagging roads, dying forests, unexpected forest fires and disruption of marine life.” The article concluded by quoting Alaska Republican Senator Ted Stevens’s concern about “global warming’s potential cost to his home state” and “Washington’s indifference.” The Alaska Climate Research Center entered the debate by issuing a note that challenged and openly countered the data reported by Timothy Egan. The statement read:

> the article ‘Alaska, No Longer So Frigid, Starts to Crack, Burn, and Sag’ written by Timothy Egan, stated that the average temperature has risen seven degrees in the last 30 years. This statement was repeated in an editorial by Bob Herbert of 24 June 2002. This statement is incorrect. The correct warming for Alaska is about 1/3 of the quoted amount for the last climatological mean 1971 to 2000.... It should be pointed out that ... data [come] from first class weather stations, which are professionally maintained and generate high quality data. The three stations, Barrow, Fairbanks, and Anchorage, represent a cross section of Alaska from north to south. Further, Barrow, situated in Northern Alaska, which gave the largest temperature increase, is the only long-term first class meteorological weather station in Northern Alaska. All changes are based upon the time period 1971 to 2000 and are compiled from a linear trend.

SEE ALSO: Alaska; Climatic Data, Historical Records.

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Albania

ALBANIA IS A small and relatively underdeveloped country in southeast Europe. Since the collapse of the Communist government there in 1991, Albania has transformed itself from an isolated country to one whose government has sought to take an active part in European affairs. The country has a population of 3.6 million (2007), and covers 11,100 sq. mi. (28,748 sq. km.), with a population density of 318.6 per sq. mi. (134 per sq. km.). Some 21 percent of the land is arable, with 5 percent under permanent cultivation, and 15 percent as meadow or pasture. In addition, some 38 percent of the country is forested; most of the trees are oak, elm, pine, or birch.

There are a number of environmental problems facing Albania, mainly with pollution. The country is largely self-sufficient in food, and its petroleum industry produces some 100,000 barrels per day. Because much of the country is underdeveloped, Albania has a relatively low carbon dioxide emission level per capita, with 2.2 metric tons emitted per person in 1990, 1.2 metric tons in the following year, and falling off markedly to 0.7–0.8 metric tons per capita in the 21st century, showing one of the more dramatic declines of any country in the world. Albania is now 139th in the world in terms of carbon dioxide emissions per capita, the second lowest in Europe; only Georgia has a lower emission level. Similarly, the sulfur dioxide, nitrogen oxide, and the carbon monoxide emissions from Albania are all very low.

The main reasons for the low carbon emissions in Albania are relatively low private ownership of cars, heavy use of public transport, and a reliance on hydroelectric power. Only 3 percent of Albania’s total electricity production comes from fossil fuels, with the remainder from hydropower generated from the dams along the Drin River, especially from where Vau I Dejes runs to the junction of the White Drin and Black Drin rivers at Kukës.

The building of the hydroelectric power network at Kukës resulted in some of the villages in the region being submerged in the early 1970s, with the building of a new town called Kukësi i Ri (“New Kukës”). The dam located at Fierzë led to the formation of the largest artificial lake in the country at 28 sq. mi. (73 sq. km.), further adding to hydroelectric power. There are also other dams operated by the Albanian Energy Corporation (K.E.S.H.) that help in hydroelectric production, such as the Bovilla Dam. Not only does hydropower help Albania, but it also provides much electricity for Greece, helping reduce Greek carbon emissions.

The Albanian government of Sali Berisha, which came to power in April 1992, took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, as part of a move to involve Albania more with the West. However, it was not until the presidency of Alfred Moisiu that Albania accepted the Kyoto Protocol to the UN Framework Convention on Climate Change, which took place on April 1, 2005, coming into force on June 30, 2005.

SEE ALSO: Georgia Nation; Greece; Kyoto Protocol.

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Albedo

ALBEDO ORIGINATES FROM a Latin word *albus*, which means white. Albedo is the amount of sunlight (of all wavelengths) that is reflected back from an object or a substance. The more the amount of light reflected back, the brighter the color of the object. A lesser amount of light is reflected back from darker objects. The albedo of an object varies from 0–1. Black objects have zero albedo, while white objects have an albedo of one. Sometimes it is also expressed in terms of percentage, 1–100. An ideal white body thus has an albedo of 100 percent, while an ideal black body has an albedo of zero percent. Some standard amounts of sunlight reflected from certain objects are shown in Table 1.

Usually, albedo is used in the field of astronomy to describe reflective properties of planets, satellites, and asteroids. There are two types of astronomical albedo: normal and bond albedo. Normal albedo is a measure of a surface's brightness when illuminated and observed vertically, while bond albedo is defined as the fraction of total solar light reflected back to space and is a measure of a planet's energy balance. The value of bond is defined over the entire range of wavelengths.

Surface reflectance values vary across the globe, mainly because of variation in presence or absence of snow, ice, or clouds, which increases albedo values in those areas. The presence of ice and snow, for example, on poles and the absence of snow and ice on the equator reflects the difference in albedo values at the poles and equator. It is interesting to note that the reflectance value (and hence the albedo value) changes with the change in dust concentration, thickness of the clouds (or amount of cloud cover) and zenith of sunlight falling in that zone, which is also reflected in seasonal variation in albedo value for the same region. This can be observed best at higher altitudes, where in winter the surface is covered significantly by snow (or ice), thus increasing the surface reflectance values, while in spring, when most of this snow (or ice) melts, the surface (bare soil) absorbs a lot more sunlight, thus decreasing the albedo values for the same place.

Table 1: Reflectivity values of various surfaces

Surface	Details	Albedo
Soil	Dark and wet Light and dry	0.05 0.40
Sand		0.15–0.45
Grass	Long Short	0.16 0.26
Crops		0.18–0.25
Tundra		0.18–0.25
Forests	Deciduous Coniferous	0.15–0.20 0.05–0.15
Water	Small zenith angle Large zenith angle	0.03–0.10 0.10–1.0
Snow	Old Fresh	0.40 0.95
Ice	Sea Glacier	0.30–0.45 0.20–0.40
Clouds	Thick Thin	0.60–0.90 0.30–0.50

Sources: Oke; Ahrens.

Albedo is an important concept in climatology. When albedo is expressed in percentages, snow has an albedo of 90 percent and charcoal has an albedo of 4 percent. When seen from a distance, the ocean surface has a low albedo as do most forests, while desert has one of the higher albedo values.

The role of the concept of albedo in climate change can be seen in the following example: ice reflects back more sun radiation than water; with the snow cover getting smaller and the water in lakes (and seas and oceans) increasing, the amount of sunlight absorbed (and, hence, heat retained) is increasing, leading to further increases in the temperature of lake, sea, and ocean water. On the other hand, if more snow is formed, a cooling cycle starts. The amount of sunlight (radiation) absorbed or reflected back causes fluctuations in temperature, wind, ocean currents, and precipitation. In a way, the hydrological cycle changes with the fluctuations in temperature (which is related to how much evapo-transpiration takes place). Also, the climate system equilibrium is dependent on the balance between the amount of solar radiation absorbed and the amount of terrestrial radiation emitted back to space.

Thus, Earth's albedo values are important in shaping both local and global climate through their radiation budget (difference between the amount of absorbed short-wave radiation and outgoing long-wave radiation). For example, clouds have an impact on the amount of energy (sunlight/radiation) that reaches the Earth's surface. Because cloudiness varies geographically, with the lowest values of cloudiness observed in the subtropics and the highest values observed in mid- to high-latitudes, this has an impact on surface reflectance globally. The variation in surface reflectance determines how much of the sunlight is absorbed or reflected back. Approximately half of the solar energy is absorbed by the Earth's surface, which causes evapo-transpiration and precipitation, and thus, impacts the hydrologic cycle as well.

Table 1 shows albedo values for different landforms and covers. Land areas have a higher albedo value than oceans, mainly due to cloud contributions over land. Human activities such as clearing of forests for farming, human settlements, urbanization, and industrialization have changed the landscape and, in turn, have changed the albedo value of different places. Since forests/trees have a low albedo, removal of forests/trees tends to increase the albedo, thereby cooling the planet. In winter, in snow-covered areas, the albedo of treeless areas is about 10 to 50 percent higher than forested areas (where snow does not cover the trees that readily). Studies have also shown that new forests in tropical or mid-latitude areas tend to be cooler, while new forests in higher latitudes are more neutral or may be warming. Scientists have also focused on planting forests and carbon sequestration and its use in dealing with climate change.

Urbanization, especially, has led to changes in natural albedo values, because many human-built structures absorb light before the light actually reaches the Earth's surface. Studies have shown that cities in the northern part of the world are relatively dark, with an average albedo of 7 percent, which increases a bit during summer, while cities in tropical countries have an average albedo of 12 percent. Some of the reasons for this difference may include different natural environments of cities in tropical regions, such as the presence of darker trees. Also, city buildings are built with different materials, and in warmer regions might be made of light-colored material to keep structures cooler; asphalt (used in the building of roads in urban areas) also changes the albedo value of the surface. Remote-sensing technology is generally used to measure surface reflectance and albedo. Values observed through satellites are fed into mathematical models to get the albedo values.

SEE ALSO: Atmospheric Absorption of Solar Radiation; Sunlight; Weather.

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Algeria

ALGERIA IS A North African country that was occupied by France until 1962. It experienced a major insurgency from 1992 until 2002, resulting in the deaths of up to 160,000 people. It covers a land area of 919,595 sq. mi. (2,381,741 sq. km.) and has a population of 33,333,216 (2007 est.), of which 96 percent live in the north of the country, which covers only 17 percent of the overall area. Approximately 45 percent of the population live in urban areas. Thus, although the population density for the entire country is 26 people per sq.

mi. (13.6 people per sq. km.), the density the north of the country is considerably higher.

Only 3 percent of the country's land is arable, yet in spite of this, intense cultivation, developed by the French, has resulted in Algeria becoming self-sufficient in food. In 1960, the government started a program of soil restoration, and although this ended in 1965, many of the ideas and concepts were incorporated into the program of the Agrarian Revolution of 1971, which helped Algeria retain its self-sufficiency in food in spite of the large rise in population. In Algeria, some 13 percent of land is used for meadows and pastures, with only 2 percent forest, which includes 1.2 million hectares of Aleppo pine and cork oak trees.

The major ecological problem facing the country is continued desertification, with the heavy reliance on petroleum production and exporting resulting in Algeria being reliant on the world consumption of fossil fuels. Much of Algeria's oil production has traditionally been used for airline fuel, tying the country's wealth closely to an industry that has been at the forefront of greenhouse gas pollution.

In fact, carbon dioxide emissions per capita in Algeria have steadily increased, from 3 metric tons in 1990, to 6 metric tons in 1998, and falling slightly to 5.1 metric tons per capita in 2003, nearly 250 percent more than its neighbor Tunisia. This is largely because the oil wealth of Algeria has led to a much higher standard of living, with the widespread use of air conditioning.

In addition, there is heavy private use of cars, with public transport being extremely limited. Buses are operated by the national bus company. The last tramway service in Algeria, located in Algiers, closed in 1959. Although there is a relatively good railway network, it only covers some parts of the country, forcing most businesses to use road haulage on a regular basis. Traditionally, the price of gasoline has been low. In addition, in an attempt to open up the country, the government contributes further to greenhouse gas emissions by subsidizing many internal airfares.

The start of the insurgency in 1992 led to the formation of a High State Committee to run the country. Anxious to continue engagement with the West, it took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992. The Algerian government of Abdelaziz Bouteflika ratified the Kyoto Protocol to the UN Framework Convention on Climate Change on April 28, 2004, through a presidential decree, although the official date for the country acceding to the Kyoto Protocol was February 16, 2005; it took effect on May 17, 2005. Since then, the Algerian government has promoted policies to reduce carbon levels, with the rising world temperature likely to increase desertification significantly, although the per capita emissions have risen with the increased use of gaseous fuels in the country.

SEE ALSO: Carbon Emissions; Desertification; Oil, Consumption of; Oil, Production of.

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Alliance of Small Island States

THE ALLIANCE OF Small Island States (AOSIS) is an umbrella lobby and negotiating body representing the interests of low-lying and small island states at the level of the United Nations. AOSIS has played an important role in shaping international climate change policy by ensuring that the concerns of small island developing states are represented on an international level.

Specifically, AOSIS has been a leading advocate for reductions in global greenhouse gas emissions. Operating on an ad hoc basis and primarily through the diplomatic missions of its member countries, AOSIS has no formal charter, no regular budget, and no secretariat organizing the group's work. Decisions are made based on consultation with member states, with major policy decisions made in ambassadorial plenary sessions. The alliance operates on a consensus basis, requiring all members to be in agreement before a decision can be formalized.

AOSIS traces its inception to the 1989 Small State Conference on Sea Level Rise, held in the Maldives, where a proposal to establish an action group to address issues related to small island developing states was presented. AOSIS first met as an official group in 1990 during the Second World Climate Conference. Though the alliance was first formed to address sea level rise and other threats caused by climate change, its focus has broadened over time to include a variety of development or trade-related issues.

With an initial membership of 24 states, as of 2007 AOSIS had grown to a coalition of 43 members and observers from around the world. The members and observers of AOSIS originate from three regions: the Caribbean, the Pacific, and the African, Indian Ocean and South China Seas (AIMS). Many of the alliance's members also belong to the United Nation's Group of 77 and China (G77), an intergovernmental organization composed of developing states within the UN system.

The AOSIS, begun in the vulnerable Maldives, began calling for a 20 percent reduction of CO_2 emissions as early as 1994.

The AOSIS member and observer states are heterogeneous. They vary along geographic, economic, social, linguistic, and political lines; yet despite these differences, they face many of the same development challenges, including their geographic isolation, small political voice, and limited economic clout. However, the characteristic that unites AOSIS states is their potential to be severely affected by climate change and sea-level rise. Though small island states produce relatively minute amounts of carbon dioxide, methane, and other greenhouse gases, these countries will be profoundly affected by climate change, given their low elevations. As many of the countries participating in the alliance are located only a few meters above sea level, climate change and its effect on rising sea levels has historically been one of the key issues addressed by the alliance.

Traditionally, due to their weak political influence, small island states have had difficulty being heard internationally. As a result of their position within the international system, concerns specific to small island and low-lying states have often been lost amongst other international issues. AOSIS seeks to mitigate this situation by providing a collective voice for its members and applying greater pressure to the rest of the international community. As a group, small island states have a greater international voice and are in a better position to effect change than as individual negotiators. As a result, ASOSIS has increased the representation of small island developing states and lowland areas within the UN system.

Historically, AOSIS has favored and pursued legally-binding agreements or hard laws to address issues such as sea-level rise, while the remainder of the international community has generally favored soft law agreements, especially with regards to climate change and the environment more broadly. In this regard, AOSIS has led or been involved with numerous international treaties, conferences, and negotiations.

The Alliance of Small Island States was one of the first groups to submit a draft protocol addressing climate change under the UN Framework Convention on Climate Change. This proposal, submitted in 1994, called for a 20 percent reduction of CO_2 emissions by 2005.

Further, AOSIS's involvement and awareness-raising activities surrounding the negotiations of the Kyoto Protocol facilitated the incorporation of issues of concern to small island development states, such as capacity-building and dispute resolution mechanisms.

Aside from climate change negotiations, AOSIS has also lobbied for greater recognition of the special needs of small island developing states. As a result of AOSIS activities, a program of work on small island developing states was adopted during the UN Conference on Environment and Development in 1992. These activities were increased in 1994 with the adoption of the Barbados Program of Action for the Sustainable Development of Small Island Developing States, which provided a framework for the sustainable development of small island states.

In 2004, at the Small Island Developing States Inter-Regional Meeting, a draft document entitled "Alliance of Small Island States (AOSIS) Strategy for the Further Implementation of the Barbados Program of Action for the Sustainable Development of Small Island States" was presented. This strategy further advanced the cause of small island states on the international stage.

SEE ALSO: Kyoto Mechanisms; Kyoto Protocol; Sea Level, Rising; United Nations.

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Alliance to Save Energy

ESTABLISHED IN 1977, the Alliance to Save Energy (ASE) is a nonprofit coalition of business, government, environmental, and consumer leaders. The ASE supports energy efficiency as a cost-effective energy resource under existing market conditions and endorses energy-efficiency policies that reduce costs to society and individual consumers, and that limit greenhouse gas emissions and their impact on the global climate. To achieve these results, the ASE undertakes research, educational programs, and policy advocacy; plans and implements energy-efficiency projects; promotes technological innovation and collaboration; and sets up public-private partnerships, both in the United States and in other countries.

The alliance's mission is to promote "energy efficiency worldwide to achieve a healthier economy, a cleaner environment and greater energy security." Its corporate statement describes the ASE as leading "worldwide energy-efficiency initiatives in research, policy advocacy, education, technology deployment, and communications that impact all sectors of the economy." Leaders from academia, business, government, and other fields serve on the board of directors.

HISTORY

Republican Senator Charles Percy and Democratic Senator, former Vice President, and presidential nominee Hubert Humphrey founded the ASE in 1977. In the same year, U.S. President Jimmy Carter also established the Department of Energy. Since its founding, the ASE has been a bipartisan endeavor. It had to face the energy crisis of the late 1970s, when the United States recognized its oil dependency and the economic importance of energy. In those years, the Iranian Revolution generated a second, severe oil crisis worldwide (the first had occurred in 1973 with the Organization of the Petroleum Exporting Countries [OPEC] oil embargo). The crisis caused the doubling of oil prices. The Three Mile Island accident exposed the risks of nuclear energy. The ASE started its first major campaign in 1978, mounting a national television public-service advertising campaign that used Gregory Peck to promote energy conservation. The slogan of the campaign was "Don't Blow It America."

During Ronald Reagan's presidency, characterized by drastic reductions in federal efficiency activities, the alliance restructured its organization by initiating new research programs and pilot demonstrations that outlined innovative methods to promote energy efficiency in private markets. In the first half of the 1980s, the ASE came to the forefront in national debates on energy efficiency. In 1982, it promoted the adoption of utility demand-side management, designing the first methodology to evaluate efficiency as an energy resource for Arkansas Power and Light. Two years later, the ASE began to explore the use of energy-saving performance contracting, producing workbooks and hosting seminars on innovative, private sector financing techniques for energy-efficiency projects. The alliance also promoted legislation to allow governors to shift fuel assistance funds into energy-efficiency upgrades in low-income homes. Encouraged by then-alliance chairman Senator John Heinz, this piece of legislation devoted nearly $2.5 billion into energy-efficiency investments.

The nuclear accident at Chernobyl in 1986 renewed interest in energy saving at a time when the collapse of oil prices had given a false impression of abundance. The following year, President Reagan first vetoed, but then signed, the National Appliance Energy Conservation Act, fixing federal energy-efficiency standards for many commonly used appliances. The alliance began to arrange the energy-efficiency industry so that its voice could be heard on national energy policy issues.

The 1990s opened with the Gulf War, which again called public attention to energy issues. In 1991, the alliance indicted the federal government's poor performance in reducing energy use in the government's own facilities. The ASE calculated that the federal government wasted more than $1 billion annually of taxpayers' money. The ASE worked closely with the energy-efficiency industry to propose legislative responses to the problem. Thanks to the lobbying of the ASE and other associations for energy efficiency, President George W. Bush signed the comprehensive Energy Policy Act, including major terms to improve federal energy management, building codes, equipment standards, and home energy ratings.

Beginning in 1993, the alliance played a major role in the creation of the Business Council for Sustainable Energy, the Building Codes Assistance Project, the Export Council for Energy Efficiency, the Northwest Energy Efficiency Council, and the Hungarian Energy Consumers Association. Recognizing that the need for energy efficiency was becoming a global emergency, the alliance also launched an international program resulting in projects in Russia, Ukraine, Central Europe, Mexico, Ghana, and China. As the U.S. dependence on imported oil reached a new record in 1994, the ASE started to cooperate more closely with the energy-efficiency industry to undertake educational and market development export missions to Mexico, then to Portugal and China. New business deals created American jobs while promoting a cleaner global environment.

RAISING PUBLIC AWARENESS

In 1995, the ASE successfully blocked the attempts of the new Congress to eliminate federal efforts at energy efficiency. Faithful to its original public education role, the ASE began a new television and radio public service campaign to increase public awareness of the importance of energy efficiency in saving the Earth, jobs, and money. In 1996, the expansion of the alliance beyond American borders became a reality as the organization opened offices in Kaliningrad, Russia, followed by offices in Ukraine and Hungary (1997).

In the late 1990s, the ASE's public outreach campaign achieved an important series of successes, including three animated television spots that garnered $2.2 million in broadcast time in 49 states; four radio spots airing in 45 states; the Power$mart consumer booklet; an animated, interactive consumer website; and a new educator website with free energy lesson plans. The campaign earned the ASE a National Energy Resources Organization award for public education.

The ASE's 1999 report *Leading by Example: Improving Energy Productivity in Federal Government Facilities* was instrumental in persuading President Bill Clinton to issue an executive order calling for the federal government to reduce its energy use 35 percent by 2010, compared to 1985 levels. The order also pledged the government to cut its greenhouse gas emissions to 30 percent below 1990 levels by 2010. Greenhouse gas emissions and global warming have become the focus of several of the ASE's initiatives, including the organization of the First Climate Summit in Washington, D.C., in 2006.

SEE ALSO: Bush (George H.W.) Administration; Energy Efficiency; Energy, Renewable; Sustainability; United States.

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Alternative Energy, Ethanol

WITH INCREASING UNCERTAINTY in the global fuel market, the search for gasoline substitutes is becoming more and more important. One viable option is using ethanol as an alternative fuel, unlike fossil fuels, it is a renewable energy source. There are many chemical compounds that make up ethanol; the molecules contain a hydroxyl group, and are bonded to a Carbon atom. Ethanol that is made from cellulosic biomass instead of the usual starch crops is known as Bioethanol. Ethanol is in a liquid state, and is clear and colorless. As a diluted aqueous solution, it has a somewhat sweet flavor, but in more concentrated solutions, it has a burning taste.

The shift toward ethanol-based fuel has positive social, economic, and environmental effects. The combination of better efficiency with cleaner emissions yields makes it a promising future source of fuel. For transportation, ethanol can be blended with petroleum-based gasoline or can be used on its own. It has a chemical component that consists of ethyl alcohol, grain alcohol, and EtOH; it is also ethane with a hydrogen molecule replaced by a hydroxyl radical. When ethanol alone is used as fuel, it is mixed with a small amount of water, usually 5 percent of the total mixture.

SOURCES AND PRODUCTION PROCESSES

Ethanol is derived from several sources. Food products such as corn, wheat, sugar cane, and rice are all viable candidates for ethanol production. Ethanol is produced through the fermentation of the sugars supplied from these foods. Materials used in ethanol production are wood chips, yard waste, crop residues, and solid animal waste. It can be made from just about any feedstock that has ample amounts of sugar, or materials that can be converted to sugar, such as sugar beets, sugar cane, or organic materials containing high levels of sugar such as starch and cellulose. Corn is widely used to produce ethanol. There are certain elements that are not as easily converted to sugar, such as trees and grasses, which are made of cellulose. Ethanol is also made from a wet-milling process. Many larger ethanol producers use this process, which also yields products such as high-fructose corn sweetener. These other materials are viewed as potential sources of low-cost ethanol production, because corn may not always be practical for ethanol because land needed to grow corn is needed for food and feed corn.

There are several ways to produce ethanol. One method is to convert lignocellulosic materials to ethanol. This method involves two processes. The first step is the hydrolysis of cellulose in the lignocellulosic materials to fermentable reducing sugars. After hydrolysis comes the fermentation of the sugars to ethanol. Another mode of production involves cereal grains. The grains are milled, which produces amylase and heat. The results go through a gelatinization process, resulting in amyloglucosidase and yeast. Next, saccharification and fermentation are conducted, and the product is heated, and then distilled. This produces ethanol, as well as stillage. When heat is added to the stillage, dry grain is produced.

Ethanol can be manufactured from a variety of different naturally-growing carbon-based organisms. For instance, in India, sugar cane molasses, a byproduct of the sugar industry, contains 45–50 percent fermentable sugars, allowing India to efficiently produce a significant amount of ethanol. Fermentation represents an ideal way to produce ethanol, as it is easy to ferment these sugars, and quite cost effective.

USES AND EFFECTS

Ethanol is used mainly as a fuel additive, replacing methyl tertiary butyl ether (MTBE). Thailand's government has passed regulations to reduce MTBE emissions, and they are looking to ethanol for the answer. A 10 percent ethanol fuel mixed with gas, coined *gasohol*, is currently used, decreasing the amount of toxic volatile organic compound emissions. Diesel engines can use a 15 percent mixture of ethanol and gasoline, resulting in a visible reduction in fumes.

It is not feasible to completely replace gasoline with ethanol. It costs more for the United States to produce ethanol than gasoline. Turning to ethanol as a substitute, and possibly a primary fuel, has the potential to positively affect the environment, however. Ethanol burns cleaner than gas, releasing fewer volatile organic compounds into the atmosphere. Ethanol also runs up to one-third more efficiently than gasoline, while polluting less. Pure ethanol fuel (95 percent ethanol, 5 percent water) has numerous benefits because of low pressure and the reduced emission of ethanol into the atmosphere, along with clean burning characteristics. Although there is some environmental benefit from using ethanol, there are also some environmental concerns, because ethanol is listed as a carcinogen for humans. The use of ethanol can lead the raising of peroxyacl nitrates (PAN), which is extremely toxic for plants. Ethanol combustion emits formaldehyde, also dangerous to humans. Health issues related to this include eye irritation, respiratory complaints, and nervous disorders.

The large-scale production of ethanol would have other effects. Because cars will need specialized parts, workers will be required to make and install them, Ethanol could create jobs in rural areas. There could also be a large swing from oil to agriculture if ethanol becomes a highly-sought resource. Different forms of agriculture may be developed to handle the demand for corn to produce ethanol. One such form is called biotech; however, its corn has not been proven healthy. There are limits to its production, also, as only a few companies comprise the entire ethanol business, and only one company in California holds the patent.

Another agricultural issue deals with the land requirements for corn production. One study estimated that almost one-fourth of the United States would need to be used to produce enough ethanol to replace gasoline. This raises issues of converting land from other uses to that of corn production. While the change from gasoline to ethanol is partially environmentally stimulated, the destruction of other environmental sites such as forests seems counter-productive.

Besides Thailand, many countries around the world are using ethanol in combination with gasoline. In the United States, Michigan produces and consumes the most ethanol. Many states are adopting a requirement that ethanol to be used as a fuel additive in place of MTBE. Brazil is a large producer and consumer of ethanol. Ethanol use in the United States is 10 percent, and 22 percent in Brazil.

Brazil and the United States intend to create an ethanol market to meet the needs of citizens. Last year, the United States produced 5.3 billion gallons of ethanol and imported another 720 million gallons, almost two-thirds of it from Brazil. Both the United States and Brazil have begun spreading agriculture and ethanol refinement technology to parts of the Caribbean and Central America to enhance sugar cane production, which, in turn, will enhance the production of ethanol. There are also many other sources of ethanol throughout the world; the top five areas are the United States, Brazil, China, France, and India. The United States not only imports from Brazil, but also from Jamaica, El Salvador, China, and Costa Rica. By 2010, it is estimated that Brazil will provide key ethanol resources with at least 77 more ethanol plants; this will help boost the production of ethanol by one-third, for a total of 7 billion gallons a year.

BENEFITS AND DRAWBACKS

Despite its advantages over MTBE, ethanol does have limitations. It has a lower BTU than gasoline, making it less powerful. It costs more to produce a gallon of ethanol fuel than it does to produce a gallon of gasoline. Ethanol is also corrosive to some metals, gaskets, and seals, and ethanol air mixtures can be explosive in the ambient temperature range. Land space is also a limiting factor, as large amounts of land are required for corn production.

Also, the substitution of ethanol has been noted to cause negative impacts on climate change. Despite the fact that it does not emit carbon dioxide into the atmosphere, it does release other toxins, and it does not reduce air pollution. Brazil's air quality worsened during the big ethanol push in the 1970s. Compared to gasoline, ethanol produces less benzene and butadiene when burned, but more acetaldehyde and formaldehyde.

Driving the strong political backing for ethanol are energy security concerns, agricultural interests, and environmentalists. In the future, a drive for better efficiency could force ethanol to compete with electric cars and fuel cells, as well as gasoline. The trend for fuel seems to be shifting toward ethanol. In India, the blend of ethanol in gas is expected to double in the next few years. Brazil, because of their efficient sugar cane production, already produces ethanol for about 40 percent less than gasoline. More testing is needed on the health and environmental issues surrounding ethanol. As testing increases, cheaper ways of producing ethanol will be implemented. Engines will likely become more efficient, and more cars are likely to come with ethanol-ready parts.

Ethanol also enhances the performance and maintenance of many old and new cars. Since ethanol burns at cooler temperatures than gasoline, it does not burn valves. It may loosen noxious wastes and residues, usually in older cars, which have been deposited by previous gasoline fuels. However, changing the fuel filter will correct the problem and increase the performance of the car. Ethanol is used in aircraft as well, because it offers a low volatility, high-octane fuel to replace gasoline. Unlike many other fuel types, such as regular unleaded, unleaded plus, diesel, and premium, it can be used in any type of engine. Ethanol decreases the amount of water accumulated in an engine while providing better engine longevity. However, many people question whether ethanol provides good performance if used without gas line antifreeze.

Ethanol appears to be viable as an alternative fuel. Once solutions are found to its pollutant problems, ethanol may become even more desirable. It appears to be better for the environment than gasoline. It may create jobs, and free the United States from dependence on foreign oil. An electric hybrid using ethanol fuel may be the future of the automobile industry. Ethanol as an alternative fuel is a good, currently available solution to the problem of diminishing fossil fuel supplies.

SEE ALSO: Alternative Energy, Overview; Automobiles; Carbon Emissions; Energy, Renewable; Oil, Consumption of; Oil, Production of.

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Alternative Energy, Overview

WE USE ENERGY to grow our food, power our vehicles, and run the appliances in our homes, schools, and workplaces. Over the past two centuries, industrial societies have used inexpensive, and readily available, sources of energy to fuel urbanization and economic development. This growth has created, at least in some countries, the highest level of human development in the history of civilization. A question to ponder, though, is if this level of development can be sustained indefinitely. Many of the great civilizations of the past declined, at least in part, due to environmental change caused by human activities.

Starting in the late 18th century with the Industrial Revolution, the global economy has increasingly relied on fossil fuels such as coal, petroleum, and natural gas. In the future, the global economy will run out of these fuels. In the meantime, some scientists argue that dependence on fossil fuels has contributed to global warming. The Intergovernmental Panel on Climate Change (IPCC), founded in 1988 by the World Meteorological Organization and the United Nations Environment Programme, argues that measurable global warming has occurred, and that humans are at least partially to blame.

Some scientists and commentators from across the political spectrum downplay the significance of global warming—especially the role humans might play in climate change. However, even famous skeptics such as author Michael Crichton, or contrarian scientist Bjørn Lomborg, agree that the Earth is getting warmer, but do not believe that humans are to blame. The heavy reliance on fossil fuels raises several questions. First, how long into the future will these resources last? Second, to what extent do fossil fuels contribute to climate change? Third, are there alternative fuels that are less likely to influence the climate and that will last into the foreseeable future? Alternative energy strategies based on wind, biomass, geothermal, solar and photovoltaics (PV), hydrogen fuel cells, and improved fuel efficiencies could ameliorate climate change.

ALTERNATIVES TO FOSSIL FUELS

The phrase *Alternative energy* implies that these energy sources are alternatives to nuclear and traditional fossil fuels such as coal, petroleum, or natural gas. Alternative energy, therefore, is a catchall category of energy sources that proponents argue can replace traditional fossil fuels in daily life, while causing less harm to the environment.

Alternative energy is increasingly important for at least three reasons. First, fossil fuels are nonrenewable; eventually, they will be exhausted. The United States is already witnessing a decline in its petroleum production. In 1950, the United States was largely self-sufficient in fossil fuels, producing 32,562,667 billion Btus of energy. At the same time, Americans consumed 31,631,956 billion Btus of fossil fuels. The United States therefore enjoyed a slight fossil fuel surplus. Now, fossil fuel consumption in the United States far outstrips production. In 2006, the United States produced 56,032,329 billion Btus of fossil fuels, but consumed 84,760,343 billion Btus. Advocates of alternative energy argue that alternative energy sources need to be developed now, so that when fossil fuels are gone, there will be other dependable energy resources.

Second, many advocates of alternative energy argue that as oil production declines, Americans and others around the world will become increasingly reliant on foreign sources of oil. This will require heavy investments in the military to ensure that fossil fuels continue to flow, especially from politically unstable regions of the world such as the Middle East.

Third, alternative energy has received increased attention because of a scientific consensus that the average temperature of the planet is rising. Scientists argue that a leading cause of global warming is the emission of so-called greenhouse gases such as carbon dioxide, methane, various nitrous oxides, hydrofluorocarbons, sulfur oxides, and particulate matter. These gases come from the combustion of fossil fuels in vehicles, in the production of electricity from coal or natural gas, and in many other processes.

Carbon dioxide and other greenhouse gases are not inherently bad. In fact, these gases naturally occur in the atmosphere and help moderate the global climate to support living organisms, including humans. In this process, the Earth's surface is first warmed directly during the day by incoming solar radiation. At night, this energy is radiated back into the atmosphere as latent heat energy, some of which is absorbed by atmospheric gases such as carbon dioxide. The problem, say many scientists, is that the growing use of fossil fuels is increasing the concentrations of carbon dioxide, methane, and other gases, which, in turn, increase the capacity of the atmosphere to absorb latent heat energy. The National Aeronautical and Space Administration (NASA) notes that the atmospheric concentration of carbon dioxide has increased 35 percent 1750–2007. At the same time, the Earth's average temperature has increased between 1.1 degrees F to 1.6 degrees F (0.6 degrees C to 0.9 degrees C) and that warming continues at an accelerating rate. The only way to slow global warming is to reduce greenhouse gases. This means that the use of fossil fuels will have to be reduced.

Reducing the reliance on fossil fuels will not be easy. The United States relies on fossil fuels for 85 percent of its energy needs. Nuclear energy accounts for another 8 percent. Hence, only 7 percent of the energy consumed in the United States comes from renewable sources such as biomass, hydroelectric, wind, or solar power. Another way to look at the heavy reliance on fossil fuels is to see the amount of energy consumed in absolute terms—data show that Americans consumed more fossil fuels in 2006 than they did in 2002. However, renewable energy is playing a slightly larger role in the U.S. energy portfolio.

DEFINITIONS

To maintain the current standard of living in the industrial world, and promote human and economic development in the less prosperous regions of the world, alternative forms of energy must be found. Some scientists use the phrases *alternative energy* and *renewable energy* interchangeably. International agencies such as the IPCC and World Bank, as well as government agencies such as the U.S. Department of Energy

A hyrdoelectric plant in Tennessee. Once the water level reaches a high enough level, a gate is opened in the dam, allowing gravity to carry water down toward the generator. The force of the water falling spins the turbine and generator, creating electricity.

(DOE) or the U.S. Environmental Protection Agency (EPA), offer separate, but somewhat overlapping definitions for alternative versus renewable energy.

The word *alternative* can be seen as somehow marginalizing the importance of the concepts it embodies. However, an argument can be made for its use because of the need for a clear distinction between the various forms of energy. In the future, alternative energy may, in fact, become the dominant form of energy used. Maybe a better term is *sustainable energy,* to focus on its potentially mainstream status and renewable nature. However, for the time being, these energy sources represent only a small fraction of the energy used.

USE OF ALTERNATIVES

The World Bank definition for alternative versus renewable energy differs. It uses a hierarchical strategy to categorize energy forms. Alternative energy represents the broadest category of energies that are not based on fossil fuels or nuclear energy. These energy forms are thought to produce fewer greenhouse gases than the fossil fuels they are intended to replace. Within this broad category, there are two subcategories of energy sources or strategies for greenhouse gas reduction: renewable energy and improved energy efficiencies.

Renewable energies can be further sorted into energies used to generate electricity and energies used for transportation. While there is certainly overlap between these two categories (for example, solar energy can generate electricity for distributed use in homes and it can also be used to power vehicles), it makes sense to examine the efficacy of renewable energies by starting with these two categories.

Electricity is produced by finding a way to convert kinetic energy (energy associated with movement) into electrical energy. A generator typically does this. A generator consists of a rotating magnet, called a rotor, and a stationary coil of copper wires known as a stator. By turning the rotor continually past the stator, an electrical current is generated. The challenge is to find a source of energy to move the rotor. In simplified form, a rotor is attached to some type of turbine or propeller that is forced to turn by some external force, usually water, steam, or air. Fossil fuels such as coal, natural gas, and oil, and nuclear fission can be used to generate heat. This heat is used to convert water into steam within a confined space. As steam is created, it expands, creating pressure. This pressure can be directed at a turbine, and when released in a controlled manner, can cause the turbine to turn.

The problem with using fossil fuels for generating electricity is that the combustion of fossil fuels to create the heat needed to rotate turbines creates carbon dioxide and other greenhouse gases. Furthermore, these forms of energy are nonrenewable, and the extraction of fossil fuels through mining and oil drilling itself requires considerable amounts of fossil fuels. The process also transforms the landscape in profoundly destructive ways.

HYDROELECTRICITY

The major renewable forms of energy include hydroelectric, solar, and wind power. These energies produce electricity, but do not use the combustion of fuels to spin a turbine. For example, hydroelectricity works by converting potential energy into kinetic energy. A hydroelectric generating station uses a dam on a river to create a reservoir. As the reservoir fills up with water behind the dam, the water level rises above the turbine, which is located on the downstream side of the dam. There is a large pipe called a penstock, which connects the reservoir above to the turbine below. Once the water level reaches a high enough level, a gate is opened in the dam, allowing gravity to carry water down the penstock toward the generator. The force of the water falling from the height of the reservoir spins the turbine and generator, creating electricity.

A similar mechanism operates to generate electricity from tidal power. In places where there are large tides, such as the Bay of Fundy in Canada, the rapid flow of incoming and outgoing tides can be used to spin a turbine. Annapolis, Nova Scotia, hosts an operating example of a tidal power plant generating electricity from tides that fluctuate 40 or more ft. between low and high tide. The tidal plant operates using a reversible turbine that generates electricity as the tide rises. The turbine then reverses to generate power as the tide goes back out.

From a global warming perspective, hydroelectricity and tidal power are low-impact ways to generate electricity. However, they have limitations. They only work in certain geographic and climatic areas. Hydroelectricity can only be generated where there is sufficient precipitation to keep the reservoirs full. It also works better in areas of rugged topography where rivers flow through steep valleys. This makes the construction of dams and reservoirs more cost-effective. Reservoirs also cause considerable damage, as land previously occupied by towns, or used for agriculture, is flooded. This is a particularly sensitive topic in countries such as India and China that have rapidly-expanding energy needs, but also have large populations that will be displaced by any large-scale hydroelectric project.

Tidal power may be even more restricted in the places where it can work economically. In many parts of the world, daily tidal variations may be only a few feet, which is too small to merit large-scale investments in tidal power. Furthermore, the tidal power plants require that dams or so-called “barrages” be built across estuaries in order to channel the force of the tides through the generator. Barriers of this sort can disrupt ocean ecosystems and hinder boat navigation.

WIND POWER

Electricity generated by wind power relies on air moving past a propeller to spin a turbine. Wind is created as a result of the differential heating of the earth’s surface of the sun. Air masses move from areas of high atmospheric pressure to low atmosphere pressure. Wind energy creates very few greenhouse gases and will exist as long as the sun shines and winds blow. There are challenges to implementing wind energy, though. Wind energy, like other forms of renewable energy, operates effectively only in certain geographic areas and climates. Wind speeds and direction can vary hourly, daily, and seasonally. For example, winds are typically stronger during the day than at night. In temperate climates, the wind tends to be stronger during the winter than during the summer. Hence, a wind turbine only makes economic sense if, on average, the wind blows at a certain minimum average velocity, usually at least 10 to 12 mi. (16 to 10 km.) per hour for much of the calendar year. Winds lower than that cannot move the large propellers to spin the turbine.

A wind turbine also needs a relatively open space, so that trees or buildings do not affect wind speeds. Critics of wind farms also argue that wind turbines can harm migrating birds and bats, are an aesthetic blight on the landscape, and cause irritating "flicker" as sunlight reflects off of the rotating propeller blades.

SOLAR POWER

Solar power can reduce greenhouse gases in several ways. First, passive solar energy can be used for heating. Dark surfaces absorb energy from the sun better than light surfaces. This principle can be used to heat water or warm a house. Water stored in a dark container or cistern on the roof of a house can become very hot. This water can be used for showers, laundry, or cleaning. Similarly, a dark exterior on the roof or walls of a house can help warm the house on a cold winter day. This helps reduce greenhouse gases, because like all renewable energies, its use offsets the use of fossil fuels.

Second, active solar energy can generate electricity through the use of photovoltaic cells. This technology relies on semiconductors to take direct light from the sun and convert it into electricity. This form of energy production is renewable.

However, it has several limitations, including the daily fluctuations in light, as well as regional variations in the amount of annual sunshine received. Solar energy is more economical in the American southwest, where sunshine is abundant. It is less viable in areas that have more cloud cover. However, solar energy is viable in most parts of tropical and mid-latitude regions.

Geothermal energy can be used to offset fossil fuels in several ways. First, the energy can be used to heat and cool buildings. Typically, a residential geothermal system relies on the fact that the Earth's temperate remains constant at about 55 degrees F (12.7 degrees C) at about 12 ft. (3.6 m.) below the surface. During the summer, the heat from the house is drawn down into the ground through a closed system, where it dissipates into the cool ground. During the winter, the relatively warm temperature of the ground is brought to the surface and used to help heat the house on a cold day.

HYDROGEN AND BIOMASS

Many researchers tout hydrogen as the ultimate renewable energy source, because it is the most common element in our universe. Hydrogen-based fuel cells operate by reacting pure hydrogen with oxygen to generate electricity. Energy is released that is then converted into electricity, with water as the only by-product. Unfortunately, pure hydrogen must be created through the hydrolysis of water. This is an expensive process that relies largely on conventional energy sources. Hence, there are significant technological barriers to the widespread adoption of hydrogen power.

Biomass, or plant material, can also be a significant source of energy for the production of electricity and for transportation. The DOE identifies three biomass sources: wood, waste, and biofuels. Wood can be cut and burned directly for home heating. The by-products of processing wood into paper products can also be co-fired with fossil fuels to make coal-fired electrical plants burn cleaner. Combustible biomass can also come from municipal solid waste, industrial waste, and landfill gas. Biomass can be used to create alcohol fuels such as ethanol, or diesel fuels, such as soy diesel. Advocates of these fuels, used largely for transportation, argue that their production and use creates fewer greenhouse gases than conventional fossil fuels.

Critics argue that biofuels must still be burned and therefore still generate greenhouse gases. They also argue that the increased production of corn and soybeans for ethanol or soy diesel will increase food prices, while degrading soil quality. This will require more use of petroleum-based fertilizers. Finally, skeptics suggest that biofuels are not a viable alternative because the energy it takes to produce ethanol is more than the energy contained in the fuel.

COST OF ALTERNATIVES

The high cost of production and related technological barriers affect all alternative energy sources. A comparison of production costs shows that fossil fuels are simply cheaper to produce than alternative fuels, which often need government subsidies to make them economically feasible. For example, it costs approximately 4.0 cents per kilowatt hour (¢/

kWh) and around 5.0 ¢/kWh to produce electricity from natural gas and coal, respectively. Electricity from large-scale hydroelectric generators can cost between 5.0 and 12.0 ¢/kWh. Electricity from nuclear fission can cost between 11.0 and 15.0 ¢/kWh.

Great technological strides have been made in the advance of renewable fuels. Electricity from wind, which cost over 40.0 ¢/kWh in 1980, now costs in the range of 4.0 to 6.0 ¢/kWh. However, that makes it barely competitive with coal. Electricity from solar photovoltaics still costs almost 20.0 ¢/kWh, while that from hydrogen-powered fuel cells costs $4.00 per kWh. That is why some scientists suggest that while research is done over the long term to reduce the costs of producing energy from wind, solar, biomass, or hydrogen, the focus should be on increasing the efficiency of current systems. Environmentalist Amory Lovins argues that existing technologies can help reduce energy needs. Examples include more fuel-efficient vehicles, homes with better insulation to reduce heating and cooling costs, and more efficient appliances. The refrigerator exemplifies this progress in energy efficiency. In 1980, a 20 cu. ft. refrigerator used about 1,300 kWh of electricity per year. In 2001, a comparably sized unit used 500 kWh of electricity per year.

Alternative energy can be an important part of a strategy to reduce global warming if the commitment to energy efficiency can be increased in the short term, with continued research on alternative energy technologies in the long term. It may also mean combining energy types to maximize the amount of work that can be done. Increasing investments by the public and private sector in research and development can help make this happen.

SEE ALSO: Alternative Energy, Ethanol; Alternative Energy, Solar; Alternative Energy, Wind; Biomass; Energy, Renewable; Nuclear Power; Sunlight.

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Alternative Energy, Solar

SOLAR ENERGY REFERS to forms of energy emitted by the sun, including light, radio waves, and x-rays. Accounting for 99.8 percent of the mass in our solar system, the sun is a self-sustaining nuclear fusion reaction by which hydrogen is converted to helium. Every second, the sun converts over 4 million metric tons of matter into solar energy. This matter is converted and released from the sun in the form of radiation waves that travel through the void of space and eventually reach earth. The radiant energy that eventually reaches the earth's surface is estimated around 1,000 watts per sq. m. The sun is similar to a fusion reactor that emits 3,800 million, million, million, million watts of energy each second, which is 20,000 times the energy requirement of the world.

Solar power, as an alternative fuel, involves transforming some of the sun's massive thermal energy into electricity. Individuals driven by environmental and other concerns encourage the implementation of policies that require the use of solar and other renewable energies. Solar energy can be broadly classified in two categories on the basis of its use: active and passive.

ACTIVE SOLAR ENERGY

Active solar energy can be converted to electricity and used directly, as in the case of solar heating applications and solar photovoltaic (PV) applications. In a PV cell, sunlight strikes a layer of semiconductors, which in turn creates an electrical current. By 2005, this proven technology was being used to provide heat and power to well over 650,000 homes, primarily in the United States, Germany, and Japan. Electricity can be produced from solar power by placing solar panels on roofs. These panels consist of PV cells that can convert sunlight directly into electricity. Moreover, electricity produced as solar power during the day may be stored in batteries for use at night.

Another method of electric generation employs the use of turbines. In turbines, the sun's heat can be used to convert water into steam and then this steam is used to run turbines. The turbines, in turn, run generators, which produce electricity. Solar PV applications have found many uses in rural areas for multiple activities besides home lighting. Remote villages deprived of grid power can be easily powered using solar photovoltaic technology. The economics of rural electrification can be attractive considering the high cost of power transmission and erratic power supply in rural areas. From portable indoor uses such as calculators, to generating plants alongside railways and roads, PVs are adaptable. They easily function across most areas in both the Northern and Southern Hemispheres.

PASSIVE SOLAR ENERGY

Passive solar thermal technology is employed for collecting and converting the sun's energy to heating applications such as water and air heating, cooking and drying, steam generation, and distillation. To accomplish this, a solar thermal collector device absorbs and stores heat. Solar thermal technology requires good heat conducting materials, insulation, and reflectors. Solar geysers, solar concentrators, and solar cookers are some examples of devices based on solar thermal technology.

Also, solar energy can be put into use by incorporating appropriate designs in buildings to maximize utilization of solar energy for various purposes such as lighting, air conditioning, and water and space heating/cooling and thereby reduce external energy inputs. PV cells require high exposure to direct sunlight. To assure maximum exposure to the sun throughout the day, a phyrheliometer is used to calculate how much sun exposure a location experiences. This information is useful in determining whether or not a specific location is suitable for solar energy, as well as what direction the cells should face. In many cases, these cells are placed on rooftops.

USE AND DEVELOPMENT

Increasingly, PV cells are being added to residential and commercial structures. This approach to using solar energy is modular, as panels can be added to any existing structure with sufficient exposure to sunlight. In addition, photovoltaic cells are able to tie directly into the existing electrical grid, thus avoiding the need to build additional transmission lines. In cases where the solar energy provides more energy than any one location can use, it can actually supplement the electrical grid with additional power to be used elsewhere. In such cases, the electric company is required to pay the individual the same amount they would charge per unit of electricity. Therefore, rather than being billed for using electricity from the grid, the individual could actually receive a check from the electric company for any power that was sold to the grid. This helps offset the initial cost of installing solar cells.

Different groups perceive the issue of solar energy differently. Advocates see solar energy simply as another fuel to plug into the existing energy system and do not feel that it carries any social or political relevance. They argue that the removal of conventional impediments to the diffusion of solar power, such as financing or getting high-quality installation on new devices, leads to substantial growth in the solar energy market. Solar advocates tout the technology as environmentally benign, and believe it will be an important part of the solution to the structural problem of energy-related pollution. Other groups maintain that there are too many barriers for solar energy to be a large-scale option in the immediate future.

Economic barriers have stood in the way of using solar energy because of the high price of solar equipment. However, technological advances and economies of scale are making PV electricity production steadily more cost-effective. The market for solar power is growing, primarily overseas, where two billion people, most in developing countries, still live without electricity. In countries where energy from the sun is abundant, a small PV panel on a house can create enough power for two light bulbs, a television, and a radio. With installation costs of

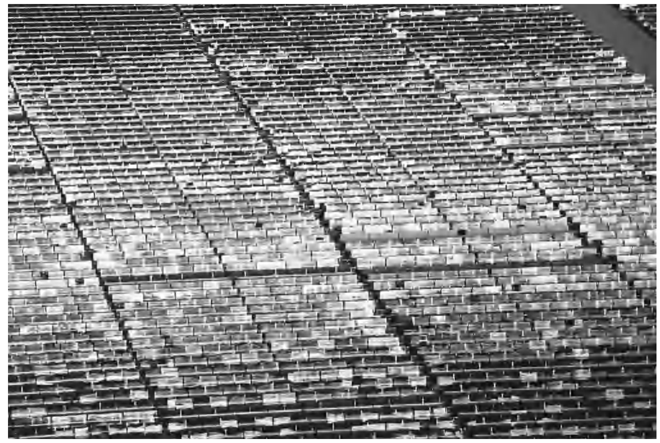
$400–$600 per house and low maintenance, these solar panels already appoint thousands of rooftops in India, Indonesia, Mexico, and Brazil. In addition to residential buildings, many commercial buildings are now starting to add photovoltaic cells, as well. Large areas such as rooftops of office buildings are ideal places for these cells, as they are otherwise wasted space. They are also high enough to avoid any obstructions that might block exposure to the sun.

GROWTH OF A NEW INDUSTRY

The solar PV industry grew at an annual rate of over 20 percent worldwide in the past decade, and 40 percent from 2007–07, reaching an annual PV module production of 100 megawatts (MW) in the United States and about 400 MW globally. Worldwide, in 2001, photovoltaics were a $2 billion business. In the United States alone, the industry employs about 20,000 people in high-value, high-tech jobs. In the swimming pool sector of solar thermal, according to the Florida Solar Energy Center, the equivalent of 594 MW of power was installed last year in the United States. For solar hot-water heating for general home use, one utility, Hawaii Electric, has installed systems that produce approximately 60 MW per year, and it continues to add around 12 MW of capacity annually.

The "power tower" in California uses a field of mirrors focusing on a boiler atop a tower. A working fluid is heated, which in turn makes steam to drive a turbine. The hot fluid also may be stored to generate electricity at night. A simple but promising idea is the solar pond, developed in Israel. If the bottom layer of water is heated by the sun and then prevented from rising, then heat can reach usable temperatures and be stored in the pond. Electricity can be generated, or, for that matter, any low-temperature heat demand can be met.

Although geography, daylight, and weather present major barriers to the use of solar power, high cost is still its biggest impediment. Most new technologies need initial research and development support to get established, which represents a major institutional hurdle, especially because governments are the most probable source of initial support. There are likely to be disagreements about which projects should be funded and over how projects should be developed. In addition, there may be resistance to new developments from those with vested interests in the existing range of technologies, and a lack of commitment from decision-makers to press ahead with what may seem to be risky and long-term development programs.



Fields of solar mirrors in California collect some of the 100 MW of solar power produced in the United States every year.

The growing energy demand is mounting pressure on conventional energy supplies, such as oil, coal, and natural gas. By 2025, worldwide electricity use is projected to increase. Solar energy could provide a large percentage of the future electricity used. Solar energy is expected to form a significant share of the U.S. energy market by 2020, and by 2030 is expected to meet 10 percent of U.S. peak energy demand. For this statement to become a reality, millions of homeowners and businesses would have to switch to solar energy. This is possible only if solar power becomes affordable.

It is expected that some of the technologies, such as roof-mounted systems, solar dishes, and concentrating PVs, will also play a role in America's energy future. Experts predict that the main use for solar energy in the future will be for space heating. Currently, houses are being designed to make maximum use of solar heat so that the needs for space heating could be met almost entirely by solar energy in populated regions of the world as far north as Boston.

ENVIRONMENTAL AND ECONOMIC IMPACTS

Perhaps the greatest benefit of using solar energy is the environmental impact. The beauty of solar energy is that it simply uses existing energy. No hydrocarbons need to be burned in order to release the energy required for doing other forms of work. Energy from the sun is simply collected and used. In essence, the sun is doing all of the work that a conventional nuclear reactor would be doing on Earth. However, the sun takes care of this process without fuel or maintenance. There are costs and environmental impacts associated with manufacturing PV cells to harness this energy, though. Initially, these cells would need to be manufactured in facilities powered by a conventional source of energy, such as coal or nuclear power.

Although progress is being made in the field of solar energy, one of the major concerns holding solar energy back is the high cost. Currently, solar cells must be viewed as an investment in order to justify the initial cost of the cells, and the installation. However, the government does offer incentives at both the state and federal level for those interested in adding solar cells to homes.

The economic impact of solar energy is huge. Because solar energy is dispersed more evenly throughout the globe than fossil fuels, no one country or government would be able to control it. This would ultimately lead to a more stable infrastructure for countries whose energy needs are dependent on foreign nations. Solar energy would not only alleviate the pressures of oil dependence, it would also bring seemingly free energy to developing regions of the world, where conventional forms of energy are either too expensive or impractical. For instance, there are regions of the world that do not have any sort of power grid. For places such as these, the modular design of solar cells allows for the construction of cells on a case-by-case basis.

Solar energy does have its limits. While the distribution of solar energy is much more homogeneous than that of fossil fuels, there are portions of the world that experience more or less solar exposure. For instance, during winter, the sun does not shine for months at a time at the North pole. For the rest of the world, there is the dilemma of night. Solar energy alone cannot provide power 24 hours a day. To overcome this barrier, batteries are required to store the energy overnight until they can be recharged the next day. Also, because PV cells are constantly exposed to the elements, they are susceptible to damage from high winds or hail storms. However, solar energy will continue to gain momentum as a practical source of energy in the coming decades. As more and more manufacturing facilities are built to handle the demand, the cost of such cells will be reduced, and solar energy will become more practical for the average consumer.

SEE ALSO: Alternative Energy, Overview; American Electric Power; Edison Electric Institute; International Solar Energy Society (ISES); Solar Energy Industries Association (SEIA); Solar Wind; Sunlight.

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Alternative Energy, Wind

WIND IS A source of solar energy that does not rely on the condition of the sky. Unlike fossil fuels, wind energy can be collected during storms, snow, or the night. Wind power is the alteration of wind energy into more purposeful forms, usually electricity using wind turbines, and is a form of renewable energy. Wind power is greenhouse gas extenuating, clean, abundant, infinitely renewable, domestically produced, widely distributed, and supportive of rural economies.

The International Energy Agency (IEA) projects that, 2000–30, global energy consumption will increase and electricity use could double, placing pressure on nonrenewable resources, public health, international stability, and the natural environment. One solution lies in finding and utilizing alternative energy sources. Renewable energy sources pose lower costs, whether environmental or health-related. The use of alternative energies to generate electricity is especially advantageous to developing countries, because of the new employment opportunities it will create, as well as the stimulation of local economies by attracting investment. One of the resources leading the way to a more sustainable future through the use of alternative energy is wind power.

People have been harvesting the wind for hundreds to thousands of years, with functions varying from sailing, to grinding grain, to pumping water. Windmills have been found dating back to 10th century Persia, while their appearance in Europe is believed to have begun around the Middle Ages. It was not until the 20th century that people became interested in using the wind to generate electricity. In 1941, the 1,250 kilowatt (kW) Smith-Putnam wind turbine was constructed in the United States. There are records of 100 kW turbines in the former Soviet Union in 1931, and other innovative designs originating in Germany during the 1950s to the 1960s. However, after the 1950s, lower-cost fossil fuels made wind energy technology economically unprofitable, and only in the 1970s did rising fuel prices bring it back into popularity.

MECHANICS

Wind energy moves over the Earth's surface as kinetic energy. This energy is received by the blades of a turbine, which is attached to an electrical generator that sits atop a collection tower. Collection sites consist of a single turbine, or many, constituting a wind farm.

Projects like this wind farm in California may help the U.S. Department of Energy's Wind Powering America Initiative reach its goal of generating 5 percent of the nation's electricity through wind power by the year 2020.

Each turbine consists of a tower structure, rotor with blades attached to the hub, shaft with mechanical gear, electrical generator, yaw mechanism, and sensors and control. Modern structures must come equipped with a control system for operational and safety functions.

Certain terms are necessary to understanding of the wind industry. The gearbox increases the turbine speed from around 45 rotations per min. (rpm) to about 14,500 rpm. The rotor connects to the nacelle, which sits atop the tower and contains the gearbox. Upwind refers to a turbine operating facing the wind in front of the tower. Downwind turbines run facing away from the wind behind the tower. Finally, the yaw drive maintains the direction of the upwind turbine facing the wind.

The tower is the support structure. It can be steel or concrete, and tubular or lattice. They must be at least 82 ft. (25 m.) tall to capture adequate energy. The turbines range in size from a few kW to a few megawatts (MW), used for utility-scale power generation. Turbines usually consist of two or three aerodynamic blades constructed to capture the most energy possible. The blades operate using the Bernoulli principle. A lift is created by the difference in pressure on the sides of the blades when the wind flows over it. The lift rotates the blades around the hub. A drag force is created that acts perpendicular to the blades and slows down the rotor. The purpose of this design is to achieve the highest drag to lift ratio, optimizing the turbine's power.

IMPACTS

When assessing the introduction of wind energy conversion to a new area, it is important to consider the environmental, economic, and social impacts. Birds feel the environmental consequences of collecting wind energy, and humans experience noise emissions and the visual impact of the turbines. The presence of turbines may alter the breeding and feeding patterns of some avian species. Some birds have been killed or injured from collisions with blades. Some may be sucked into the draft created by the rotating blades, but some may just be attracted to the hum of the machine. However, the 300 birds killed in Altamont Pass, California, in the 1980s do not seem as significant when compared with the millions of birds killed by U.S. hunters and the one billion birds killed annually by flying into glass windows. To combat these occurrences, certain measures have been put in place, such as avoiding migration routes and using fewer, larger turbines.

The visual aspect may not be considered an important environmental impact, but it has generated public concern. The elements that must be considered are the number and design of turbines, the turbine arrangement, their color, and the number of blades. The wind turbines may not be aesthetically pleasing, but it is hoped that with the knowledge of the technology and services they deliver, they will become more acceptable.

Noise emission due to wind energy is another consequence that is relative to the public's perception. Its impacts can range from annoyance, to sleep interruption, to effects on hearing. A 600 kW wind turbine will produce around 55 decibels (dB) of noise when a receptor is 164 ft. (50 m.) away. This amount will decrease as the distance increases. This level falls in between that of the noise produced in the average office (50 dB) and that of an average factory (60 dB). While this may seem a tolerable amount, it is dependent on individuals' personal discretion and tolerance. Because an individual's level of tolerance of noise is subjective, there is no way to please everyone; hopefully public education about the technology will increase acceptance.

The economic impact of employing wind technologies is beneficial. This would be especially helpful in developing countries where billions of people still lack access to electricity and other modern forms of energy. Limited access to fossil fuels and the abundance of renewable, sustainable sources has led to the creation of 100,000 jobs in the wind industry worldwide. In 2003, $9 billion was invested in the wind industry globally.

This influx could greatly assist weaker, developing economies. The decreasing costs of the operation and services provided by wind energy are also appealing to poorer countries. By 2020, the cost may even be reduced to 2.6¢/kW hour.

One of the factors determining the economic worth of wind energy production is siting. The strength of wind spectra is one of the critical factors in deciding the cost of wind-generated electricity. Therefore, as the velocity of the wind increases, the cost is reduced. Also included in site-specific factors are the cost of land, installation, and environmental factors such as climate and harmful substances in the atmosphere.

Machine parameters include the cost of the turbines themselves. The cost of wind-generated electricity can be reduced with an increase in turbine size. When the size is scaled up from 20 kW to 50 kW, the cost/kW is reduced by 18 percent. Other factors that influence the cost are the existing energy market and policy issues, including incentives and exemptions. With the goal of promoting clean and easily accessible energy sources, several governments are giving financial support to the development of renewable energies.

WIND POWER IN ACTION

Despite the limitations and boundaries that wind energy may extend, Germany has proven to be a success story and has become the world leader in wind power. In the early 1990s, Germany started out with almost no renewable resource industry, and it seemed unlikely that it would ever be considered a leader in these technologies. The decision of the German government, in 1990, to pass a law that required utilities to purchase the electricity generated from all renewable technologies, and to pay a minimum price, was governed by the public's increased concern about the security of energy supplies and its environmental impact.

The results that Germany has experienced are staggering. The average cost of manufacturing wind turbines fell 43 percent 1990–2000. In 1997, Germany surpassed the United States to become the world leader in wind energy production. The percent of total electricity accounted for by wind power has increased from 3–6 percent 2001–07. In 2002 the renewable resource industries totaled $11 billion in sales. Nearly 45,000 Germans were employed in the wind industry alone in 2003. The country is taking further steps by pledging to reduce its CO_2 emissions by increasing its use of renewable energy. The government aims to meet 25 percent of national electricity needs by 2025 and at least half of its total energy needs with renewable resources by 2050.

The world can learn a lesson from Germany's innovative renewable energy technologies, especially wind power, and many nations are taking the initiative. Countries such as Spain and Denmark have established similar laws as Germany. Spain is a leading turbine producer, generated 5 percent of its electricity from wind in 2003, and has some of the world's largest turbine manufacturers. In Denmark, 20 percent of its electricity has been generated by wind. In the United States, at least 38 states have enacted similar laws.

These numbers are projected to increase. Major oil companies, including BP and Shell, are investing hundreds of millions in renewable energy. The U.S. Department of Energy's (DOE) Wind Powering America Initiative intends, by the year 2020, to have 5 percent of the nation's electricity generated through wind power. The European Wind Energy Association (EWEA) has developed a program, Wind Force 12, to produce 12 percent of the world's electricity by wind for the year 2020. Some countries may expect wind to contribute to larger percentages of their total energy by 2010.

For years, the exploiting and burning of fossil fuels has caused emissions of harmful gases and severe degradation of the environment. People worldwide are becoming conscious of the consequences of their actions for the environment. Only with a suitable amount of time, money, and energy invested in wind power can countries reap its full benefits. It does not emit pollutants into the air or water. There is no chance of hazardous waste as a byproduct of its use. The wind is a sustainable, natural, renewable resource which can never be diminished, unlike the finite supply of natural gas, coal and oil.

SEE ALSO: Alternative Energy, Overview; Energy, Renewable; Germany; Wind Driven Circulation; Winds, Easterlies; Winds, Westerlies.

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American Council for an Energy-Efficient Economy

THE AMERICAN COUNCIL for an Energy Efficient Economy (ACEEE) is a nonprofit organization located in Washington, D.C. Its staff is comprised of scientists, lawyers, engineers, and policy analysts. Its mission is to increase the economic well being of the world and foster a cleaner environment through energy efficiency. ACEEE is not a membership-driven organization; however, it does send out conference information, publications, and online newsletters to over 30,000 registered individuals.

Since its inception in 1980, ACEEE has helped to save American energy consumers over $50 billion and 60 billion kilowatt hours (kWh) annually. These savings are brought about by standards and policies recommended by the American Council for an Energy Efficient Economy and included in the energy policies of the last four U.S. presidents. ACEEE promotes five main program areas: energy policy, buildings, utilities, industry, and transportation. The goals of these programs are to educate consumers, businesses, policy makers, and program managers through collaboration and publications. ACEEE often works with energy experts, universities, national laboratories, and those in the private sector.

The first of ACEEE's projects was to influence energy policy. In 2006, the United States used approximately 100 billion British thermal units (Btu) of energy. ACEEE seeks to decrease this amount by lobbying Congress to include efficiency measures in national legislation. The organization has worked with Congress on major laws, such as the National Appliance Energy Conservation Act of 1987, the Energy Policy Act of 1992, the Energy Policy Act of 2005, and draft bills of comprehensive energy legislation in both the U.S. House of Representative and U.S. Senate.

ACEEE is also an established leader in creating ways to improve the efficiency of buildings, thereby decreasing overall impacts on global climate change. It has been instrumental in creating voluntary and mandatory labeling programs. ACEEE also consults with the U.S. Environmental Protection Agency (EPA) and Department of Energy (DOE) on the Energy Star program to achieve program targets. Finally, ACEEE is working to engender new, more stringent state-regulated building codes, which will require a greater emphasis on energy-efficient technologies.

ACEEE also works with the utility sector to design and implement efficiency policies and programs. They accomplish this by working with states and utilities on an individual basis, advocating for funding for end-user and system-wide efficiency programs, and creating sound policy advice. ACEEE also offers strategies for implementation, such as "reliability-focused" energy-efficiency, which promotes energy savings during times of high demand.

AnotherACEEE program area is industry. The goal of this program is to promote and analyze new technologies and polices that bolster energy efficiency while also increasing the competitiveness of businesses and agriculture. Staff members review energy-use trends, options for implementing energy and cost-saving technologies, and potential productivity and capital gains from such implementation options. ACEEE believes that sustainable businesses usually have the strongest bottom lines; therefore this nonprofit organization works to facilitate communication among businesses, government, and the environmental community. ACEEE accomplishes this by hosting a Summer Study in Energy Efficiency in Industry each year.

Another area that ACEEE works to improve is the transportation sector. ACEEE advocates for incentives for green vehicles, stronger Corporate Average Fuel Economy (CAFE) standards, market initiatives to promote greater vehicle efficiency, and more research and funding for new, clean technologies. ACEEE maintains a website for consumers to research the most fuel-efficient vehicles, read recent publications, and find tips for greener driving at www.greenercars.org.

ACEEE works with international companies and foreign nations to support energy efficiency programs. Most of this work is in conjunction with developing countries such as Brazil, China, and Thailand. In Brazil, ACEEE helped to establish PROCEL, the national energy conservation program. PROCEL has received over $100 million from the World Bank and the Global Environmental Facility. ACEEE's work in China has led to the establishment of the China Green Lights Program and the China Motor Systems Energy Conservation Program. These efforts helped

China to adopt national efficiency standards and integrated resource planning. ACEEE is expanding their international efforts to include the Czech Republic, Egypt, India, Poland, and the Slovak Republic. In addition to their Summer Study institute, the group also publishes several consumer guides, including the *Consumer Guide to Home Energy Savings*.

SEE ALSO: Energy; Energy Efficiency; Green Design; Policy, International; Policy, U.S.

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American Electric Power

AMERICAN ELECTRIC POWER (AEP) was founded in 1906, and served electric utilities in various parts of the United States for over 100 years. The company was originally formed from a utility holding-company in 1899, but began its electric utility service business in Albany, New York, on December 20, 1906, as American Gas and Electric (AG&E), acquiring its first utility properties on January 2, 1907. In 1917, AG&E operated the first super power plant on the Ohio River at Wheeling, Ohio, and named it the Windsor Plant. It was the first major steam plant built at the mouth of a coal mine, eliminating the need to haul coal over long distances. It provided a significant amount of power over the nation's first long-distance 138,000-volt transmission line. The AG&E made the greatest expansion in its history 1922–27. It acquired a number of major properties such as Indiana Michigan Electric, American Electric Power Company in Philadelphia, and Appalachian Power Company in Virginia.

With the increasing demand for electricity in the 1920s, AG&E constructed three large generating stations: the Twin Branch plant in northern Indiana, the Philo plant in southeastern Ohio, and the Stanton plant in northeastern Pennsylvania. Even during the Great Depression, the company persevered and maintained its financial integrity through the stock market crash in 1929.

AG&E constructed 36 new generating units at 14 locations in five states 1941–61 with a total generating capacity of 6 million kilowatts (kW). At that time, many AG&E plants occupied the top of the list of America's most efficient electricity generating stations. After that, it added 11 new generating units for 2 million kilowatts capacity. It also managed a 390-mi. (628 km.), 345,000-volt transmission system for the Ohio Valley Electric Cooperative (OVEC), which had been formed to supply electrical power to the federal government's uranium enrichment plant at Piketon, Ohio. In 1958, AG&E changed its name to American Electric Power (AEP). AEP continued to grow 1961–75, adding 21 new generating units to bring the total system's generating capacity to 17.6 million kW.

In 1967 AEP announced that it would build a nuclear generating station on the shores of Lake Michigan. The 1,020,000-kW Unit 1 of the Donald C. Cook Nuclear Plant went into commercial operation in 1975, and the 1,090,000-kW Unit 2 was completed in 1978.

New York City was AEP's headquarters for nearly three-quarters of a century, but it began moving its corporate offices to Columbus, Ohio, in 1980, and completed the move in 1983 with the completion of a new 31-story office facility at One Riverside Plaza. During 1996, AEP's sales of electricity to retail customers reached a record 100 billion kW hours. On December 22, 1997, AEP announced a definitive merger with Central and South West Corp. of Dallas, Texas. The merger was completed on June 15, 2000, and created a combined electricity sales amount of 200 million megawatt hours. As of 2007, AEP had more than 5 million U.S. customers and served parts of 11 states, including Arkansas, Indiana, Kentucky, Louisiana, Michigan, Ohio, Oklahoma, Tennessee, Texas, Virginia, and West Virginia. It was one of the largest investor-owned utilities in United States.

AEP has undergone successful expansion to date; however, with increasing concern for the environment, and greater international and governmental policing of energy corporations, AEP must consider the environment a corporate responsibility. Climate change, attributed to increasing atmospheric concentrations of greenhouse gases (GHG), is a growing concern for

AEP, because it is one of the largest consumers of coal in the United States. Therefore, reducing GHG emissions and supporting a reasonable approach to carbon controls is crucial to AEP.

AEP has been researching clean technologies. In August 2004, it announced plans to construct an Integrated Gasification Combined Cycle (IGCC) coal-fired power plant. IGCC technology is expected to reduce the atmospheric concentration of emissions, while providing additional electricity capacity to the customers served by AEP. IGCC is an innovative clean technology that turns coal into a gas, and then removes impurities from the coal gas before it is combusted. This results in lower emissions of sulfur dioxide, particulates, and mercury. It also results in improved efficiency compared to conventional pulverized coal.

IGCC technology is proven to work well with high-British thermal unit (Btu) coals such as the bituminous Appalachian coals readily available in AEP's eastern area. With this technology, AEP has concentrated research on developing technologies for carbon capture and storage. AEP became a founding member of the Chicago Climate Exchange (CCX), the first voluntary GHG credit trading system in the United States, and committed itself to reducing GHG emissions below baseline emission levels. The total cumulative CO_2 equivalent reduction requirement to meet the CCX commitment is approximately 46 million metric tons by 2010. AEP also committed to the recycling of its coal combustion products through the Coal Combustion Products Partnership in cooperation with the U.S. Environmental Protection Agency. Coal ash of the highest quality is dispensed to customers as products and unsuitable ash is identified and diverted for disposal. Examples of the utilization of coal ash include the construction of dams, plant roads, stacks, cooling towers, and buildings.

Approximately 73 percent of AEP's generating capacity is coal-fired plants, 16 percent natural gas, and 8 percent nuclear. The remaining 3 percent is wind, hydroelectric, and other sources. The company also operates its own inland barge line and owns major tracts of land throughout its service areas. In 2001, AEP acquired MEMCO Barge Line, Inc., and enhanced its coal transportation resources. As of 2007, AEP's transportation infrastructure consisted of approximately 7,500 rail cars, 1,800 barges, and 37 tugboats.

SEE ALSO: Emissions, Baseline; Energy; Energy Efficiency; Global Warming.

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American Gas Association

THE AMERICAN GAS Association (AGA) is a national trade organization composed of natural gas-providing companies. This large group of companies, founded in 1918, was organized to better represent the interests of natural gas providers at the legislative level. The AGA is headquartered in Washington, D.C., on Capitol Hill. According to the AGA, nearly one-quarter of American energy is supplied by natural gas.

The AGA vision statement is "[T]o be the most effective and influential energy trade association in the United States while providing clear value to its membership." Membership includes 200 companies providing natural gas service to their local communities. The AGA and its members deliver 92 percent of the United States' natural gas supplies. Member companies represent suppliers from all 50 states. The companies are privately-owned, publicly-traded, or municipally-owned. Natural gas distribution companies in the United States are considered full members of the AGA. Additionally, brokers, distributors, gatherers, marketers, pipelines, and storage facilities can be Associate Members of the AGA if they are in North America; natural gas distribution companies in Mexico and Canada may also be associate members. Finally, international or international-affiliate memberships are extended to those companies beyond North America that support international communication between natural gas companies and governments.

Membership privileges include conferences and courses for company executive directors and other employees covering topics such as finances and investments, as well as compensations, legislation, and customer service. Members can also elect to receive newsletters. The five newsletters are the *Associate Update, Executive Bulletin, Financial Edge, International Bulletin*, and *Operations Bimonthly Review*.

The AGA also provides written documents related to the use of natural gas and current concerns about climate change and global warming. On February 19, 2007, the company released the "AGA Climate Change Principles," outlining how changes can be made that would result in natural gas being a safer, more environmentally responsible form of energy. Another document from the same day, the "AGA Climate Change Talking Points," outlines various significant facts about natural gas, focusing on the improved efficiency of modern appliances and industrial machines, low rate of emissions compared to coal and fuel oil; and arguing for construction of domestic natural gas plants, access to natural gas wells, and the construction of other plants and factories in the United States that would use natural gas power. The organization does not offer a solution to the problem of natural gas wells in protected areas. Nevertheless, due to limited availability of natural gas, AGA proposes research into alternate energy sources as a complement to natural gas; namely, solar and wind power, along with cleaner coal and oil fuel usage.

To further disseminate information about issues concerning natural gas, the AGA publishes a magazine approximately every two months, *American Gas Magazine*. Issues are focused by theme, including technology and partnerships, legislation, natural gas supply, and even climate change. The climate change issue (August/September 2007) provides information to its readership about carbon footprint reduction and how using natural gas directly for power, rather than using it to generate electricity, provides a cleaner energy source. Because of the relative environmental and economic benefits of natural gas, the AGA has adopted the slogan *Natural Gas: the Nation's Energy Advantage*.

A board of directors manages the AGA. A total of 45 of the full member companies have senior executives on the AGA board. The board is composed of a chair, a president and chief executive officer, officers, directors, and non-voting advisory directors. The Environmental Regulatory Action Committee (ERAC) is a sub-committee in AGA. Its members report to the Government Relations Policy Committee and the Operations Sections Managing Committee. ERAC acts on behalf of AGA to influence environmental legislation. The sub-committee writes documents defending its statements, testifies when needed, recommends pertinent legislation, and otherwise deals with matters concerning environmental legislation.

The AGA website offers information for members, policy makers, and the public. Summaries of congressional hearings and legislations are available, as well as information on the stance of the AGA on issues regarding natural gas, the environment, and energy. Information is also available on statistics such as trends in natural gas usage and prices. For example, the website states that the average annual residential gas cost rose from $597 per consumer in 1996 to $935 in 2005. Additionally, in 2005 the average gas price was three and one-half times higher in the second-most expensive state (Florida) than the least expensive state (Alaska). The most expensive state was Hawaii, with an average gas price that was another one and one-half times higher than that of Florida. When examined by region, New England pays more for gas than any other region, with the South Atlantic states close behind.

SEE ALSO: Emissions, Baseline; Energy; Energy, Renewable; Natural Gas; Policy, International.

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American Geophysical Union

THE AMERICAN GEOPHYSICAL Union (AGU) is a nonprofit organization of geophysicists with over 50,000 members from over 140 countries. The AGU's activities are focused on the collection and dissemination of scientific information in the interdisciplinary and international field of geophysics. The geophysical sciences include four fundamental areas: atmospheric and ocean sciences, solid-Earth sciences, hydrologic sciences, and space sciences. The AGU's mission is to promote the scientific study of Earth and its environment in space and to disseminate the results to the public; to encourage cooperation among scientific organizations involved in geophysics and related disciplines; to initiate and participate in geophysical research programs; and to advance the various geophysical disciplines through scientific discussion, publication, and dissemination of information. In December 2003, the AGU clearly stated its position on global warming, explicitly pointing to human activities as determining factors in changing the Earth's climate.

The AGU was established in 1919 by the National Research Council and for more than 50 years operated as an unincorporated affiliate of the National Academy of Sciences. In 1972 the union was incorporated in the District of Columbia and membership was opened to scientists and students worldwide. The AGU offers to its members a wide range of publications, meetings, and educational and other activities that support research in the Earth and space sciences. Many AGU members are involved in crucial research for the future of the planet on issues such as global warming, climate change, ozone depletion, natural hazards, water supply and quality, and other environmental factors. The AGU's membership includes many of the world's foremost geoscientists from industry, academia, and government.

The AGU is an individual membership society and membership has increased each year, doubling during the 1980s. About 20 percent of the members are students. Members and associates receive *Eos*, the AGU's weekly newspaper, and *Physics Today*, a magazine produced by the American Institute of Physics. All members may vote and hold office. The AGU's fellows are selected from the membership because of their acknowledged expertise in areas of the geophysical sciences.

The AGU organizes an annual meeting in San Francisco every December, known as the fall meeting. This is the largest annual scientific conference in the world. The AGU also holds a joint assembly cosponsored with other societies such as the Geochemical Society, the Mineralogical Society of America, the Canadian Geophysical Union, and the European Geosciences Union every spring in various locations around the world. Traditionally held in Baltimore, this spring meeting was moved to different locations, starting with Boston in 1998, due to declining interest. With the meeting in Nice, France, in 2003, the event was renamed the Joint Assembly. In addition to these meetings, which cover all areas of the geophysical sciences, the AGU also sponsors many specialized meetings that are intended to serve the needs of particular scientific disciplines or geographical areas, including the Ocean Sciences Meetings and Western Pacific Geophysical Meetings, which are held in even-numbered years. The Chapman Conferences are smaller, and highly-focused meetings.

The AGU Council runs the union, has full responsibility for all affairs of the AGU, and is its representative in its external relations. The Council consists of the AGU's president, the president-elect, the immediate past-president, the general secretary, the international secretary, the executive director, and the president and president-elect of each of the AGU's 11 scientific sections. The executive director serves as secretary to the Council. The Council usually meets twice a year, at the AGU's spring and fall meetings. The Executive Committee, composed of the president, the president-elect, the general secretary, the international secretary, and the executive director, conducts the affairs of the AGU between meetings of the Council according to the policy decisions of the Council.

Adopted in December 2003, "Human Impacts on Climate" is the AGU's official statement on global warming. They explicitly argue that human activities are increasingly altering the Earth's climate and the level of greenhouse gas concentrations in the atmosphere is already affecting the climate. The AGU strongly recommends enhancing national and international research and other efforts to support climate related policy decisions. They conclude that because science can serve as a useful tool to deal with natural hazards such as earthquakes, hurricanes, and drought, it can also provide an answer to human-caused global warming.

SEE ALSO: Geophysical Fluid Dynamics Laboratory; International Union of Geodesy and Geophysics (IUGG).

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American Meteorological Society

THE AMERICAN METEOROLOGICAL Society (AMS) supports the growth and diffusion of information and education on the atmospheric and related oceanic and hydrologic sciences and the development of their professional applications. Founded in 1919, AMS has a membership of more than 11,000 professionals, professors, students, and weather enthusiasts. AMS publishes nine atmospheric and related oceanic and hydrologic journals, both in print and online and sponsors more than 12 conferences annually. It also offers numerous programs and services.

Charles Franklin Brooks of the Blue Hill Observatory in Milton, Massachusetts, founded the American Meteorological Society. Its initial membership was formed primarily by the U.S. Signal Corps and U.S. Weather Bureau and numbered less than 600. Its initial publication, the *Bulletin of the American Meteorological Society*, served as a supplement to the *Monthly Weather Review*, which, at the time, was published by the U.S. Weather Bureau. Many of the initial members were not professionals in the field, but after the dues increased from $1 to $2 in 1922, the amateur meteorologists began dropping out, and the AMS moved toward a membership primarily of practicing meteorologists. It has made important official statements on ozone depletion and climate change that recognize human activities as a cause of the phenomena.

The 1930s and 1940s were a period of significant progress in the atmospheric sciences, and the AMS contributed substantially to such progress through the publication of fundamental articles in the *Bulletin*, the production of books and monographs, and the organization of specialized meetings. World War II increased a new interest in meteorology. The conflict had shown the key role that the discipline played in support of military activities in ground and air operations. A large number of meteorologists were trained as part of the wartime effort and were employed in military research during the Cold War. After the war, the military and civilian sectors of society had a substantial number of meteorologists in their ranks. The AMS saw significant growth during this period, which corresponded to the birth of many departments of meteorology at universities. Because of new research and newly-trained meteorologists, the publications and meetings of the AMS increased. C.G. Rossby served as president of the AMS 1944–45, and developed the agenda for its first scientific journal, the *Journal of Meteorology*, which later divided into the two AMS journals: the *Journal of Applied Meteorology* and the *Journal of the Atmospheric Sciences*.

The AMS now publishes, in print and online, nine scientific journals and an abstract journal of high academic standard, in addition to the *Bulletin.* It also organizes over a dozen scientific conferences each year. It has published a series of monographs, as well as many other books and educational materials. The AMS administers two professional certification programs, the Radio and Television Seal of Approval and the Certified Consulting Meteorologist (CCM) programs. The Radio and Television Seal of Approval was established in 1957 as a way to recognize television and radio weather forecasters who present clear and scientifically-informed weather reports. The original seal of approval program will be discontinued at the end of 2008, and after that date, only the Certified Broadcast Meteorologist (CBM) seal will be offered. The CBM was introduced in January 2005, together with a 100-question multiple-choice closed-book examination as part of the evaluation process, covering many aspects of the science of meteorology and forecasting.

In the education sector, the AMS offers a variety of undergraduate scholarships and graduate fellowships to support students wishing to undertake a career in the atmospheric and related oceanic and hydrologic sciences. The AMS considers education as one of its strategic areas of intervention because, as its 2007 strategic goals brochure states, "the atmospheric and related sciences serve as a gateway to introduce both young people and adults to broad scientific issues."

The AMS has made several statements on climate change. It identifies climate change as one of the most important factors that will impact societies, and the environment as one of the fundamental elements that will influence the economies of developed and developing nations. The AMS's third strategic goal is "to promote science-based decision making" about climate and weather variability. Such variability can produce huge swings in national economies; thus, it is in the interest of nations to be able to cope with this phenomenon. Global warming causes rising sea levels and retreating glaciers. The most significant changes in U.S. climate have taken place in Alaska and in the west.

Although weather has always changed for natural reasons, the AMS concludes that, at least over the last 50 years, human activities have made a major contribution to climate change. The most apparent result of human activities on climate is the rising concentration of greenhouse gases that act as a blanket to reduce the outgoing infrared radiation emitted by Earth and its atmosphere. The AMS document closes with a plea to policymakers to take better care of the Earth.

SEE ALSO: National Oceanic and Atmospheric Administration (NOAA); Weather.

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Andorra

SITUATED IN THE Pyrenees Mountains along the French-Spanish border, Andorra is approximately 180 sq. mi. (470 sq. km.), or the size of New Orleans, Louisiana. The population (est. 80,000) inhabits a region with a cool, temperate climate, amid mountainous terrain. Its economic revenues come from tourism and regional agricultural specialization, both industries with links to climate change. With nearly 12 million visitors per year, tourism comprises over 80 percent of the country's Gross Domestic Product (GDP).

Roadways are limited and inadequate, making stagnant traffic commonplace. Pollution swells during the peak winter and summer tourist seasons, reducing air quality and concentrating greenhouse gases in the valleys. These conditions are exacerbated by high carbon dioxide emissions from low-grade coal-burning power plants in Andorra and northern Spain.

The stronghold of Andorran tourism is the ski industry. Like much of mountainous Europe, Andorra has seen snowfall amounts decline and winter seasons considerably shortened in recent decades. Global climate models indicate European locations below 4,921 ft. (1,500 m.) are most vulnerable to permanent snow loss. Unlike many Alpine locations, Andorran ski resorts are largely above this critical altitude. Snow reduction impacts include a decrease in tourism, investment in snowmaking machines, cancellation of winter events, and expansion of alpine grasslands. Diminished tourism revenue has prompted a recently-proposed corporate tax, a controversial initiative for a historically tax-free state.

Unlike most of the European community, Andorra is not active in global climate change policy and state-sponsored efforts are minimal. An official position regarding the Kyoto Protocol has not been entered according to the latest poll (2007) from the United Nations Framework on Climate Change (UNFCC). Despite close socioeconomic ties with France and Spain, Andorra has not followed the climate initiatives of its neighbors by ratifying the treaty. Instead, Andorra maintains neutrality and observer status in these proceedings, a similar position retained by Serbia and the Vatican City, the only other European states not to have ratified the protocol.

The Andorran Weather Service, established in 1980 as a joint effort with Meteo-France to homogenize data for the region, conducts climate monitoring. The service has three automated weather stations and seven manual ski resort stations. Continuous weather data monitoring began in 1934, with three stations (Ransol's Dam, Casa del Guàrdia d'Engolasters, and the Central) providing the primary historical climate record.

SEE ALSO: Climate Change, Effects; France; Kyoto Protocol; Spain; Tourism.

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Angola

LOCATED IN THE southwest of Africa, the Republic of Angola gained its independence from the Portuguese in 1975, and the civil war that followed lasted until 1991. The country covers 481,354 sq. mi. (1,246,700 sq. km.), with a population of 15,941,000 (2005 est.) and a population density of 34 people per sq. mi. (13 people per sq. km.).

Because of current upwelling, one of the salient feature's of Angola's geography is the very cold surface water along its coast on the south Atlantic Ocean. The largest concentration of people in the country remains Luanda, the capital, which has nearly a quarter of the entire country's population. The soil in Angola has always been poor, with only 2 percent arable land, and no permanent cultivated crops. Some 23 percent of the land is used as meadows or pasture, with large cattle herds adding to the increasing desertification of the country.

The result is an economy heavily dependent on the sale of petroleum, which contributes about 40 percent of the nation's Gross Domestic Product. This reliance on oil contributes to the high use of fossil fuels for electricity production, with 40.3 percent of Angola's electricity coming from fossil fuels, and 59.6 percent from hydropower.

The major hydroelectric electricity generation takes place at the Cambambe (Capanda) Dam located on the Cuanza River, with further production at the Biopio and the Lomaum dams located along the Catumbela River. In addition, there are other hydroelectric power generation plants, such as that at Luachimo used by the diamond mining works. The war led to the damaging of places such as the Ruacaná Falls dam, which was out of action for a long period.

All these factors have helped reduce the carbon dioxide emissions from Angola, which is only 0.4 metric tons per capita, although it rose to 0.9 metric tons per person in 1995, and then fell to 0.57 metric tons per person. The government has also tried to further reduce the already relatively low level of emissions from sulfur dioxide, nitrogen oxide, and carbon monoxide.

The Angolan government of José Eduardo dos Santos took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, and the government also accepted the Kyoto Protocol to the UN Framework Convention on Climate Change on May 8, 2007—the 171st country to do so. The Angolan government has argued that dealing with climate change should accompany a global political framework for reducing world poverty.

SEE ALSO: Desertification; Oil, Production of; Portugal.

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Animals

WHILE GLOBAL WARMING and associated climatic change have profound geological impacts on animal habitats, they also impact the dynamic living processes of the ecosystems of animals. Though the two types of impacts are highly interconnected, it is paramount to distinguish between changes that express themselves mainly at a climatic and geological level, from changes that require an ecosystems perspective. Unfortunately, the mass media, governments, and transnational conservation agencies and organizations often conflate these two types of changes. This conflation represents a major impediment to public understanding of global warming and global climatic change.

While many of the geological and climatic consequences have become starkly visible to the non-scientific community, ecosystem effects often have either not yet manifested themselves, or are only noticeable through the application of some form of expert knowledge. This includes scientific knowledge, as well as the traditional knowledge of peoples with generations of experience in interacting with specific environments.

This problem is exacerbated by the fact that both public and scientific reporting on global warming and climate change are rarely impartial or value-neutral. Information is not equally accessible to all groups of people. Accordingly, people's views on the veracity of global warming tend to differ according to their social, cultural, economic, and political position, as do their views on the importance of introducing measures to halt global climatic change, and what these measures should be.

THE ICONIFICATION OF ANIMALS

This reality is especially evident in reporting the impact of climactic change on animals, as some animals are perceived as having higher conservation and aesthetic value than others. European and North American elites have claimed more appreciation of these values as a mark of distinction since the turn of the 19th century, according to Karl Jacoby. These values were institutionalized and exported to the rest of the world in the setting of a global conservation regime that emerged in the context of European empires and westward expansion in North America.

These values were popularized with the rise of car culture after World War II, as large numbers of North Americans began visiting wild places in their leisure time, as explained by Roderick Neumann. They also became enshrined by the Walt Disney-style nature films that became popular during this period, and by the dramatic international success of Bernard Grizmek's book *Serengeti Shall Not Die!* For the most part, middle-class and formally-educated people embraced these values.

Over time, the popularization of charismatic fauna in the media has literally increased the value of certain animals. Images of soaring eagles sell pickup trucks, wild mustangs sell cigarettes, and a cartoon tiger sells cereal. Popular tourist destinations are marketed by promises of seeing grizzly bears, jaguars, scarlet macaws, kangaroos, elephants, lions, and rhinos in distant and exotic locations. These same types of animals and exotic locales are also a major selling point for films, such as *Finding Nemo*, *Madagascar*, and *The Wild*. Finally, the association of certain animals with major conservation organizations has been a source of advantage in a highly-competitive funding environment. The World Wildlife Fund panda is one of the most successful logos in the world. The African Wildlife Foundation's ivory ban campaign was the most successful direct mail charity solicitation of all time. Ironically, it contributed to an international treaty that resulted in an explosion of elephant populations in Southern Africa, such that the animals began destroying their own habitat.

Some species have become icons for conservation, while others have been neglected, even though their species may be under threat of extinction. The iconic value of some species is rising, while the iconic value of others is falling. In the 1980s and 1990s, for instance, many environmental movements and non-governmental organizations used images of whales to promote their conservation campaigns. In the context of anti–global warming, however, polar bears and penguins have come to assume pole-position in the effort to sensitize the masses to the seriousness of environmental problems. This makes sense, as it is clearly easier for lay people to grasp the relationship between these animals and the dangers of global warming.

The anthropomorphization of Antarctic animals in *Happy Feet*, produced in Imax 3-D, along with images of Knut the baby polar bear being bottle-fed at the Berlin Zoo, has also contributed to increased identification with these animals. And both these species naturally display characteristics similar to those typical of human beings: they can walk on two feet, their body forms are in many ways similar to the human body, and they display highly complex forms of social behavior. These developments have not been entirely negative. Documentaries such as Al Gore's *An Inconvenient Truth*, which features an animated polar bear crying in the middle of the ocean and Luc Jacquet's *The March of The Penguins* have played a major role in raising public awareness of global warming.

As icons, however, these animals represent only the most visible consequences of global warming and climate change. They stand for the problems of global warming symbolically, but they cannot stand for all that is wrong. The iconification of global warming through images of these animals for the most part glosses over the complex dynamic living processes of ecosystems. Instead, they emphasize the geological impact of rising temperatures on the habitats of these animals, which are easily captured through images of polar bears struggling across melting ice fields and drowning in the process. Rising temperatures are also easily represented through images such as the melting ice cap on Mt. Kilimanjaro, and they are experienced directly by people during highly-publicized heat waves.

The iconification of global warming through images of certain animal species may keep the public from understanding the extent and complexity of these phenomena. While climate patterns have always oscillated between given thresholds, for example, maximum and minimum numbers of hurricanes per season, climatic oscillations now show a tendency to increasingly occur at upper-end thresholds. What is at issue is that the iconification of these changes through images of animals conceals their complexity.

It is important to note, however, that the exact causal mechanisms that link the two are so complex that they have not yet been completely understood and explained by scientists. While, on average, the global temperature of the planet has increased, the manifestation of its consequences in terms of climate-related phenomena varies greatly from region to region. In some regions, it is associated with higher incidence of tropical and subtropical storms; in others, extreme rainfall and flooding; and in yet others, the onset of extreme drought. It has entailed record-beating temperatures in Europe, and an increase in erratic and destructive weather patterns in North America.

The plight of polar bears and penguins may call public attention to the fact that the melting of glaciers that began at the end of the last glacial period has accelerated at an exponential rate in the past four decades. However, it does not highlight the broader ecosystem impacts of the melting of the Earth's ice reserves. Many ecosystems of the world that simultaneously depend on, and sustain, animal life may disappear under the ocean, as may entire nation-states in the Pacific.

Erosion is another geological problem that occurs as a consequence of global warming and the related increase in the number and strength of storms. This is a particularly acute problem in areas of the globe that have already been subjected to human-caused erosion or land destruction. An example of this problem can be found in the Bayou areas in the Mexican Gulf Coast of Louisiana in the United States. The construction of human-made water canals had slowly deprived Bayous of much needed sediments that the Mississippi previously deposited there during its yearly cycles, according to MacGillivray Freeman.

As a result, extensive marsh areas that formerly protected New Orleans from floods and ocean surges underwent a process of severe erosion. This erosion tends to accelerate when the Bayous are hit by storms. To a great extent, the incalculable damages New Orleans suffered in the aftermath of hurricane Katrina were caused by the absence of previously-existing protective marshes. Meanwhile, the continent of Africa is currently undergoing processes of desertification that surpass previously known rates. As deserts expand into previously non-desert ecosystems, the existence and survival of the plants and animals that were part of these ecosystems is seriously threatened. Consequently, the role of animals in the ecological processes of these systems is also compromised.

HUMAN-INDUCED MASS EXTINCTIONS

Ever since ecosystems have comprised the living component of the planet, there have been periods where mass animal extinctions took place because of catastrophic events, such as the impact of large meteors, or because of relatively sudden drastic climatic changes, such as the onset of glacier periods. These types of mass extinction appear to have been a regular and natural occurrence in long temporal spans of ecological cycles and ecological change. What is a recent and new phenomenon in the history of the planet is the rapid mass extinction of animal species due to human-induced ecosystem changes. The most notable of these include agricultural expansion, industrialization, urban sprawl, and the appropriation of ecosystems for commercial purposes, such as forestry, fishing, hunting, and ecotourism.

All of these are closely related to climatic changes that affect animal life on unprecedented spatial and temporal scales. Ironically, tourists climbing on airplanes to see charismatic species in exotic locales contribute directly to climate change through the burning

Whales have been icons for conservation since the 1980s, but their iconic value is in decline in relation to arctic species.

of jet fuel. This, along with the iconification of global warming through images of animals, may give people an increased sense of being closer to nature. However, it does not encourage people to think about how their consumptive activities are contributing to climatic change and perhaps, ultimately, to the demise of the very species they wish to protect and preserve. These types of simplified understandings of nature and animals also hinder public understanding of the ways in which climactic changes impact the dynamics that characterize the lives of ecosystems, as opposed to more obvious geological changes.

Ecosystems are living entities, and as such they respond actively to change and difference by adjusting their patterns of behavior. Assessing environmental change from the perspective of an ecosystem requires paying attention to how patterns of relationships among the different species that comprise that ecosystem are altered and/or disrupted. It also entails paying attention to if new patterns of relationship emerge between them and what consequences this produces. Moreover, because these patterns unfold in distinct temporal frames, noticing change frequently requires long-term observation and study.

BIRD REPRODUCTION AND GLOBAL WARMING

Two examples elucidate the complexity of understanding changes to inter-species patterns of relationship and, thus, comprehending the complexity of the changes that global warming introduces to ecosystems. One example comes from the United Kingdom and concerns relations between flower blooming, butterfly production of caterpillars, and bird reproduction. For 47 years, naturalist Richard Fitter wrote down notes about the flowering times of many plant species, the arrival and reproduction of birds, and the life cycles of butterflies that he observed around his house and garden. In 2001, his son Alistair Fitter, an ecologist, analyzed these detailed data in order to assess what they might reveal about the potential impact of global warming on patterns of relationships within ecological systems.

He also sought to determine the extent to which such an impact might bear significant consequences in regard to the sustainability of interdependent species. The results, published in *Science* in 2002, were astoundingly informative. They were subsequently confirmed by research conducted under the auspices of the Intergovernmental Panel on Climate Change that same year, and by other independent researchers around the world.

This research shows that as late as 1980, the hatching food-needs of birds matched the peak mass of the quantity of caterpillars that were available within that ecosystem. In other words, the patterns of reproduction for these two interdependent species were coupled in time. By 2002, however, these patterns had been decoupled as a result of global warming and the onset of a sequence of years marked by a two-week earlier arrival of spring.

By 2002, the birds had maintained their average date for laying eggs (April 23) and their date for hatching (May 15), which marked the beginning of a two-week period where birds were in the highest demand for the caterpillars to feed their offspring. The birds' peak demand for nutrition, which in 1980 had corresponded with peak availability in caterpillar mass, continued to be on May 28. By 2002, however, caterpillars displayed different hatching dates, most likely related to an earlier arrival of spring temperatures, as well as to the consequent early blooming of flowers. The peak mass of caterpillar availability in 2002 was May 15, almost two weeks earlier than in previous decades. It is for this reason that ecologists say that the two species are now decoupled.

This example points toward four dimensions of the complexity implicit in the challenge of understanding the effects of global warming and climate change on ecosystems. First, it indicates that responses to the temperature variations that come with global warming are relative and peculiar to each species within an ecosystem. Some species, such as flowers and butterflies, seem to have a lower threshold for sensing temperature variation and respond accordingly by blooming and reproducing earlier in the season. Species such as birds, by contrast, seem less sensitive to temperature variations and continue to produce offspring at the same time as before.

Second, this example shows that a comprehensive understanding of the impact of increased global warming can be neither based on a discussion of absolute values, nor on the effects that such variations might have for a single species in an ecosystem. The full appreciation of the effects that global warming has on ecosystems must be based on an analysis of the extent to which, and the ways in which, this phenomenon affects relationship patterns among species.

A third dimension that must be considered in assessing the effects of global warming is that there are complex interactions between different ecosystems. Ecosystems do not exist autonomously and the sustainability of one ecosystem often depends on interactions with other ecosystems. This is particularly true of ecosystems that are connected through migratory species, such as ecosystems spanning from Central America to Canada, which rely on monarch butterflies for pollination. In addition, ecosystems are frequently nested within wider ecosystems such that their resiliency depends on complex interactions across different spatial scales.

Finally, this example shows that understanding the effects of global warming on ecosystems requires a temporally-extended view of the patterns that connect these different species, which are crucial elements in their long-term sustainability. It was only by means of analyzing the data that Richard Fitter collected over a period of 47 years that the decoupling of reproducing patterns of flowers, butterflies, and birds became visible.

BALEEN WHALES AND CLIMATE CHANGE

A second example concerns the sustainability of baleen whales in relation to the availability of plankton and krill. Baleen whales constitute a particularly interesting example in that they simultaneously point to the importance of the ecological relationships among different species at different scales, as well as to the importance of considering the temporal complexity of these processes. Most species of whales are migratory, with complex migratory patterns across the oceans, sometimes spanning more than half the planet. These patterns are fairly well-known across a relatively long span of history, not only through the efforts of scientific research and data collected by nongovernmental organizations, but also through many detailed records of whales' movement of that were collected by the whaling industry during the 18th and 19th centuries.

The migratory movement of whales tends to be coupled with the availability of nutrition. The main source of nutrition for baleen whales is krill. Krill, in turn, depend on plankton as their main source of nutrition. If ocean waters become too warm, plankton populations tend to expand to the point where they are poisoned by their own metabolic processes. Without plankton, krill populations are not sustainable, and, consequently, baleen whales may find themselves deprived of their main source of nourishment. In recent years, it has been reported that warmer ocean waters have affected the level of krill available to whales.

This example sheds light on the complexities of scale and time that are inherent in patterns of interspecies relations in an ecosystem. While ecosystems may become toxic from the perspective of the scale of plankton, they may not be toxic from the perspective of the scale of larger species, such as baleen whales. However, baleen whales are still affected, because their survival relies on a food chain in which plankton play a crucial role.

This example also raises the issue of temporal complexity in ecosystems. Whales live for several decades, on average 70–80 years. Therefore, understanding the long-term effects of krill deprivation will require years of systematic investigation and data analysis. As there are other factors that affect the health state of whales, scientists will have to consider which of these other factors may accentuate or attenuate the effects of the lack of krill-based nutrition on whales.

BEYOND POLAR BEARS AND PENGUINS

Simplified presentations on polar bears and penguins that do not account for spatial and temporal processes can never engage the types of ecosystem complexities that these two ecosystem examples reveal. In other words, the iconification of globalization through images of single species precludes a deeper understanding of global warming from an ecological perspective. Moreover, the focus on specific species of animals deemed more worthy of protecting and saving from extinction reflects the dominant views of Western societies and cultures, at the expense of alternative cultural views about animals. Different cultures have distinct views of which animals they value most. These views are often related to the different political and economic priorities of various societies. In many cases, however, they are grounded in more direct and long-term interactions with specific ecosystems than the dominant Western view.

This phenomenon is not exclusive to discussions of global warming, and it has long been at the core of tensions around conservation efforts going back to European colonialism and westward expansion in North America. In Tanzania, for example, efforts to create nature parks meant to preserve wild animal life have often produced conflicts with local populations that are displaced as a result. These conflicts have been well documented by social scientists such as Jim Igoe and Dan Brockingon. These researchers have shown that nongovernmental organization conservation efforts in Africa often reflect the political and economic interests of North American and European countries, transnational conservation nongovernmental organizations, and African elites. These groups are interested in protecting animal life so that it can be preserved as legacy for future generations, and as an economic resource for profitable commercial activities such as ecotourism. The local peoples who are displaced, however, often have different cultural and economic priorities, such as securing the sustainability of the local resource management practices on which their livelihoods depend.

While these debates do not pertain directly to global warming and climatic change, they are indicative of the sort of conflicts that emerge in the context of efforts to preserve animal life. They reveal political, cultural, and economic priorities about which species should be protected, for whose benefit, and at whose expense. Such conflicts are likely to proliferate and intensify as the impact of global warming and global climatic change on animals becomes increasingly prominent. As such, it will be important to consider that debates about these issues will need to foster productive communication among views and interests that, although distinct, often reflect equally legitimate perspectives. Most importantly, temporally and spatially complex human understandings of specific ecosystems should not be displaced in the rush to preserve and iconify individual species.

Recent scientific developments allow for the artificial manipulation of the gene pools of animal life. Though it has not yet gained mainstream acceptance, it is now possible through gene technologies to bring back species that may become extinct as a result of global warming and climactic change. Without more complex understandings of the dynamics of living ecosystems, however, it is questionable what value the revival of previously extinct species will have for the future of the planet.

SEE ALSO: *An Inconvenient Truth*; Conservation; Media, Books and Journals; Oceanic Changes; Phytoplankton; Polar Bears; Public Awareness; Sea Ice; World Wildlife Fund (WWF).

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An Inconvenient Truth

ARGUABLY THE MOST famous documentary of the early 21st century about the issues of global warming and climate change, *An Inconvenient Truth* was directed by Davis Guggenheim, with former U.S. Vice President Albert A. Gore, Jr., as narrator and creator. Gore steals the show, and very few people remember the filmmaker's name. *An Inconvenient Truth* is in essence a filmed public lecture, one and a half hours long, delivered by a former politician, not a scientist, about the importance and dangers of global warming.

The main character, Al Gore, is progressively introduced in the first scenes of the film, just before the film's title appears on the screen. The opening images show only nature: a calm river. Then, Gore's voice is coupled with various images of individuals from the audience who listen carefully to his message. At this point, Gore is viewed only from behind. Reaction shots are taken from individuals in the audience: most people listen, applaud; in another shot, others have the chance to get nearer or to talk to him directly. A man who seems impressed takes a photograph of nearby Gore, another candidly films him with his mobile telephone, showing that this is an important person, and this rare meeting is to become a memorable moment for all those who had the chance to encounter him. In the background, soft, instrumental music plays in a New Age style.

Then, perhaps on another day, in another city, Gore is about to enter on stage; first his shadow, from feet to head, then his whole person is shown. Until that moment, his face is not visible; then the magnified Gore introduces himself in a general shot, declaring jokingly, but without a smile, to the audience in a serious tone: "I used to be the next president of the United States of America." This opening sequence lasts about four minutes, until the film's title appears; it constructs Gore's image and credibility for the forthcoming demonstration.

The first hour shows Gore explaining how the climate went out of control in just a few years. Graphs, photographs, data, short films, and anecdotes are shown. From the beginning, the film mentions a national disaster from 2005, Hurricane Katrina in New Orleans, as a patent case of a tragedy that was not considered very important by the U.S. Government. At some point in the argument, these terrible events in New Orleans are presented as the direct consequence of the global warming. It also explains that the administration in Washington, D.C., does not seem to be fully aware of the danger of global warming to U.S citizens.

Among many facts, mixed with some personal memories, Gore mentions his admiration for his former professor at Harvard, Roger Revelle (1909–91), who in 1957–58 was already doing research and teaching about climate change, with the help of his partner Charles David Keeling. Both men are seen as the pioneers in the research and measures related to global warming. Gore recalls he was in Revelle's class in the mid-1960s; later, in the mid-1970s, when sitting in Congress, Gore wanted to bring his former professor Roger Revelle in as an expert to explain his position, during a congressional hearing about the climate.

One famous scene is when Gore wants to show his audience the exceptionally high level of carbon dioxide concentration, but he is not tall enough to point out the curve on the board. He also shows two variables on another graph, which he analyses in his own terms: "When there is more carbon dioxide, the temperature gets warmer." He adds that the string of big hurricanes occurred the same year the United States had an all-time record for tornados. But at some point, Gore brings the debate into another field, far from science and data, arguing that "Ultimately this is really not a political issue so much as a moral issue. If we allow that to happen, it is deeply unethical."

After the first hour, the movie introduces stronger images: for instance, the floods and droughts in Asia, Darfur, and Niger; Lake Chad, which dried up; or permafrost thawing in the Arctic. Many countries face the consequences of climate change, and the two poles are changing as well: the problem is worldwide. However, Gore does not pretend to be a scientist; he keeps a distance between the academic world and himself, for instance, when he "translates" into lay terms the fact "that Earth's climate is a nonlinear system," Gore adds that this is "just a fancy way they have of saying that the changes are not all gradual."

Throughout the movie, Gore also brings up lessons from history, quoting other repeated warnings that were not widely heeded, such as those of Winston Churchill in the 1930s about the Nazi threat. He adds, "…there had been warnings that hurricanes would get stronger." There was alarm as well about the dangers of cigarette smoking in the 1960s, although some skeptics used to pretend there was no danger. This last example about tobacco is used again later in the film, and transposed to illustrate how opponents often try to transform the evidence made by clear facts into a useless debate, in this case about the real existence of global warming.

The film concludes with the explanation of its title, when Gore shows how many people who deny climate change, sometimes identified as the "so-called skeptics," often raise doubts with feeble arguments, sometimes because they are influenced by powerful lobbies, either oil companies or energy producers. Gore compares them to scientists who used to serve in totalitarian regimes or communist countries, who could not enjoy free speech in presenting scientific opinions. In other words, their scientific conclusions were in contradiction with the official discourse and dominant ideologies, and therefore, raised more questions than answers, and had to be silenced.

The final images carry a touch of hope, given past gains: in sum, many challenges in the past such as slavery, Apartheid, and even the hole that was found in the ozone layer above the North Pole have been resolved. Therefore, the narrator calls for citizen involvement and a stronger advocacy for environment. When the film's credits are rolling, positive messages of good will such as "Recycle," "Speak up in your community," "Call radio shows and write newspapers," "Try to buy a hybrid vehicle," and "Encourage everyone you know to watch this movie" appear. Although some U.S. presidents such as Ronald Reagan and George H.W. and George W. Bush are portrayed as not acknowledging the facts of climate change, the Clintons are not shown anywhere in the film (except for a few seconds, when George W. Bush becomes the new president in the presence of President Bill Clinton and other guests).

REPUTATION

More than two decades before its release, *An Inconvenient Truth*'s lesser-known precursor was *If You Love this Planet* (1982), a short film by Terri Nash about nuclear dangers. It was so impressive it was even labeled in the United States as "political propaganda." It was also a documentary based on a lecture similar to a slide show, given to a university audience by Dr. Helen Caldicott (at State University of New York at Plattsburgh), with stock-shot images showing the consequences of the nuclear bombings in Hiroshima in 1945. Similarly, *If You Love this Planet* was also the winner of the Academy Award for Best Documentary (in 1982).

Other films that have created or fed public debate about environmental hazards include Roland Emmerich's *The Day After Tomorrow* (2004), which depicted a catastrophic global warming scenario. A Canadian documentary titled *The Refugees of the Blue Planet* (co-directed by Hélène Choquette and Jean-Philippe Duval in 2006) focuses on people around the globe who have had to move because of climate change. However, none of these had a social impact like *An Inconvenient Truth*, which was even presented in universities and colleges, mainly for debates in social sciences courses.

An Inconvenient Truth received countless reviews and criticisms; it brought the issues of global warming and climate change to a wider audience, especially in high schools. In Canada, the film was offered for free in some video rental stores by owners who believed the film had to be seen by everyone; in this case, the environmental cause seemed more important than profits from rentals. It is one of the few DVDs sold on the Amazon.com website that got more than 1,000 reviews.

However, some critics were perplexed, especially by the use of the term *truth* in the movie, because the whole issue is part of an ongoing debate. For instance, in the Canadian newspaper the *National Post* on May 19, 2007, Kevin Libin explains that the "Al Gore movie is too one-sided to be taught as fact"—most students who watch the movie in class cannot find two sides of a debate in the film. In fact, Libin's article gathered most of the previous criticisms that were expressed about *An Inconvenient Truth*. Libin wrote that most scientists do not agree with Gore on the predictions related to climate change, and some terms such as *science, facts, truth*, and *global warming*, do not have a single definition. Furthermore, schoolchildren are seen as too "credulous" to challenge the film's message.

Some Canadian academics, such as Professor Tim Patterson (from Carleton University), would even label this movie as "propaganda." Thus, some opponents argue that the documentary *An Inconvenient Truth* should not be used as a tool for environmental education because it is not neutral. On the other hand, other critics argue that *An Inconvenient Truth* illustrates what has become "politically correct" in the debate surrounding global warming, or could provide "facts, arguments and bullets" for anti-American ideologies linked with environmental issues. But Gore had already addressed his potential critics in his film, when referring to the "so-called skeptics." Some Republican voters have identified the film with the Democrats.

Despite its critics, *An Inconvenient Truth* was seen by millions and won two Oscars in 2007: one for the Best Documentary Feature, and a second Academy Award for the Best Achievement in Music Written for Motion Pictures (Original Song) given to singer Melissa Etheridge for her theme song "I Need to Wake Up," which plays during the final credits. The film *An Inconvenient Truth* was subsequently translated (in subtitled or dubbed versions) in many languages. Its DVD version gave an even wider audience to what was seen in the beginning as "just a slide show." The international success of *An Inconvenient Truth* proves that whenever scientific debates are brought to a wider audience in the public sphere, science itself can become an issue linked with many other debates: social, ethical, economical, environmental, and political. On Friday, October 12, 2007, Al Gore and the Intergovernmental Panel on Climate Change were given the Nobel Peace Prize for 2007, from the Norwegian Nobel Committee, with a medal and award of $1.5 million.

SEE ALSO: Clinton Administration; Global Warming; Gore, Albert, Jr.; Media, TV; Public Awareness.

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Antarctic Circumpolar Current

THE ANTARCTIC CIRCUMPOLAR CURRENT (ACC), also known as the West Wind Drift, is the only current that flows completely around the globe, unimpeded by continents. Famous explorers have often referenced the ACC in their navigational logs, including Edmond Halley (the first to note the ACC in a 1699–1700 voyage), James Cook, James Clark Ross, Sir Francis Drake, James Weddell. The ACC is notably the roughest sea crossing for navigators, particularly the 497 mi. (800 km.) wide Drake Passage extending around Cape Horn and the Antarctic Peninsula. The role of the ACC as "mixer of the deep oceans" also has a significant impact on global climate.

The ACC, as the name implies, flows around the continent of Antarctica in an eastward direction driven by westerly winds through the Atlantic, Indian, and Pacific Oceans. The ACC is as deep as 6,562–13,123 ft. (2,000–4,000 m.) and as wide as 1,243 mi. (2,000 km.), accounting for the vast transport of waters despite its relatively slow eastward current. It is estimated that some of the seawater of the ACC travels the entire circumference of the globe (24,900 mi.) in a mere eight years. For comparison, the ACC carries 150 times more water around Antarctica than flows through all of the world's rivers combined.

While flow of the ACC is not blocked by any landmasses, it is severely constrained by them. The borders of the ACC are further defined by convergence fronts with significant temperature and salinity variability. The greatest temperature change is north of the ACC in the Subtropical Convergence (Front), where the average sea surface temperature decreases from 54 degrees F (12 degrees C) to 45–46 degrees F (7–8 degrees C) in the ACC and salinity decreases from 34.9 or greater to 34.6 or less.

The southern boundary of the ACC is defined by the westward flowing Antarctic Coastal Current with a surface temperature around 30 degrees F (minus 1 degree C). Mean ACC temperature ranges from 41–30 degrees F (5 to minus 1 degree C). Climate change and ocean warming will likely have a significant effect on the ACC, because of this typically narrow temperature range. Any otherwise small increases in sea surface temperatures may induce dramatic effects on the system.

EFFECT ON THE CLIMATE

The ocean water temperatures of the ACC and the southern oceans play a critical role in the climate of the rest of the planet. Scientists have found that the ACC controls the climate of Earth in three ways. First, the ACC connects the world's major oceans (Atlantic, Pacific, and Indian), resulting in the redistribution of temperature and salinity. Changes in sea surface water temperatures can have severe impacts on regional weather patterns. Second, the vertical circulation of the waters of the ACC renews the deep waters of the world's oceans. This occurs as the waters freeze during the Antarctic winter and warm during the summer. The cooling of the surface waters during freezing increases the density of the water, causing it to sink, and dragging life-sustaining physical (heat and nutrients) and chemical (gases) resources from the surface to the depths, up to 2.5–3 mi. (4 or 5 km.) below the surface).

And, third, due to the vast size of the ACC, it contributes significantly to gas exchange with the atmosphere. It is estimated that the oceans contain 50 times the levels of carbon as the atmosphere on average, and the oceans act as a carbon sink, drawing carbon dioxide (CO_2) out of the atmosphere. CO_2 is produced by the burning of fossil fuels and deforestation and has been identified as a greenhouse gas. The ocean removes approximately half of the 6–7 billion tons of carbon that are released annually into the atmosphere.

MIXER OF THE DEEP OCEANS

The ACC is referred to as the ocean's mixer. The center of the current is the Circumpolar Deep Water. This water is a mixture of deep water from all of the world's oceans. The upper areas of this water are oxygen poor, where deep waters have been brought toward the surface by vertical circulation. The deeper waters are typically very saline, with primary sources in the Mediterranean Ocean (via exchange with the Atlantic). In the ACC, these "extreme waters" mix with waters from all of the oceans, including waters that are more oxygen rich and less saline, concomitantly forming a more uniform composite. This mixture is then redistributed to all of the world's oceans by the ACC, driven by wind, replenishing the deep waters and increasing overall ocean productivity.

Regionally, shifts in the ACC relocating warmer and colder waters can cause severe weather changes in those areas. While few landmasses are directly impacted by ACC contributions to weather patterns, these currents are carried far north, directly affecting some of the world's most populated areas. Further, organisms within the ACC are dependent on the stability of currents and temperatures in the ACC surface waters. Included in this are microorganisms, algae, phytoplankton, zooplankton, fish, and migratory species, including whales.

Warming of sea surface temperatures beyond the narrow range of 30–41 degrees F (minus 1 to 5 degrees) C will affect primary productivity (phytoplankton growth rates) in addition to survival, growth, and reproduction of all food web species. Researchers are most interested in the interaction of the ACC with the ice system of Antarctica (drift ice and the Antarctic Ice Sheet) and the global atmosphere. Knowing more about the transport of temperature and salinity by these waters will provide greater insight into climate modeling and predicting future climate conditions on Earth.

SEE ALSO: Antarctic Ice Sheets; Intertropical Convergence Zone; Modeling of Ocean Circulation; Oceanography; Sea Ice; Sea Water, Composition of; Thermohaline Circulation; Wind-Driven Circulation; Winds, Westerlies.

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Antarctic Ice Sheets

ICE COVERS MUCH of the polar regions of Earth, and is a critical component to the planet's climate. An ice sheet is defined as a mass of ice that is greater than 31,067 mi. (50,000 km.) in area, such as those of Antarctica and Greenland. Ice sheets should not be confused with ice caps, which are masses of ice covering less than 31,067 mi. (50,000 km.) in area. It is estimated that approximately 90 percent of the Earth's total ice mass, or 27 million cu. km., is located in the Antarctic Ice Sheet. Scientists are concerned that increasing temperatures of air and sea will cause significant melting of the world's ice, including the Antarctic Ice Sheets, causing sea level rise.

Ice sheets, glaciers, ice caps, permafrost, snow, and sea ice are all components of the Earth's cryosphere (portions of the Earth's surface that are frozen over land or water). In the Southern Hemisphere, the Antarctic Ice Sheet covers approximately 98 percent of the Antarctic continent and is the single largest mass of ice on the planet. Ice sheets form as snow and frost build up in an area, compressing the previously fallen snow into ice. The total area of ice sheets is changed regularly by melting, primarily where the ice comes into contact with water or warmer dry land at its base, and by calving, or the falling off of large pieces of the ice sheet, which become known as icebergs. The Antarctic ice sheet covers the major landmass of the continent in the eastern Antarctic and extends over the ocean in western Antarctica. In western Antarctica, the ice sheet is as deep as 8,202 ft. (2,500 m.) below sea level.

The Antarctic continent is cold year round, and is extremely dry (desert; little to no annual precipitation). Because of this, the Antarctic ice sheet has historically experienced very little melting from the surface. Typically, the summertime melt that is experienced by the ice sheet is focused around the northern Antarctic Peninsula and the northeasternmost regions of the ice sheet. Most ice from the Antarctic ice sheet is lost by calving of glaciers from the protruding ice shelves of the sheet.

With climate in a constant state of flux on Earth, scientists have begun to give considerable attention to the warming trends that appear to exceed normal climate oscillations. While gradual melting and refreezing of ice is common anywhere on Earth, sudden large-scale melting of the polar ice sheets may have significant implications for local and global ecosystems. It is believed that the interaction of warming ocean waters and increasing air temperatures is contributing to the thinning and breaking up of the ice sheets. This disturbance of the ice sheets, and glacier tongues (extension of glaciers projecting seaward, typically afloat), primarily in western Antarctica at the ocean interface, has increased floating ice (drift ice), changing the ecosystem structure of this sensitive region. Long term, such disturbances may have a significant impact on macro-fauna, such as seals and whales, which are dependent on the ice sheet–water interface for feeding.

The contribution of melting ice to seawater will have a multitude of effects on global climate. While natural fluctuations of sea level do occur from gradual melting and thermal expansion, mean sea level has been on the rise in recent years. Data show that 1870–2001, mean sea level rose by almost 7.87 im. (20 cm.), whereas 1993–2006 global sea level raised an average of .12 in. (3.1 mm.) per year, or 2.7 in. (4.3 cm.) in 13 years. Experts are concerned that melting of the Antarctic ice sheet across its entire surface, not just minimally at the base and edges as is normally seen, accompanied by an increase in calving, may contribute to sea level rise. The Antarctic ice sheet accounts for about 61 percent of all of Earth's freshwater, whereas, together, the polar ice sheets of Antarctica and Greenland account for 98–99 percent of the freshwater ice on Earth. If the Antarctic Ice Sheet were to melt, over the next thousands of years there would be a 183.7 ft. (56 m.) increase in sea level, causing catastrophic scenarios. If the Western Antarctic Ice Sheet (WAIS) alone were to melt, there would likely be a five to six m. increase in mean sea level.

Approximately 150 million people live within one meter of high tide, and 250 million live within five meters of high tide. Melting of glaciers and ice caps is second only to thermal expansion of the oceans as the primary contributors to sea level rise. The immediate effects of melting are submergence and increased flooding of coastal zones. Under current coastal protection scenarios, and with the predicted 40 cm. rise in sea level by 2080, more than 100 million people will be flooded annually.

Beyond sea level rise, experts are concerned that the influx of freshwater to the oceans with the melting of the Antarctic ice sheet will significantly alter the salinity and temperature of the oceans, causing unpredictable effects on the ecosystems in this region. Such changes are known to affect the evaporation of the oceans to the atmosphere, potentially altering the precipitation events that contribute to the build up and maintenance of the Antarctic ice sheet. However, this rise in sea level will also force more saline waters further inland than has been experienced in recent times, flooding mangroves and coastal flood lands with seawater.

The breakup and collapse of the Larson B ice shelf, in 2002, off of the northern Antarctic Peninsula drew worldwide attention to the thinning and melting of the polar ice sheets. Experts report from sediment core records that a breakup of the ice sheet of this magnitude was unprecedented since the last Ice Age. Over the last 100 years, nine ice shelves around the Antarctic Peninsula have broken up. Reports by the National Aeronautics and Space Administration (NASA) indicated in 2002 that the overall mass of the Antarctic Ice Sheets were on the increase. Since then, satellite data compiled at the University of Colorado at Boulder suggests that, to the contrary, the amount of ice in Antarctica is actually decreasing.

SEE ALSO: Climatic Data, Ice Observations; Glaciers, Retreating; Glaciology; Little Ice Age; Radiation, Ultraviolet; Sea Level, Rising; Vostok Core.

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Antarctic Meteorology Research Center

THE ANTARCTIC METEOROLOGY Research Center (AMRC) is part of the Space Science and Engineering Center (SSEC) at the University of Wisconsin–Madison's Graduate School. The AMRC collects most of its data from automatic weather stations. The center is funded by the National Science Foundation to make available daily composite images from weather satellite data. AMRC also monitors icebergs and has tracked the large iceberg B-15 since it calved in March 2000.

The AMRC was established in the 1992–93 austral summer season and initially consisted of work stations able to organize and display Advanced Very High Resolution Radiometer data, based on the existing satellite imagery acquisition system. This was followed by the acquisition and integration of a system that provided data collection, data display and archiving, scientific applications, network communications, and remote user access. The AMRC runs the Automatic Weather Station Project, which places automatic weather station (AWS) units in remote areas of Antarctica in support of meteorological research and operations. The AWS data are recorded by the ARGOS Data Collection System (DCS) on board the National Oceanic and Atmospheric Administration (NOAA) series of polar-orbiting satellites.

Antarctica is the highest and coldest continent in the world. 97 percent of its territory is covered with ice with an average elevation of 2,300 meters and an average annual temperature of minus 31 degrees F (minus 35 degrees C). Since large portions of Antarctica are difficult to reach regularly by humans, the idea of an automated system appealed to many, and thus the AWS project was born. Maintaining staffed sites for collecting meteorological observations was considered too expensive. An automatic weather station would allow the gathering of important weather information without having to have a person on duty at each site.

DATA COLLECTION

These stations have proven to be an invaluable resource for researchers and forecasters, as well as the public for the retrieval of important meteorological information about the Antarctic. At the end of the 2003–04 field season, just under 60 stations were operational in the Antarctic. Three new sites, Wanderer, Vito, and Emilie were added during the 2003–04 field season. As of 2004, Amundsen-Scott Station at the south pole was the only year-round interior station in Antarctica with personnel. The remaining year-round stations are located on the Antarctic coast at sites that can be reached by ship.

Charles R. Stearns, the principal investigator and founder of the AMRC, was the man behind the AWS. A renowned polar researcher for over two decades, Stearns began the AWS project at the University of Wisconsin in 1980 by purchasing the first AWS designed at Stanford University. These stations were then modified for transfer on location in Antarctica. The purpose of the AWS's was to allow for the first meteorological data to be acquired for the continent. The data from the AWS systems are transferred back to the University of Wisconsin for processing and distribution to the public free of charge. The weather stations are 10 feet tall and are equipped to record temperature, humidity, air pressure, and wind speed and direction. The cost of each station is approximately $15,000.

The automatic stations were mounted onto the frozen water of an iceberg or ice sheet and also include a global positioning device to track their migration with the ice. In addition to the 50 stations which are part of the University of Wisconsin's network, there are others that are used for research programs at British, French, German and Japanese sites. The AMRC stresses that the project entails a great degree of international collaboration and cooperation. After processing the temperature readings and barometric levels collected by the stations, the AMRC passes them on to international weather labs and researchers. The Man-Computer Interactive Data Access System (McIDAS) is a versatile computer-based system developed by the University of Wisconsin that is the basis of AMRC. It allows the organizing, manipulating, and integrating of environmental data. It receives the flow of Antarctic meteorological information from polar-orbiting satellites, automatic weather stations, operational station synoptic observations, and research project data.

The real-time data used to forecast also can be used to develop accurate forecasting models for future climate change. Computer programmers integrate these data into equations and design programs to predict climate change phenomena, such as global warming. It was thanks to the data collected by the automatic weather stations that the center was able to conclude that El Niño, which contributes to the warming up of the tropics, also extends its effects to the Arctic region.

The position of the AMRC and its staff with regards to iceberg breakage and global warming has been to deny a clear connection between the two. In 2002, it became apparent that another massive iceberg had broken off from the Ross Ice Shelf, reducing the Antarctic formation to about the size it was in 1911 when explorer Robert Scott's team first mapped it. Yet, through Stearns and other researchers, the AMRC stated that the breakage is part of the normal iceberg formation or "calving" that comes as thick layers of ice gradually slide down from the high Antarctic plateau, and is not related to climate changes or global warming.

Stearns and his assistant Mathew Lazzara have repeatedly stressed that icebergs break due to natural phenomena, not because of global warming. Admitting that the iceberg detaching in 2002 was unusually large, Lazzara maintained that the phenomenon was entirely natural, although not one frequently witnessed. Lazzara explained that "as the ice shelf develops and gets influences from the ocean it starts to deteriorate where the ice meets the ocean waters. The ocean tides act upon it, causing it to crack and wearing it away. The ocean currents and the tides are responsible for getting it going and putting it into motion." Charles Stearns explicitly denied that global warming was a factor in the break off and concluded that the piece of iceberg might have been in motion for the past 30 years: "Climate change is not a factor in the break off, although people try to use the event to further their objectives. If the ice did not flow off Antarctica, all the water in the oceans would be deposited there. Be glad that all the water in the world does not collect on Antarctica."

SEE ALSO: Antarctic Circumpolar Current; Antarctic Ice Sheets; Climatic Data, Ice Observations; Climatic Data, Instrumental Records; Modeling of Ice Ages.

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Anthropogenic Forcing

ANTHROPOGENIC FORCING IS one of two parts of radiative forcing in the classification used to describe disturbances in the Earth's energy budget when humans are considered as a factor to the Earth's climate system. The radiative forcing (in units of watts per m. squared) is the net downward radiative flux at the surface or at some level in the atmosphere, usually at the top of the atmosphere or at the tropopause. In atmospheric and climate sciences, the radiative forcing is used to predict surface climate response and for comparative studies of different forcings. A synonym for anthropogenic forcing is human-induced forcing. The other part of radiative forcing is natural forcing, which is a disturbance of the Earth's energy budget without human direct or indirect influences. Examples of natural forcing are volcanic eruptions, solar variability, or changes in a space object's orbital parameters.

Anthropogenic forcing is a change in the Earth's energy balance due to human economical activities. Human economical activities cause changes in the amount of atmospheric radiatively active gases; in the amount of gaseous precursors of atmospheric aerosols and atmospheric ozone (O_3), and in the Earth's system's albedo. Radiatively active gases, such as carbon dioxide (CO_2), methane (CH_4), nitrous dioxide (N_2O), and chlorofluorocarbons (CFCs), are mixed well in the atmosphere, while O_3 and atmospheric aerosols have regional structures due to their shorter turnover (lifetime) in the atmosphere. Changes in the radiatively active gases' atmospheric concentrations are accounted for by changes in the their emissions. Changes in O_3 and atmospheric aerosols are defined by emissions of their gaseous precursors. Changes in Earth's system's albedo are related to changes in land-use practices, reflective aerosols emissions, and changes in cloud cover due to air pollution and climate change.

It is assumed that changes in radiatively active gases, aerosols, and the Earth's system's albedo due to natural causes are small in comparison to changes from human economical activities. The unique radiatively active gas is an atmospheric water vapor, which has both direct (via irrigation and land use) and indirect (via change in cloud cover) influences from human economical activities. The phrase *greenhouse gases* combines radiatively active gases, O_3, and water vapor in one class. For policy applications, the total of atmospheric radiatively active gases is represented by an equivalent amount of CO_2.

Regional and temporal anthropogenic forcing strength can be calculated using an approach that requires estimation of a few parameters: the radiative forcing per unit emitted quantity (usually in watts per square m. per mass), an emission factor (usually in mass per unit of human economical activities), and a quantity of a particular human economical activities per unit time. Rigorous anthropogenic forcing estimation is difficult, as it carries uncertainties from every step of its calculation. Each step is based on an accuracy of information provided by a particular science: social science in description of social infrastructure of a region or a country, economics for human economical activities quantification in terms of emissions and land use, and atmospheric and climate sciences for radiative forcing calculations and conversion of the emissions to the atmospheric concentrations.

Regional anthropogenic forcing estimation is complex. Human economical activities are classified in primary, secondary, and tertiary industries. Primary (agriculture, forestry, and mining) and secondary (construction and manufacturing) industries are the main direct emitters and controllers of land use. In tertiary industries, the transportation, electricity, and gas suppliers are the main air polluters. Population, wealth, leadership, and technology are factors that define specification of the human economical activities by region.

A desirable goal for constructing accurate anthropogenic forcing estimates and projecting them into the future is to define a set of main pathways from a particular human economical activities to anthropogenic forcing, which takes into account all direct (emissions—forcing) and indirect (emissions—climate system—forcing) influences and resolves feedback loops in the Earth's system on the time scale much smaller than the period chosen for anthropogenic forcing estimation. When only the global or hemispheric changes in radiative forcing from the pre-industrial time to present are taken into account, calculation of anthropogenic forcing is based on assumptions of how the radiative forcing depends on the historical evolution of each radiatively active gas or precursor concentration or their emissions. For example, because CFCs have low concentrations in the atmosphere, their radiative forcing increases linearly with concentration.

These assumptions are derived from the numerical models, which accurately calculate the atmospheric distribution of the radiative fluxes for small temporal and spatial variations in each radiatively active agent. For aerosols, as they stay in the atmosphere only for a short time and have a large spatial variability in concentrations and radiative properties, estimation of their radiative forcing is based on inverse modeling, when the radiative forcing is constrained from aerosols' hemispheric asymmetry and observed temperature record, and on aerosols models built from the first principles. It is assumed that the total radiative forcing is a simple sum of its parts.

According to radiative forcing calculations, anthropogenic radiatively active gases make the largest warming contribution to changes in anthropogenic forcing from pre-industrial times. The contribution from the anthropogenic aerosol and land use is very uncertain in magnitude and patterns. Except for black carbon, most of the aerosols have a cooling effect. The indirect effect of the aerosols is larger than its direct effect. The contribution from airplane contrails is small.

SEE ALSO: Albedo; Energy Balance Models; Radiative Feedbacks.

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Anticyclones

ANTICYCLONE IS A term for a region of closed circulation of air in the troposphere (the lowest 6 mi. [10 km.] or so of Earth's atmosphere) with descending air from aloft and high atmospheric pressure at the surface. Anticyclonic circulation is usually accompanied by relatively high atmospheric pressure at the surface, and so the term *high* is often used interchangeably with *anticyclone.*

Anticyclones, as the name suggests, are the opposite of cyclones, which are regions of low pressure and typically associated with clouds, precipitation, and storms. On a surface weather map, meteorologists often denote anticyclones with a capital letter "H," and cyclones by a capital "L." Unlike cyclones, anticyclones are not usually associated with weather fronts. Anticyclones are sometimes referred to as ridges of high pressure. This is not quite accurate, as an anticyclone is a closed circulation and a ridge is not, but both are associated with regions of high surface pressure.

Anticyclones are typically characterized by descending air, high surface pressure, clear skies, and calm winds. In the mid-latitudes, anticyclones and cyclones are transient eddies steered by the westerly wind belt at the boundary between warm tropical and cold polar air masses. In subtropical and polar regions, anticyclones are semi-permanent features of the general circulation of the atmosphere, associated with some of the world's major arid regions.

The descending air associated with an anticyclone suppresses convection, and causes the air to become warmer and drier through the process of adiabatic heating. As a result, the weather associated with an anticyclone is generally fair skies and clear weather, with relatively high pressure at the surface. The circulation of surface winds around an anticyclone rotation is outward from the center of high pressure, and is deflected by the Earth's rotation. The result is a clockwise spiral outward from the center of high pressure in the Northern Hemisphere, and counterclockwise in the Southern Hemisphere. This difference is the result of the difference in the direction of motion deflection by the Coriolis effect in each hemisphere—to the left of motion in the Southern Hemisphere, and to the right in the Northern Hemisphere.

In the mid-latitudes of both hemispheres, cyclones and anticyclones are transient features that develop and dissipate as embedded eddies in the Rossby (or planetary) waves of the westerly wind belt, steered generally from west to east by the polar jet stream. Regions in which anticyclonic circulation is a primary, semi-permanent feature of climate (persistent and dominant), such as the subtropical highs, are associated with some of the world's great deserts such as the Sahara in Africa, the Atacama in Peru, and central Australia.

Historically, ocean regions at subtropical highs were described as the doldrums or horse latitudes, becalmed areas in which mariners might find themselves stranded at sea for extended periods. In extreme cases, mariners would be forced by food and water shortages to either eat or jettison the horses aboard, thus the horse latitudes. The polar regions are also areas in which persistent anticyclones, or highs, dominate general circulation. The Siberian High is an example of a semi-permanent, high-pressure region that significantly affects climate in the high northern latitudes of Europe.

Changes in climate resulting from anthropogenic emissions of greenhouse gases will likely affect patterns of global general circulation and influence the development of high and low pressure systems. The consequences of global climate change on anticyclones are challenging to predict in detail. Increased persistence and development of anticyclones would enhance warm, dry conditions, thereby increasing the risk of droughts, heat waves, and forests fires.

SEE ALSO: Climate; Coriolis Force; Cyclones; Doldrums; Jet Streams; Trade Winds; Tropopause; Waves, Rossby; Winds, Easterlies.

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Antigua and Barbuda

ANTIGUA AND BARBUDA, located in the Caribbean, are part of the chain of islands known as the Leeward Islands. The two main islands of Antigua and Barbuda have, respectively, land areas of about 100 sq. mi. (281 sq. km.) and 57 sq. mi. (161 sq. km.), with a total population of 82,786 (2005 est.), the vast majority of whom live on the island of Antigua, with the island of Redonda, which is currently uninhabited, having dependency status. Antigua and Barbuda have a population density of 394 per sq. mi. (184 per sq. km.).

The main environmental problems facing Antigua and Barbuda are hurricanes and tropical storms from July through October, and irregular droughts. In terms of carbon dioxide per capita, Antigua and Barbuda rank 78th in the world, with 4.8 metric tons of carbon dioxide per capita in 1990, and the amount falling and rising slightly until 2003 when the country exceeded its 1990 figure, recording 5 metric tons per person. In recent years, there has been a steady bleaching of coral reefs near Antigua, with the rising temperature of the waters also affecting the diversity of fish in the coral reefs. It is also expected that with the rising sea level, parts of Antigua and Barbuda that are low-lying could be flooded.

Antigua's role in global warming is related to its tourist industry. This is both in terms of the flights to and from the country taken by tourists, often from distant locations, and also the heavy demand the tourists make on the infrastructure of the island in terms of power (most of which is produced through using liquid fuels) and water usage, as well as increasing the amount of imported food and produce on the island. To try to offset this, there have been proposals since the mid-1980s to try to harness wind energy.

To combat climate change and global warming, the government of Antigua is a party to the Kyoto Protocol to the United Nations Framework Convention on Climate Change, having signed it on March 16, 1998, and ratifying it on November 3, 1998. On June 4, 2007, W. Baldwin Spencer, the prime minister and foreign minister of Antigua and Barbuda, in his speech to the 37th Session of the Organization of American States Assembly in Panama City, urged that greater action should be taken in the world to confront climate change. Antiguan delegates have also taken part in raising the issue of climate change and global warming at other international forums. However, some have challenged Antigua's environmental status under the government of Vere Bird and his son Lester Bird because Antigua traditionally votes with Japan on the International Whaling Commission (against the protection of whales), and has done little to reduce the heavy reliance on tourists using air travel.

SEE ALSO: Hurricanes and Typhoons; Tourism.

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APPLIED ENERGY SERVICES, INC. (AES) is a global power company providing energy to five continents (all but Australia and Antarctica). Since its founding in 1981, AES has expanded globally with a purpose of bringing safe electric power to people, including those who have never before had access to it. To this end, the company uses the slogan *The Power of Being Global*. The first AES power plant was built in Texas in 1985; the AES power plant cadre subsequently increased to four U.S. plants by 1989. Three additional plants were constructed in California, Oklahoma, and Pennsylvania.

Within the next decade, AES had expanded its business into the global market, supplying power to Argentina, Brazil, China, Hungary, Pakistan, the United Kingdom, and other countries. AES was the first U.S. power company to provide service to China. Further expansions included Bulgaria, Cameroon, Oman, Qatar, Sri Lanka, West African, and Central American nations. In 1988, AES, in partnership with other companies, became a member of the only privatized power generator in India.

AES is researching cleaner forms of energy, such as wind and solar power, and other means of environmental protection. Two decades after building its first U.S. power plant, the first AES wind farm was built in Texas, in 2006. The European countries of Bulgaria, France, and the United Kingdom also boast new AES wind farms. AES may also expand into liquefied natural gas. AES is also a partner with United Kingdom–based AgCert in AES AgriVerde, a coalition dedicated to reducing greenhouse gas emissions by tens of millions of tons per year, by the year 2012. Additionally, through other environmentally conscious endeavors, including capturing methane released by power generation reactions, the company plans to further reduce emissions by equivalent values. The power plants that participate in the emissions reductions are selected plants from Africa (northern), Asia, and Europe.

In the late 1980s, AES spearheaded a 10-year campaign to plant 52 million trees in Guatemala. The company is also reforesting an area along Brazil's Tiête River with native plants. In addition, since 1999 AES has invested more than $150 million to reduce emissions in coal-fired New York power plants that. At AES Greenidge, located in Dresden, New York, researchers investigate cleaner methods for harnessing power from coal. In Africa, Europe, and Kazakhstan, AES manages 24 power plants, employing more than 14,000 people. A total of 13 generation plants employing nearly 700 people supply Asia and the Middle East. Central and South America combined have 48 AES generation plants, with 10,000 employees. Finally, North America houses 33 power plants that employ more than 3,000 people.

An executive office, led by a president and chief executive officer, manages AES. An executive vice president manages each of the four regions in which AES provides power. There are also officers leading the AES divisions of Alternative Energy; Business Excellence; Communications; Energy and Natural Resources; Finance; Forecasting, Strategy and Risk Management; and Legal. Additionally, AES has a board of directors, with four standing committees. Members of these committees work to guide the company in the areas of Compensation; Finance and Investment; Financial Audits; and Nominating, Governance, and Corporate Responsibility. In the AES company guidelines, corporate responsibility is a global responsibility to provide safe, reliable, and responsible energy to all its recipients.

SEE ALSO: Alternative Energy, Overview; Emissions, Baseline; Energy; Energy, Renewable.

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Arakawa, Akio (1927–)

AKIO ARAKAWA HAS been a leader in the field of atmospheric general circulation model (AGCM) development from its beginning. AGCMs are essential tools for studies of global warming and projecting the consequences of anthropogenic climate change. Arakawa's inventiveness and extraordinary insight on atmospheric processes have resulted in fundamental contributions to the design of AGCMs in several areas, primarily: 1) numerical schemes suitable for the long model integrations required by climate studies; 2) modeling of cloud processes including cumulus parameterization; and 3) modeling of planetary boundary layer (PBL) processes. His work has influenced the design of practically all numerical weather and climate prediction models.

Arakawa obtained his B.Sc. in physics and D.Sc. in meteorology from the University of Tokyo in 1950 and 1961, respectively. From 1961 to 1963 he visited the University of California Los Angeles (UCLA) and worked with Yale Mintz on developing the Mintz-Arakawa AGCM, the first among several generations of what would be the UCLA AGCM. Versions in each generation (currently the VII) have been made available to other institutions for further development and application. In 1965, Arakawa joined the faculty at UCLA, where he is currently Professor Emeritus and Research Professor.

In AGCMs the governing equations of fluid motion are written in a format suitable for numerical integration with a high-speed computer. The format used is particularly important in long-term integrations, since inadequacies can result in distortion of the solutions and unrealistic amplifications of kinetic energy. Arakawa designed elegant numerical schemes in which such unrealistic amplifications cannot occur and distortions were reduced. The schemes guarantee that flow properties constrained to be either constant or bounded in the continuous equations remain so in the corresponding expressions numerically solved by the computer. In this way, he derived the Arakawa Jacobian in late 1961, which was followed over the years by the derivation of families of numerical schemes for AGCMs.

The most widely influential of Arakawa's works in the context of global warming and climate change has been the parameterization for AGCMs of the effect of clouds generated by convection. The parameterization problem consists of formulating the collective effect of processes not resolved by the model grid in terms of the resolvable-scale prognostic variables, and is a crucial part of general circulation modeling. Arakawa struggled with the cumulus parameterization problem for several years. The breakthrough came in collaboration with his graduate student Wayne Schubert during the early 1970s. The basic tenet in the Arakawa-Schubert parameterization is the approximate cancellation (quasi equilibrium) between destabilization of the atmosphere by large-scale processes and stabilization by convection. Arakawa and several of his students would later refine the original formulation. The parameterization is still used today in different versions, including the Relaxed and Simplified Arakawa-Schubert schemes (RAS and SAS, respectively).

Arakawa has also made major contributions to the parameterization of PBL processes. These determine the complex interactions between the atmosphere and Earth's surface and as such must be represented correctly in climate models. PBL processes, however, are dominated by turbulent transport and mixing, which AGCMs in general cannot explicitly resolve. Furthermore, the PBL can be topped by stratiform clouds, which are also difficult to explicitly resolve. Errors at the surface due to misrepresentations of PBL cloud effects can spuriously amplify due to feedbacks, particularly over the ocean.

For the parameterization of PBL processes, Arakawa adopted a unique framework based on including a variable depth PBL in the model, which becomes the lowest layer in the UCLA AGCM generation IV. The PBL depth is explicitly predicted using the mass budget relationship, in which mass at the top can be added through turbulence processes and removed by cumulus mass flux for given large-scale conditions above the PBL. The latter term can be provided by the Arakawa-Schubert cumulus convection parameterization. In this way, interactions between PBL and cumulus convection processes can be modeled.

The increased power of computers has challenged the unambiguous separation between resolvable processes, which can be highly transient, and parameterized unresolvable processes, which can only be near a statistical equilibrium. Arakawa is currently working on the unification of those formulations and the reduction of the artificial dependency of model physics on grid size.

SEE ALSO: Climate Models; Climatic Data, Atmospheric Observations; Global Warming.

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Arctic Ocean

THE ARCTIC OCEAN is one of the Earth's environments that will be most affected by climate change. As the Earth continues to warm, the Arctic Ocean will evolve into an environment that is much different from what is recognized today. Most of the animals currently living there will not be able to survive if this region warms too much. In addition, warming Arctic waters could affect ocean circulation elsewhere in the world.

The Arctic Ocean is unique in its physical properties. It has both the narrowest and the widest shelves on Earth due to glacial erosion, marine abrasion, and progradational clastics. It is a tectonically active region in which the closed-off basin of today developed in the Cretaceous (90 million years ago). The seafloor forming at the mid-ocean ridge in the Arctic is the slowest ridge system of any on Earth today.

The Lomonosov Ridge divides the ocean in half, creating the younger and deeper Eurasian (Eastern) basin and the older and larger Amerasian (Western) basin. The Amerasian Basin is divided by the Alpha Ridge into the Makarov Basin to the north, and the Canadian Basin to the south. The Alpha Ridge connects to the Mendeleev Ridge to the north. The Arctic Ocean is approximately 50 percent continental shelf, resulting in much of the sea floor being only 1,640–6,562 ft. (500–2,000 m.) below sea level.

The Arctic Ocean is the most extreme region on Earth in terms of climate and seasonality because of light and ice cover. The ocean covers an area of approximately 14,056,000 km^2 and extends below the Arctic Circle in some locations. The average depth is just over 3,280 ft. (1,000 m.), with the deepest location in the Eurasian Basin at 17,881 ft. (5,450 m.) The Arctic Ocean is surrounded on all sides by land except for narrow connections to the Atlantic and Pacific Oceans. The Atlantic water flows through the Fram Strait (8,530 ft. [2,600 m.] deep), where the largest amount of water flows into the Arctic. The other is from the Pacific Ocean through the Bering Strait, a shallow connection (164 ft. [50 m.]) that has intermittently closed during glacial periods over the past few million years.

The Arctic water column is strongly stratified into three layers: the shallow, relatively fresh surface layer; the intermediate layer; and the deep salty layer. The shallow layer obtains its water predominantly from melting ice sheets, icebergs, and river runoff. Because of its low density, this layer, approximately 9.8 ft. (3 m.) deep, creates a relatively fresh water film that easily freezes. It is because of this film and the freezing temperatures that the center of the Arctic Ocean is frozen year-round. The intermediate layer receives its water from the salty waters of the North Atlantic. The deep water forms through convection and has a very slow exchange with a residence time of 450–500 years (about half that of the world ocean residence time of 1,000 years).

Large amounts of freshwater come from rivers, specifically from the Russian rivers Yenisei, Ob, and Lena, and the Canadian MacKenzie River. Together, these rivers contribute 2,000 $km.^3$ a year of water. This influx of freshwater into an environment that is so cold creates a film of water on the surface because of the density difference and hence freezes solid. During the winter, there is $14x10^6$ $km.^2$ of sea ice, and about half of that in the summer. This number has decreased over the past several years, causing detrimental effects on the climate and resident species. The ice is critical for the heat exchange budget in the Arctic, as well as for sustaining life, from viruses, to polar bears, and subsistence hunters.

Because ice forms and leaves behind salt, during glacial periods the water is more saline due to an increased volume of sea ice. As the ice melts during interglacial periods, the surface layer becomes increasingly fresh, creating a deeper film of fresh water that does not mix with the rest of the water column. During this warmer period, there is more productivity in the surface layer, which allows more food and nutrients to sink to the bottom. It is this relationship between the surface layers and the deep sea that is recorded in the fossil record. The dominant surface productivity is from the phytoplankton that thrive in the summers due to 24 hours of light, and struggle to survive during the winter when there is 24-hour darkness.

MARINE LIFE

The structure of the water column influences biological productivity in the Arctic, making it unique in its biological properties. It hosts animals such as walruses, whales (belugas, narwhals, and bowheads), and seals. Other marine animals include squid, flatfish, Greenland halibut, worms, snails, crabs, shellfish, and krill. Polychaetes, crustaceans, and bivalve mollusks dominate the benthic macrofauna.

Many microscopic animals such as zooplankton, diatoms, copepods, and foraminifera also live in the freezing waters of the Arctic water column (planktonic) and on the sea floor (benthic). The most important primary producers are phytoplankton. However, the growing season is restricted because of the short summer season, low light angles, and the snow and ice cover. The season is between April and September with a single peak, June to July. With the retreating ice on the shelves during these summer months, an algal bloom is possible near shore.

The Arctic deep sea has been widely ignored because of the thick sea ice. Initial studies show little diversity in this area, with a dominance of deposit feeders. Dominant animals include polychaetes, crustaceans, and bivalve mollusks. Occasional tunicates, sponges, cnidarians, ophiuroids, and several species of worms have also been found. Approximately 350–400 species have been found so far in the deep central Arctic Ocean. The long-believed hypothesis that species diversity decreases with higher latitudes is being reconsidered as more species are discovered in the central Arctic. As more research is conducted in this region, the known species diversity is increasing, discounting this outdated theory.

In the Arctic, as in all high latitudes, the food cascading to the bottom of the is the limiting factor for

Many small but important forms of life underneath the ice of the Arctic Ocean still have not been adequately studied.

the benthos, not temperature, as the benthos organisms in the Arctic are adapted to the freezing temperatures. However, they need food for survival and can only obtain it from organic matter produced in the surface waters. In the shallow shelf areas during the ice-free periods, particle transport is abundant. The benthos, therefore, play an important role in the system and production of the Arctic waters.

Although collection of the pelagic organisms has gone on for over a century, many of the taxa are understudied. Only the larger organisms, mostly near shore, are well understood because of their ease of collection. Smaller taxa, deep-water organisms, and the gelatinous forms have been missed by current sampling techniques, therefore, scientists know little about these organisms.

Macro- and megafauna have received the most attention in the Arctic waters, while the meiofauna and microbial communities have been persistently ignored. This is, more often than not, because of sampling techniques and the ease of capture in the ice-filled environment. However, in terms of the quantity of organisms, there are more microbial animals per square meter than there are megafauna. There are still many species of microscopic organisms that have not been identified and further study of the microbial world will enhance knowledge of the Arctic system.

Polar bears also venture into the frozen waters, using floating icebergs as islands on which to rest before venturing onward. With the warming of the Earth and Arctic climate change, these icebergs are not as prevalent as they once were, and the polar bears are having difficulty without these resting places. In addition to the deteriorating climate, there are still many mysteries about marine life, both macro- and microscopic, and how the interaction of these many species sustains an environment that allows life to flourish despite the harsh conditions.

SEA ICE

The Arctic sea ice contains its own unique biodiversity with many endemic species. Specialized sympagic (ice-associated) communities live in brine pockets on top of the ice and in the ice-water interface. Flagellated protists, diatoms, and ice algae account for most of the primary productivity in the ice community. Protozoan and metazoan organisms (in particular turbellarians, nematodes, crustaceans, and rotifers), make up a portion of the ice community. Larvae and juveniles of some benthic animals migrate seasonally into the ice to feed on the algae in shallow waters. All of the organisms that live on and around the ice play a vital role in feeding the benthos. The climate cycle of melting and freezing causes these organisms to fall to the sea floor, creating food for the organisms living on the bottom.

The sediment record left by the sea ice can be used to reconstruct glacial/interglacial cycles. When sea ice and icebergs melt, they drop the ice rafted debris (IRD) that was contained within the ice as it scraped across the land and into the ocean. Sediment with abundant foraminifera and large sediment clasts is deposited during interglacial (interstadial) periods. Sediment that is mostly fine-grained, with few to no foraminifera, is deposited during glacial (stadial) periods. However, the lack of foraminifera in a sediment sample can also be a result of low surface salinity, a decrease in nutrients, dissolution of tests, a high sedimentation rate, or a thick layer of sea ice, causing difficulty in reconstructing glacial cycles.

The perennial sea ice is increasingly thinning, and there is a seasonal hole in the ozone layer over the North Pole. The thinning sea ice is having an effect on global albedo (amount of sunlight absorbed versus reflected back out of the Earth's atmosphere). Ice reflects more sunlight than it absorbs, so it has a cooling effect on the Earth. Without this ice to reflect the sun's rays, more heat will be absorbed, causing the Earth to warm. This causes a positive feedback that will continue to warm the earth, melting more sea ice. This is a concern because the added fresh water to the global marine system could cause a shutdown of the thermohaline circulation through the connection between the Arctic and Atlantic Oceans.

PROBLEMS WITH THE ARCTIC RECORD

The Arctic contains many records of past environments that scientists have used to recreate past climates. Bottom water temperatures can be inferred from calcite pseudomorphs such as ikaite ($CaCO_3 6H_2O$), an organic-rich mineral that accumulates in the sediment. Biomarkers such as algae, dinoflagellates, diatoms, and foraminifera are used for their stable isotopes to infer temperature and salinity over the past several million years. The $^{18}O/^{16}O$ values in these inorganic carbonates reflect sea ice and ice sheet variations through time. These can, in turn, be used to model glacial/interglacial periods. $^{13}C/^{12}C$ values in planktonic organisms reflect variation in productivity or sediment carbon flux from the surrounding continents.

The unique isolation of the Arctic Ocean may be a factor in maximizing the amplitude of some environmental signals in the sediment record. The water column is more strongly stratified than in most other parts of the world. However, throughout history, as the passageways between the Arctic Ocean and the Pacific and Atlantic Oceans opened and closed, this record was modified. Deep ocean waves may have also modified the sedimentary record. As water currents flow around the ridges on the ocean floor they move the sediment and replace it with sediment from other parts of the sea floor. Bioturbation also plays a role in the modification of the sediment record.

Modification of the sediment in the Arctic Ocean creates even more difficulty in reconstructing the history of this basin. The Arctic has extremely low sedimentation rates, so any disruption in the record could potentially create huge problems with dating and isotope analysis. The sedimentation rate is low in the Arctic for several reasons: the major reason is due to the presence of sea ice. It prevents most, if not all, sediment from settling onto the sea floor anywhere that is covered in ice. This, however, is one way that scientists can reconstruct glacial/interglacial cycles. At the beginning of every interglacial cycle, more sediment accumulates because it is dropped from icebergs and sea ice through melting. This can also be seen in the additional sediment discharge from the Arctic rivers.

Collecting enough material for stable isotope and trace element analysis can also be difficult, especially because during glacial periods when sedimentation and productivity are extremely low, there may not be any biological material to collect. During interglacial periods, there is typically enough material; however, in the event of a melt-water pulse or extreme melting, the amount of sediment is much higher than the number of organisms. This makes picking out acceptable specimens difficult. Dissolution is another problem in the Arctic Ocean. In many locations, any calcite will have dissolved before reaching the sea floor without leaving a record to what was present at one time. This also makes comparison across the ocean difficult because dissolution takes places at different times in different areas, creating hiatuses that only appear in certain sediment cores. This is usually caught when material is dated, but the dating of some cores is impossible.

Yet another problem with the oceanic record in the Arctic is the difficulty in getting to it. The field season is short, typically from late July to early October, because of sea ice. Even during this time, an icebreaker is needed to clear a path for ships to pass through, making it expensive and dangerous. Even with an icebreaker, the ice in the central Arctic is too thick to break through, and, therefore, almost impossible to study. Political boundaries also play a role in the scientific study of the Arctic. Seafloor sampling and imaging, especially on the Russian shelves, may be unwanted by foreign governments. This is especially true in areas with natural resources and suspected or known illegal dumping.

As knowledge of this region expands, scientists will gain insight into the dynamics of the past and present world climates. This information can then be used to model future climate changes that will aid in the prediction of how life will need to respond to the changing global climate. However, despite the importance of this region, the Arctic Ocean is one of the least studied places on Earth. Due to the harsh environment and perennial sea ice, this location is difficult to access. The knowledge obtained from sampling is also biased toward effort spent on certain taxa, specific regions, and techniques used for the acquisition of this data. The shallow Arctic shelves are the most studied, especially during the summer months when the sea ice melts back. The Canadian Basin is the least studied because it is covered in ice year round. There is much more that needs to be studied in this complex system of ice, water, land, and life.

SEE ALSO: Biogeochemical Cycles; Climate Models; Climate Sensitivity and Feedbacks; Climatic Data, Ice Observations; Climatic Data, Sea Floor Records; Climatic Data, Sediment Records; Cooperative Institute for Arctic Research; Phytoplankton; Polar Bears; Sea Ice.

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Argentina

THIS LARGE LATIN American country occupies the southeastern part of South America, covering 1,073,514 sq. mi. (2,766,890 sq. km.), with a population of 40,301,927 (2007 est.), of whom some 12 million live in Buenos Aires, the capital, giving the country a population density of 36 people per sq. mi. (13.7 people per sq. km.), although this varies from 14,651 people per sq. km. in Buenos Aires, to 1.4 people per sq. km. in Patagonia. Nine percent of the land is arable, and 52 percent is used as meadow and pasture, especially for cattle. Argentina has the highest per capita number of cattle, at 50,869 cattle per 1,000 people. The heavy reliance on the cattle industry has led to the desertification of some parts of the country, and has contributed to very high methane emissions.

It has been calculated that about 44 percent of the country's carbon dioxide emissions come from the cattle industry or other parts of the agricultural sector, with 70 percent of those from methane from the 55 million cattle. As a result, many of the attempts to reduce the greenhouse gas emissions of Argentina have centered on the cattle industry, with cows from Argentina producing larger emissions than their counterparts in Brazil and Uruguay. The first attempts have focused on trying to change the diet of the cattle on the basis that the simpler the diet, and the less problems in digesting the food, the lower the level of greenhouse gas emissions; this also improves in the reproductive cycle of the animals.

When implemented, these measures are expected to reduce greenhouse gas emissions in Argentina by 10–20 percent. The country is also one of the largest producers of soybeans, the production of which also contributes to the output of greenhouse gases. This is largely because the soybean, when growing, emits nitrous oxide, which is about 300 times stronger than carbon dioxide. The deforestation of some areas to increase soybean production has made the problem worse.

Methane from waste dumps around Argentina has also been identified as a problem, and these are estimated to contribute about 5 percent of Argentina's total greenhouse gas emissions. Businesses are trying to extract the methane for use, rather than simply burning off the gases. A substantial part of the population has a high standard of living, using significant amounts of electricity, and contributing to a high private automobile usage. The Argentine press regularly criticizes the wastage of natural gas, the continued reliance on fossil fuels, especially extensive use of gaseous fuels, and the minimal use of solar technology. Some 51.8 percent of the electricity generated in Argentina comes from fossil fuels, with 40.6 percent from hydroelectric power, 7.2 percent from nuclear power, and the remainder from other sources. Hydroelectricity comes from a number of dams located around the country.

While contributing to greenhouse gases, Argentina has also faced many problems from global warming. Since the heavy rains in Buenos Aires in May 2000, when more than four times the average monthly rainfall fell in less than a week, there have been very high rainfall figures, whereas, by contrast, rising temperatures have resulted in severe water shortages in La Pampa province, despite some flooding around the Argentine-Uruguayan border from August to October 2001. The most noticeable effects of global warming have been in southern Argentina. It has been estimated that the glaciers in Patagonia have receded, on average, by as much as a mile since the late 1990s, and the Upsala glacier, located in the Los Glaciares National Park, once the biggest in South America, is now losing 656 ft. (200 m.) per year. The warmer temperatures have also seen a large increase in plant life in the Argentine islands in the Antarctic region, such as Antarctic pearlwort and hairgrass.

The Argentine government of Carlos Menem took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, and in October 1997, D.A. Blasco from Argentina addressed the Fifth World Bank Conference on Environmentally and Socially Sustainable Development in Washington, D.C. In November 1998, President Menem made Argentina the first developing country to adopt binding targets for reducing emissions from greenhouse gases, and was one of the first countries to set exact targets.

This followed meetings held at Buenos Aires earlier that month in a follow-up meeting to that held in Kyoto. The ministry of social development and the environment in Argentina has managed to implement a number of policies to combat climate change, and the government of President Nestor Kirchner has argued that work on climate change should include recognition of the environmental debt that has been generated by forcing new rules on developing countries.

SEE ALSO: Agriculture; Floods; Glaciers, Retreating; Methane Cycle.

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Arizona

ARIZONA HAS AN area of 113,998 sq. mi. (295,252 sq. km.), with inland water comprising 364 sq. mi. (942.8 sq. km.). The state's average elevation is 4,100 ft. (1,250 m.) above sea level, with a range in elevation from 70 ft. (21 m.) above sea level on the Colorado River to 12,633 ft. (3,850 m.) on Humphrey's Peak. The state has a variety of elevation regions, with the high plateau in the northeast with elevations of 5,000–7,000 ft. (1,524–2,134 m.), a mountainous region running in a diagonal from the southeast to the northwest ranges from 9,000 to 12,000 ft. (2,743–3,656 m.), and in the southwest the land is primarily made up of desert interspersed with low mountains.

The climate is dependent on the elevation, with warm summers and mild winters, except in the high plateau, which has cool summers and cold winters. The air is generally dry and clear with a relatively low humidity (August humidity in Phoenix is 38 percent, Flagstaff 55 percent, Winslow 46 percent, and Yuma 33 percent) and much sun. Precipitation is governed by elevation and seasons.

Average annual precipitation on the high plateau is approximately 10 in. (.25 m.) Summer rain early July to mid-September comes from moisture-bearing wind from the southeast source in the Gulf of Mexico. Air masses from the Gulf of Mexico and Gulf of California, which release moisture while rising over the southeastern mountains.

Flood conditions are infrequent, mostly flash flooding from thunderstorms in July and August. Air currents from November through March are strongly from the Pacific in the high mountains; cold air masses come from Canada in the central and northern parts of state bringing heavy snow accumulations (sometimes reaching 100 in. or more). The highest temperature recorded in the state was 128 degrees F (53.3 degrees C), in Lake Havasu City on June 29, 1994, and the lowest temperature recorded in the state was minus 40 degrees F (minus 40 degrees C), in Hawley Lake on January 7, 1971. Annual lake evaporation is 80 in. in the southwest and 50 in. in the northeast corner.

The warm climate allows Arizona to produce vegetables for winter supply, and crops such as wheat and corn. Mining for copper, coal, sand, and gravel are important to the economy. A 1992 Colorado River Compact required 8.23 million acre ft. of water to be released every year to Nevada, California, and Mexico. In 2002, the crisis between farmers who own most of the water rights to the Colorado River and California cities downriver occurred.

The federal government ruled that California had to stick with the water allotment provided for in the compact and had to divide it equitably. The federal government further stipulated that water provided for in the compact was only excess water. Coal-powered steam, nuclear power, and some hydroelectric plants provide electricity. The Glen Canyon Dam generates hydroelectric power and created Lake Powell.

CLIMATE HARDSHIP

Arizona's climate has changed over the centuries. The ancient native peoples began farming the area in approximately 1500 B.C.E., and optimum rainfall increased arable farmland and drew a larger population. A Medieval climate anomaly in the southwest during the 8th and 12th centuries caused hardship.

While climate models vary on the amount of temperature increase possible with unmitigated global warming, Arizona's temperature could increase as much as 6.75 degrees F (3.75 degrees C) by the end of the century. The potential risks include: decreased water supplies from decreased snow pack in the mountains, thereby reducing summer flow in Arizona streams; increased risk for wildfires; changes in food production as temperatures rise beyond the tolerance level of crops; more extreme fluctuations in precipitation levels across the region (heavier rainfall and flooding events in winter, and summer drought conditions); change in rain pattern to downpours with the potential for flash flooding; and health risks of certain infectious diseases from water contamination; disease-carrying vectors such as mosquitoes, ticks, and rodents; and heat-related illnesses. The recent drought and intense wildfire seasons in Arizona are consistent with what climatologists expect will occur more frequently as global warming continues. A study by an Arizona and New Mexico team examined charcoal residues of ancient forest fires. During colder climate periods, smaller, less damaging fires occurred and during warmer climate periods, severe, stand-clearing fires occurred. Based on these data, global warming may cause more severe forest fires.

Based on energy consumption data from the U.S. Energy Information Association in 2007, Arizona's total CO_2 emissions from fossil fuel combustion in 2004 was 96.16 million metric tons of CO_2, made up of contributions from: commercial 2.04, industrial 4.62, residential 2.20, transportation 36.07, and electric power 51.22. Arizona committed to lowering its greenhouse gas emissions to 2000 levels by 2020, and 50 percent below 2000 levels by 2050. Arizona instituted a requirement that 1.1 percent of the state's energy come from renewable sources by the end of 2007.

In February 2005, Arizona established the Climate Change Advisory Group. Arizona holds member status with the Western Regional Climate Action Initiative, in which the partners will set an overall regional goal for reducing greenhouse gas emissions and design a market-based mechanism to help achieve that reduction goal.

Arizona joined the Climate Registry, a voluntary national initiative to track, verify, and report greenhouse gas emissions, with acceptance of data from state agencies, corporations, and educational institutions beginning in January 2008. The state's solar energy program issues a tax credit to individuals for installing a solar or wind energy device at an Arizona residence.

SEE ALSO: Alternative Energy, Solar; Deserts.

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Arkansas

A GEOGRAPHICALLY DIVERSE state in the southern United States, Arkansas depends heavily upon lumber and wood products, agriculture, forestry, and tourism for its economic stability. All of these sectors are particularly vulnerable to the changes global warming can produce in the state's ecosystem. Arkansans have been slow to respond to threats to the state's environment, but, in recent years, both city and state governments have begun implementing strategies designed to address the problem. A 2001 report from the Intergovernmental Panel on Climate Change (IPCC) predicts that temperatures in Arkansas could increase from 1–5 degrees F (0.5–2.7 degrees C) by 2100.

Water for irrigation of crops and maintenance of eastern Arkansas's fish farms is vital to the state's economy. The recent decrease in groundwater levels, due to heavy demands and the compromising of freshwater aquifers by seepage of saline water from underlying rocks, have already driven farmers to drill deeper wells and consider the use of surface waters from the Arkansas and other rivers within the state. Such problems are likely to worsen with warmer temperatures, and agriculture is not the only concern. Already, dry tributaries of the Arkansas River threaten the summer flow upon which fishing, and boating depend.

Even small increases in temperature could cause 40–60 percent of the state's forests to be supplanted by grasslands, a change that could, in turn, mean loss of wildlife and habitat. The timber business would suffer as a result, as would a $1.2 billion tourism industry that consists largely of wildlife viewers, hunters, and fishermen. Fears about the loss of breeding ground for the state's birds, some of them already endangered species, is a pressing concern. It was in the Big Woods of east Arkansas in 2004 that a research team sighted the ivory-billed woodpecker, believed to be extinct for more than half a century. Water quality could also be affected by warmer summers, and low oxygen, combined with increases in nitrogen and phosphorus, could threaten wetlands.

Although Arkansas meets all federal air quality standards for criteria pollutants such as sulfur dioxide, hydrocarbons, and lead, and its CO_2 emissions place it 33rd among the 50 states; in 2004, Arkansas ranked 19th among the 50 states in per capita emissions. Like other states that have grown economically, Arkansas's percentage of CO_2 emissions has risen comparatively. Between 1990 and 2001, the economy grew 49 percent and carbon dioxide emissions rose 42 percent. Power companies and the transportation sector are the greatest offenders. Despite these statistics, Arkansas has a poor record of acting to implement solutions.

The state has enjoyed some success in recycling solid wastes and in implementing building codes that encourage energy efficiency. More recently, the state has encouraged the use of solar energy. In 2005, the Eastman Chemical Company near Batesville, Arkansas, became the first plant in the state to produce biodiesel from soybean oil. Researchers suggest Arkansas's most promising experiment with biofuels may be processing cellulosic ethanol, in conjunction with synthetic fuels from large lignite reserves. The state has also provided tax credits designed to encourage the use of biofuels.

In April 2007, Governor Mike Beebe established The Governor's Commission on Global Warming to study the potential impacts of climate change on the state's environment and econom,y and to recommend global warming pollutant reduction goals and strategies. However, Arkansas's most effective strategies to combat global warming have come at the local level. Mayors of three of the state's largest cities (Little Rock, Fayetteville, and North Little Rock) signed the Mayors' Climate Protection Agreement, a movement by mayors of U.S. cities to circumvent federal delays in addressing global warming. Participating cities commit to use projects at the local level, such as anti-sprawl policies and urban forest renewal, to meet or exceed the greenhouse gas emission reduction target suggested for the United States in the Kyoto Protocol. This includes a 7 percent reduction from 1990 levels by 2012, and to urge bipartisan support for legislation targeting the same goals at state and national levels. Fayetteville Mayor Dan Cody developed the first public-sector sustainability department in Arkansas, and, in 2007, built a biofuel station for fleet vehicles that provides 60,000 gallons of Arkansas biofuel a year.

SEE ALSO: Forests; Intergovernmental Panel on Climate Change (IPCC); Kyoto Protocol.

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Armenia

THE LANDSCAPE OF Armenia is mountainous and varied, with rivers, waterfalls, forests, hot springs, natural caves, cliffs, and lakes such as Lake Sevan, one of the largest high altitude lakes in the world surrounded by non-active volcanoes. It is said that Mount Ararat, once geographically a part of Armenia, is where the biblical Noah's Ark landed after the great flood. The peaks of Mount Ararat can be seen from Yerevan, the capital of Armenia. This landscape is threatened by global warming and by deforestation—an estimated 4,000 hectares of forests are cut for fuel and other purposes every year. At this rate, Armenia may be a barren desert by 2020. Armenia has the proper climate, topography, and geography to develop renewable energy from water, solar, and geothermal sources, which would benefit the country immensely.

Armenia is one of the world's oldest civilizations. Throughout the centuries, Persians, Arabs, Greeks, Romans, Turks and Russians have invaded Armenia, but Armenia has maintained a distinctive culture and language. A land-locked country surrounded by Iran, Turkey, Georgia, and Azerbaijan, Armenia's borders have changed because of frequent religious wars. Armenia was the first nation to adopt Christianity as a national religion, and has fought to preserve its religious and cultural heritage among the encircling Muslim nations.

From the 16th century through World War I, large parts of Armenia were under the control of the Ottoman Turks, who in April of 1915, during World War I, ordered the extermination of Armenian leaders, both intellectual and religious. Historians such as Dr. Richard Hovannisian state that approximately 1.5 million Armenians were murdered or died of starvation during the following three years. This is considered the first genocide of the 20th century. Turkey continues to deny that this genocide took place.

Armenia received its independence in 1991, after having been under Soviet rule since 1922. Economic hardship and environmental destruction came with Armenia's newfound freedom. Because of the high costs of fuel and a struggling economy, many looked to the forests as a means to provide heat, using approximately 70 percent of cut timber for that purpose. Besides illegal logging, the latest threat to the forests is the possible establishment of an open strip mine that would potentially clear-cut over 1,500 acres of forest in northern Armenia. Many nongovernmental organizations, such as the Armenia Tree Project and Armenian Forests, are involved in educating communities about the need to protect their forests. An estimated 60 percent of the total 8 million Armenians worldwide live outside of the country, but still manage to keep a vested interest in the country's environmental issues.

SEE ALSO: Deforestation; Forests; Turkey.

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Arrhenius, Svante August (1859–1927)

SVANTE AUGUST ARRHENIUS is considered both a founder of physical chemistry for his work on ionic solutions and their electrolytic dissociation and the father of climate change science for his work on the contribution of carbon dioxide to global warming. Both theories were a great challenge to the scientific community of his time.

Svante August Arrhenius was born on February 19, 1859, in Wijk, near Uppsala, Sweden, as the son of

Svante Gustaf Arrhenius, a land surveyer at the University of Uppsala, and Carolina Christina Thunberg. His ancestors were farmers; his uncle became Professor of botany and rector of the Agricultural High School at Ultuna near Uppsala and later Secretary of the Swedish Academy of Agriculture. He originally went to Uppsala University to study chemistry. Finding their standards mediocre, he transferred to Stockholm in 1881, to do research under the physicist Erik Edlund, working initially on electrical polarization and then on the conductivity of solutions.

Arrhenius's doctoral dissertation (1884), titled *Recherches sur la conductibilité galvanique des électrolytes* [Investigations on the Galvanic Conductivity of Electrolytes] and presented in 1883, described his experimental work on the electrical conductivity of dilute solutions. It also contained a speculative section that set out an early form of his theory that molecules of acids, bases, and salts dissociate into ions when these substances are dissolved in water—in contrast to the notion of Michael Faraday and others that ions are produced only when the electrical current begins to flow.

Later, he proved that electrolytic dissociation influences osmotic pressure, the lowering of the freezing point and increase of the boiling point of solutions containing electrolytes. He also explored connections with biological problems, such as the relationship between toxins and antitoxins, serum therapy, and links to digestion and absorption as well as to the gastric and pancreatic juices. Although it has been modified over time, the importance of electrolytic dissociation theory is widely acknowledged today.

Arrhenius also applied physicochemical principles to the studies of meteorology, cosmology, and biochemistry. Interested in a debate about the cause of the ice ages he speculated that changes in the levels of carbon dioxide in the atmosphere lasting tens of millions of years were the trigger for a substantial change of the surface temperature of the earth. He took note of the Industrial Revolution, then underway, and realized that the amount of carbon dioxide being released into the atmosphere was increasing. Moreover, he believed carbon dioxide concentrations would continue to increase as the world's consumption of fossil fuels, particularly coal, increased ever more rapidly. He estimated that coal burning would drive a steady rise in CO_2 levels of about 50 percent in 3,000 years, leading to a much warmer climate, a prospect he found entirely rosy. He believed that a warmer world would be a positive change and that a warmer earth would be needed to feed the rapidly-increasing population.

ARRHENIUS'S GREENHOUSE LAW

In 1898, Arrhenius put forward a theory we now call the greenhouse effect. A simplified explanation is that shortwave solar radiation can pass through the clear atmosphere relatively unimpeded, but longwave infrared radiation emitted by the warm surface of the Earth is absorbed partially and then re-emitted by a number of trace gases—particularly water vapor and carbon dioxide—in the cooler atmosphere above. On average, the outgoing infrared radiation balances the incoming solar radiation, so both the atmosphere and the surface will be warmer than they would be without the greenhouse gases. Using Stefan's Law (better known as the Stefan Boltzmann Law), Arrhenius formulated his greenhouse law. In its original form, it reads as follows: "if the quantity of carbonic acid increases in geometric progression, the augmentation of the temperature will increase nearly in arithmetic progression." This is still valid in the 1998 simplified expression by G. Myhre:

$$\Delta F = \alpha \ln(C/C_0)$$

Arrhenius estimated that halving of CO_2 would decrease temperatures by 7–9 degrees F (4–5 degrees C) and a doubling of CO_2 would cause a temperature rise of 7–11 degrees F (5–6 degrees C). Although some of Arrhenius's calculations turned out to be wrong, current (2007) estimates from the Intergovernmental Panel on Climate Change (IPCC) say this value (the climate sensitivity) is likely to be between 3–8 degrees F (2–4.5 degrees C).

Nevertheless, over the decades after he developed this, Arrhenius's work was criticized, then reinforced, then criticized again. Many disregarded his conclusions, pointing to his simplification of the climate and how he failed to account for changes in cloud cover and humidity. The oceans would absorb any extra CO_2 pumped into the atmosphere, and any remainder would be absorbed by plant life, leading to a lusher landscape, skeptics argued.

Until about 1960, most scientists dismissed the hothouse/greenhouse effect as implausible for the cause of ice ages, as Milutin Milankovitch had presented a mechanism using orbital changes of the earth (Milankovitch cycles) that has proven to be a powerful predictor of most of the millions of past climate changes. Today, the accepted explanation is that orbital forcing sets the timing for ice ages, with CO_2 acting as an essential amplifying feedback.

Arrhenius was offered many opportunities to move to other European universities, and he delivered important lecture series at universities in the United States, but he always returned to Stockholm. He was elected as a foreign member of the Royal Society in 1911, was awarded the Society's Davy medal, and also the Faraday Medal of the Chemical Society (1914). Among the many tokens of distinction that he received were honorary degrees from the Universities of Birmingham, Cambridge, Edinburgh, Greifswald, Groningen, Heidelberg, Leipzig, and Oxford. In 1903, he received the Nobel Prize in chemistry, and in 1905, he was made director of the newly-created Nobel Institute for Physical Chemistry.

Nevertheless, Arrhenius was destined to have a bigger impact than he or anyone at that time could have imagined. Far beyond his mainstream work, he uncovered secrets of the Earth's atmosphere, inarguably becoming the father of climate change science. In doing so, he triggered research into what many see as the biggest threat to modern humans. Arrhenius was a contented man, happy in his work and family life. During World War I, he made successful efforts to release and repatriate German and Austrian scientists who had been prisoners of war. He was twice married—in 1894 to Sofia Rudbeck, by whom he had one son, and in 1905 to Maria Johansson, by whom he had one son and two daughters. He died at Stockholm on October 2, 1927.

SEE ALSO: Global Warming; Greenhouse Effect; Greenhouse Gases.

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Atlantic Ocean

THE ATLANTIC OCEAN is the second largest of the world's oceans, covering 31.7 million sq. mi. (82 million sq. km.) or a fifth of the Earth's surface. The Atlantic's role in global climate is well-studied, and although it is not entirely understood, it is profound. Understanding how the ocean both responds to, and affects, climate change is a challenge, given the Atlantic's expanse, mass, and both short and long term variability in its physical and chemical characteristics. Oceans, including the Atlantic, absorb most of the carbon dioxide emitted by human activity, and, thus, are extremely important for their role in mitigating the effects of increasing greenhouse gases in the atmosphere.

The immediate effects on the Atlantic of increased atmospheric greenhouse gases, most importantly carbon dioxide, include changes in the flux, or movement, of carbon dioxide within water and between the ocean surface and the atmosphere, acidification of the ocean, changes in surface temperature because of exposure to a warming atmosphere, and changes in the freshwater input to the ocean resulting from melting ice and anomalous precipitation both on continents and over the ocean. Longer-term effects include rising sea level, changes in weather patterns, and, potentially, changes in the climate of the ocean, neighboring continents, and the planet at large.

CARBON DIOXIDE FLUX

Presently, the net movement of carbon dioxide into the Atlantic and other oceans is from atmosphere to water. The oceans are an important sink, or storage reservoir, for carbon dioxide, holding as much as 60 times the amount of carbon dioxide as the atmosphere. More than three quarters of anthropogenic (human-sourced) carbon will eventually be stored in the oceans as carbon dioxide or as various carbon-containing ions and compounds. In the Northern Hemisphere, the North Atlantic is believed to be the largest reservoir for carbon. The effectiveness of the Atlantic Ocean as a carbon sink varies naturally over time.

Part of this variability is related to a phenomenon known as the North Atlantic Oscillation (NAO). The NAO refers to periodic movement of atmospheric mass and subsequent changes in the atmospheric pressure difference between two semi-permanent pressure systems that form over the Atlantic: the Icelandic Low and the Azores (or Bermuda) High. Changes in the NAO induce changes in sea surface temperature and mixing of layers of water. A strong NAO index (a relatively large difference in pressure between the two systems), tends to create warmer water and shallower winter mixing. Carbon dioxide is more soluble in water at cooler temperatures and under pressure. Thus, the carbon dioxide concentration of ocean water increases with depth. Deeper convection, or mixing of surface waters, increases the ocean's efficiency as a sink for carbon dioxide.

Mixing also affects the nutrients available for biological activity, which has a seasonal effect on the carbon flux in the oceans. Carbon dioxide is used at the ocean surface by photosynthesizing organisms, and it is incorporated into shells of organisms in the form of carbonate, most importantly, calcium carbonate. A small portion (but still a large mass) of these organisms sinks to the ocean bottom, where much of the planet's carbon is stored. At the surface, the amount of carbon dioxide is generally at equilibrium with that in the atmosphere. Thus, as atmospheric carbon dioxide increases, so does the concentration in the surface water of the ocean. Once the ocean absorbs carbon dioxide, it combines with water to form carbonic acid and a series of acid-base reaction products, thereby lowering pH. It has been calculated that ocean pH has decreased by 0.1 units since the Industrial Revolution. This decrease in pH is expected to continue as the concentration of atmospheric carbon dioxide rises.

The effect of decreasing pH on the ocean ecosystem is being investigated, and some researchers warn that it could be a serious problem. Increased carbon dioxide may favor certain organisms and harm others. Organisms that photosynthesize need carbon dioxide, but the acidification caused by added carbon dioxide can have deleterious effects. For example, corals take calcium carbonate from water to build skeletons, and many planktonic organisms, even ones that photosynthesize, use it to build shells. The solubility of calcium carbonate increases as pH decreases. Higher solubility of carbonates impedes the building of carbonate structures. This could affect the survival and population dynamics of these organisms. Depressed populations of these organisms could have an amplifying effect on global warming. Coccolithophores, for example, are abundant, shell-building planktonic photosynthesizers. Some of their carbon-containing shells end up in sediments. They also contribute to ocean lightening and cloud formation, both of which increase the amount of light reflected off the planet.

Ocean pH has decreased by 0.1 units since the Industrial Revolution, likely harming corals like this one in the Caribbean.

In addition to biological mediation of ocean carbon, the flux of carbon dioxide between the oceans and the atmosphere is affected by physical processes such as winds and circulation, and by complex chemical interactions. Layering, or stratification of oceans, affects the mixing and movements of water masses, including deep water, which differs substantially in chemistry from upper waters. For long-term storage, carbon dioxide mixed into surface water must be transported to deeper layers. Stratification in the Atlantic Ocean varies spatially by region and depth, and temporally, over short-term and long-term time scales. Near surface stratification is affected by salinity and temperature.

Stratification can be a significant barrier to mixing, and, thus, to the transport of chemicals and heat downward, and the resupply of nutrients upward. Decreases in these fluxes can negatively affect the ability of the ocean to take up carbon dioxide. Winds also influence the absorption and retention of carbon dioxide in the ocean via their effect on the ventilation of surface water. Winds, at least over some parts of the Atlantic, appear to be decreasing as a result of global warming. This lowers the rate at which carbon dioxide is taken out of the atmosphere by the oceans, thus raising the point at which atmospheric carbon dioxide will stabilize. In the southern oceans, however, winds have been speeding up, perhaps in response to warming or some other atmospheric change, such as ozone loss. The result is enhanced upwelling and ventilation of deeper, carbon-rich water.

The ability of ocean water to absorb carbon dioxide also depends upon its buffering capacity, which is determined by the carbonate and other ion concentrations in the water. The warm, tropical portion of the Atlantic, for example, has a very high buffering capacity, while cooler water is less efficient at absorbing carbon dioxide. Dissolution of carbon dioxide in water frees up hydrogen ions. These ions react with carbonate ions to form bicarbonate ions. This process serves as a buffer against change in pH; however, the buffering capacity decreases as carbonate ions are converted to bicarbonate. Thus, although the oceans will eventually take up some three quarters of human-produced atmospheric carbon, the efficiency of this process will decrease as carbon dioxide concentrations in the water increase. Further, the solubility of gases in water decreases as temperature increases.

SALINITY

The chemistry of the Atlantic Ocean is also changing in terms of its salinity, or salt content. A number of factors contribute to the salinity profile of the Atlantic Ocean. Evaporation, for example, is responsible for surface salinity being greater than the salinity of deeper water. When evaporation exceeds precipitation, salinity at the ocean surface increases. This has implications for movement of water and mixing of upper water with lower water. Melting of Arctic and Greenland ice because of warming sea and air temperatures, and increased precipitation over the ocean and neighboring continents, would be expected to have a freshening effect on the Atlantic, because these sources are low in salt. Changes in circulation, stronger winds, and changes in precipitation would be expected to increase salinity of surface waters near the tropics.

Measurements along the western basins of the Atlantic indicate significant freshening of high latitude water in both the Northern and Southern Hemispheres, and increased salinity in low latitudes during the latter half of the 20th century. The changing distribution of fresh and saline waters throughout the Atlantic and other oceans may be indicative of significant changes in the global hydrological cycle. The salinity of the Atlantic Ocean is also of particular interest because of its role in the thermohaline circulation (THC). The THC, along with prevailing winds produced by the Coriolis effect (circulation of large bodies of fluids such as air and water caused by the rotation of the planet), is the driving force behind the Atlantic meridional overturning circulation (AMOC).

THE ATLANTIC MERIDIONAL OVERTURNING CIRCULATION

The word *meridional* in AMOC indicates movement that is in a north-south direction. The AMOC is of immense importance to the global climate and is responsible for transferring heat from the tropics northward to the poles in the Atlantic. AMOC is the Atlantic component of the ocean conveyor belt. Evaporation of surface water at the tropics causes this water to be very salty, because only water is evaporated, leaving behind a high concentration of salt. At the same time, however, the density of the water is lowered through warming by the strong tropical sun. This is because water is maximally dense at 39 degrees F (4 degrees C); above or below this its density decreases. In the North Atlantic, water circulates clockwise because of the Coriolis effect. From the tropics, part of this conveyor belt takes water into the Caribbean basin and along the east of the West Indies.

These two flows unite to form the Gulf Stream, which passes along the east coast of North America. The Gulf Stream influences the climate of the east coast of North America. For example, it keeps the waters of southeast Florida considerably warmer than the rest of the North America in the winter, while in the summer it maintains warmer temperatures in Nantucket and Martha's Vineyard than are found slightly more inland, in Massachusetts Bay. Southeast of Newfoundland, Canada, the Gulf Stream turns easterly across the North Atlantic, where it breaks into numerous branches.

One branch of the warm, salty water moves northward along Great Britain and Scandinavia, shedding heat and warming that part of the world. As it cools, its density increases. It sinks and returns southward as deep water, mostly along the western side of the Atlantic. Eventually, it will recirculate to the tropics, where it will warm once again and rise to the surface. This process explains why it is termed an *overturning circulation*.

A warming climate is predicted to increase freshwater input in the northern reaches of the Atlantic via increased precipitation, continental run-off, and melting of Arctic Greenland ice. Pulses of freshwater and ice from the Arctic during the latter third of the 20th century appear to have diluted much of the upper waters in the high-latitude North Atlantic. Potentially, such freshening could weaken the circulation by decreasing the density of surface water and by pulling heat from the northern current. Uncovering a trend in the circulation has proven to be difficult because the strength of the circulation varies greatly by season and year and researchers are still learning the extent of this variation. There is presently a shortage of data to make any confident conclusions about changes in the overturning. Longer-term temperature and salinity data covering a greater range of latitudes are needed; more work along these lines is currently underway.

There is circumstantial evidence linking cooling and glacial events several thousand or tens of thousands of years ago to changes in the ocean heat conveyor. Some researchers believe that it is unlikely that a sufficient injection of freshwater is available to shut down the AMOC, or that a substantial slowing is centuries away from occurring; whereas others believe that this tipping point may be approaching. Of intense interest is the Greenland Ice Sheet, which has been losing mass in recent years. In some models, a rapid input of ice and water from Greenland could have a significant effect on the overturning circulation; other models show a melting Greenland Ice Sheet to be insufficient for such an occurrence.

TEMPERATURE AND SEA LEVEL RISE

The freshening of the high-latitude (generally from 45–60 degrees N) North Atlantic creates an exception to the overall trend of warming in the Atlantic, because water from the melting ice is cold. When examined over their entirety, the energy content in the form of heat in the world's oceans is increasing, at least since the mid-20th century. This increase in heat may be greater for the Atlantic than other oceans. Temperature increases have been measured at the surface and to depths of 9,843 ft. (3,000 m.). A warming atmosphere caused by anthropogenic greenhouse gases is widely considered to be the cause of increasing ocean temperatures.

Heat from the air at the surface of the ocean is transferred to the water, raising sea surface temperatures. Heat in the surface water is mixed downward in the summer. During winter, some heat moves by convection from deeper water to the surface and then is released to the atmosphere. Elevated sea surface temperature during winter weakens this convection, thereby trapping heat in the ocean. Factors other than greenhouse gases, such as changes in solar radiation or cosmic rays, have been proposed to explain the rising temperatures. Measured changes in these phenomena appear inadequate to explain the extent to which the heat content of the ocean and atmosphere has increased.

Both increasing ocean heat content and melting ice are contributing to sea-level rise in the Atlantic Ocean and elsewhere. Sea-level change is not uniform worldwide, with sea levels far exceeding the mean rise at some locations, and drops in levels at some others. The overall trend of rising sea levels, however, is apparent. Based largely on tidal gauge readings, this rise was from about 0.06–0.08 in. (1.5–2 mm.) per year in the 20th century. Part of this, about 0.02 in. (0.5 mm.), occurred through expansion of the water caused by heating (thermal expansion). The remainder is an actual change in the mass of the oceans caused by influx of water from melting glaciers, ice caps, and the Antarctic and Greenland ice sheets.

Scientists have determined that glaciers and ice caps around the world are melting and are responsible for most of the changes witnessed in oceans' mass. Ice caps are larger than glaciers, but larger still are the world's two ice sheets. These huge bodies of ice have the greatest potential to raise sea level, holding enough water to raise sea levels 230 ft. (70 m.). Fortunately, there is no indication that a complete melting will occur. The Greenland Ice Sheet is, however, losing mass, largely from its periphery, and there is concern that the rate of discharge of glaciers from the ice sheet into the surrounding ocean is accelerating.

THREATS TO COASTAL COMMUNITIES

Rising sea level poses a problem for people and development along the ocean. With over 60,000 mi. (100,000 km.) of coastline, rising water on the Atlantic Coast has the potential to be very costly in human and economic terms. It also poses an ecological problem by altering the hydrology of coastal land and the salinity of freshwater bodies and wetlands entering the ocean near the coast. Extreme high tides and storm surges could bring water to places that historically have only uncommonly or never flooded. Such unusual events increased along the Atlantic coast of United States in the 20th century.

Coastal flooding and erosion is not only a function of mean sea level, but is also affected by storminess and wave height. Trends in these parameters in the Atlantic Ocean are difficult to discern because of high yearly variability and naturally occurring cycles. There is some indication of slightly increased storminess and wave height in the northern Atlantic and declines elsewhere during the latter part of the 20th century. Changes in overlying atmospheric pressure appear to be the cause. These meteorological changes may be natural, however, and at this time there is insufficient evidence to directly link them to human activity.

HURRICANES

A related concern is the possible effect of climate change on hurricane activity. Hurricane records are being intensely scrutinized to identify trends. Like other weather phenomena, hurricanes seem to exhibit cyclical variation on multiple time scales, plus other naturally occurring variation. Some of this variation may occur on time scales longer than storm records have been kept.

The methods used to record storms and measure their intensity have also changed over time, adding difficulty to reaching firm conclusions. For example, intensity of storms that occurred prior to the use of satellite imagery may be under-reported. While some scientists have reported apparent effects of climate change on storm frequency, intensity, and number of strong storms, others have refuted or rejected such claims.

Because hurricanes get their energy from warm ocean water, it might be expected that increasing sea temperatures would elicit an increase in storm numbers or intensity. There are many complicating factors, however, in the formation of hurricanes. These include air movement where hurricanes form, height differences in wind speed (shear), and sea-level air pressure. The debate about the relationship between hurricanes and greenhouse gases is certain to continue.

SEE ALSO: Current; Glaciers, Retreating; Meridional Overturning Circulation; Oceanic Changes; Oceanography.

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Atmosphere, Climate and Environment Information Programme (UK)

IN RESPONSE TO rising concerns about climate change and global warming at the end of the 20th century, the government of the United Kingdom created the Atmosphere, Climate, and Environmental Information Programme (ACE) as the academic arm of the Atmospheric Research and Information Centre (ARIC). Operating under the auspices of the Department for Environment, Food, and Rural Affairs (DEFRA) and supported by the Department of the Environment, Transport, and Regions (DETR), ACE was established in part as a means of promoting DETR's "Are You Doing Your Bit?" campaign. Activities of the ACE were directed at educating the public about the ways in which human activities affect climate change and in promoting national legislation and international cooperation in mitigating those effects.

In 2005 DEFRA withdrew financial support for the Atmosphere, Climate, and Environmental Information Programme. However, much of the information distributed by ACE remains available in ACE pamphlets, papers, reports, and the internet. Through Manchester Metropolitan University, the ACE website continues to serve as a clearinghouse for information on topics such as the British government's efforts to curb air pollution, ways in which the public can mitigate the effects of air pollution on climate change, and statistics on emissions of pollutants in the United Kingdom 1970–2000. ACE data on governmental efforts to combat climate change, ozone depletion, and British participation in the Kyoto Protocol are also available. The ACE website continues to serve as a major resource of information on the environment for teachers and young students, offering basic facts, games, and puzzles.

The Atmosphere, Climate, and Environmental Information Programme's most lasting contribution may arguably be two comprehensive online encyclopedias. The award-winning *Encyclopedia of the Atmospheric Environment* offers some 400 essays on topics that include climate change, global warming, acid rain, and the weather. A number of articles offer supporting photos and statistics. Published in both English and French, this encyclopedia provides information to individuals from elementary school age to college and beyond who are concerned with global warming and climate change. The encyclopedia also serves as a valuable resource for government agencies, advocacy groups, industry, and nongovernmental organizations. The "References and Further Reading Section" of the encyclopedia directs interested parties to printed sources that explore global warming and climate change topics in greater depth.

More action-oriented than its sister encyclopedia, the *Encyclopedia of Sustainable Development* is available only in English. It provides access to approximately 100 articles that are designed to explain the intricacies of sustainable development to a general audience. In addition to the two online encyclopedias, between March 1998 and November 2004, ACE annually published six issues of *Atmospheric Issues*, a newsletter that gathered information from around the world on topics dealing with air pollution, air quality, climate change, ozone depletion, renewable energy, transport, and sustainable development.

SHIFT IN SUPPORT

After 2005, DEFRA shifted its support from ACE to the Digital Library for Earth System Education (DLESE), in which the government joined with educators, students, and scientists to generate knowledge about global warming and climate change. Funded in large part by the National Science Foundation, DLESE provides students of higher education with information on such topics as ecology, environmental science, forestry, hydrology, natural hazards, space science, atmospheric science, and biological oceanography. Information is generated from sources ranging from the GLOBE Program Collection, the New York Instructional Collection, and Realtime Atmospheric Data. Teachers are encouraged to use resources provided by DLESE, including lesson plans, maps, images, data sets, visualizations, and online courses.

As support for the ACE program declined, attention also focused on action-oriented programs designed to deal with the implications of climate change. In the early 21st century, the government established the Climate Change Programme, which set emission reduction targets throughout the economic sector, including the establishment of industry caps on pollution, promotion of the development of alternative fuels, legislative efforts to enact stricter building codes, support for more effective home energy savings, and the generation of public and business support for achieving government goals on mitigating the effects of climate change. In March 2006, the government announced that goals of the Climate Change Programme included a 23–25 percent reduction in base year levels of carbon dioxide emissions and a 15–18 percent reduction beyond 1990 levels by the year 2010.

Since the 1990s, the British government has served as a leader in promoting efforts to mitigate the effects of global warming. During that period, greenhouse gas emissions in Britain have continued to fall. In October 2006, the British government issued a controversial 700-page report written by economist Sir Nicholas Stern that sought to call worldwide attention to the economic aspects of global warming. Stern concluded that the potential effects of global warming and climate change could be more devastating than the world wars and the Great Depression combined. Some economists, most notably William D. Nordhaus of Yale University and Sir Partha Dasqupta of the University of Cambridge, questioned Stern's findings.

Then Prime Minister Tony Blair challenged nations around the world, particularly the United States and China, where efforts to reduce global warming have often run into political stumbling blocks, to join Britain in reducing the carbon emissions that are believed to be leading to warming temperatures around the globe. Despite a close political alliance between Britain and the United States, Blair urged President George W. Bush to rethink his position on global warming, which has allowed the industrially dominant United States to forego the restrictions on greenhouse gas emissions that have been instituted throughout much of the world as a result of the Kyoto Protocol of 1997. The provisions of that protocol are set to expire in 2012.

SEE ALSO: Energy; Kyoto Protocol; Pollution, Air; Sustainability; United Kingdom.

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Atmospheric Absorption of Solar Radiation

SOLAR RADIATION IS radiant energy emitted by the Sun. The process begins at the Sun's core, where hydrogen atoms are fused to helium atoms via nuclear fusion. For each second of nuclear fusion, the Sun converts 700 million tons of hydrogen into 695 million tons of helium, with 5 million tons of electromagnetic energy radiating out into space.

Some of this energy travels the approximately 92.89 million mi. (149.5 million km.) across the solar system to Earth. The importance of the Sun to Earth is hard to overstate: quite simply, it makes life here possible. It provides us with heat and light, controlling everything from daily weather patterns to the placement of climate zones, while our trips around it provide us with our annual seasons.

Not all incoming solar radiation makes it to the Earth's surface; in fact, almost half of it is deflected back into space by the outer layers of our atmosphere. Inside the atmosphere, it scatters and interacts with gasses and particles in different ways, depending on the size and composition of its wavelengths. For example, gamma rays, ultraviolet light, and x-rays of 200 nanometers in wavelength are absorbed by ozone and nitrogen is converted into heat energy. Ultraviolet rays of 200–300 nanometers in wavelength are absorbed by ozone in the stratosphere, while infrared rays of 700 nanometers in wavelength are partially absorbed by ozone, carbon dioxide, and water vapor in the lower atmosphere.

In all, an estimated 6 percent of incoming solar radiation is reflected back into space by the atmosphere, 51 percent is absorbed at the Earth's surface (where 4 percent of it is reflected back), while 39 percent is either reflected or absorbed by clouds. Solar radiation that has passed beyond these forces of scattering or absorption and reaches the Earth's surface is called *diffused* solar radiation, while that which reaches the ground without stopping is *direct* solar radiation.

The Sun's intensity changes in a number of long and short cycles, and those who do not believe in anthropogenic (human-caused) global warming often point to the Sun as the true culprit. While there is no denying the Sun's influence on past cycles of heating and cooling, the majority of scientists believe that it is a combination of natural and human-caused processes that are driving observable climate changes today.

Changes in albedo are an important part of the global warming picture. Albedo, a word derived from the Latin word for white, is the surface reflectivity of solar radiation. A dark surface will absorb more solar radiation than a light surface. The overall albedo of the Earth is 30 percent, and it plays a crucial role in keeping the planet's temperature habitable.

Albedo varies depending on the color of the surface. Open water has an albedo of 8 percent, meaning it reflects only 8 percent of the solar radiation that strikes it, absorbing the remaining 92 percent as heat. Dry desert sands have an albedo of 35–45 percent, coniferous forests between 10–20 percent, and deciduous forest between 5–10 percent. It is the polar regions that do the most to reflect solar radiation, with fresh snow carrying an albedo of 95 percent, snow-covered sea ice about 70 percent, and melting snow about 50 percent.

The interplay of anthropogenic and solar impact is best illustrated by recent events in the Arctic, where each year has seen the shrinking of summer sea ice at the North Pole and in Greenland. Something—perhaps the burning of fossil fuels—has allowed more heat to become trapped in the atmosphere and has warmed the environment. This causes some snow and ice to melt, which drops the region's surface albedo, which in turn allows an increased amount of solar radiation to reach the surface. The radiation produces more heat, which causes more snow and ice to melt, and soon the process becomes unstoppable. The loss of the polar ice caps could have tremendous repercussions around the world, from destabilizing the world's weather patterns, to rising global sea levels from the melting of the Greenland ice sheet.

SEE ALSO: Albedo; Arctic Ocean; Radiation, Absorption; Sunlight; Weather.

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Atmospheric Boundary Layer

THE ATMOSPHERIC BOUNDARY LAYER (ABL) is the bottom layer of the atmosphere. Its defining characteristic is that it interacts with the Earth's surface on a time scale of a few hours or less. Therefore, all constituents emitted at or near the surface rapidly diffuse throughout the ABL. This rapid interaction is a direct result of turbulence, which is an essential feature of the ABL. Over land, its depth can vary from a few miles in the daytime to a few dekameters at night.

The atmosphere near the earth's surface is almost always turbulent; that is, the air is continually undergoing seemingly random motions, in addition to whatever wind may exist. The sources of turbulence are wind shear (the change in wind speed and direction with height) and convection (motions driven by air density differences resulting from surface heating or latent heating from water phase changes). Defining characteristics of turbulence are its chaotic fluctuations over a broad range of scales, and its diffusiveness. Therefore, trace constituents released into a turbulent fluid are rapidly diffused and the small-scale patterns of this diffusion cannot be predicted. Because of the randomness and the large range of scales of ABL turbulence, processes in the ABL are often described in terms of statistical averages of fluctuations. This means that most measurements of ABL structure need to be spatially or temporally averaged before they can be quantitatively interpreted.

The top of the ABL is characterized by an increase in temperature (such as a decrease in density) with height, which also caps the level to which turbulence extends. The ABL grows by entraining air from the overlying non-turbulent air by turbulent eddies. That is, the kinetic energy of the ABL turbulence is used to overcome the lower density of the overlying air as it diffuses into the ABL. The lowest few yards to dekameters of the ABL is known as the surface layer (SL). This region, roughly up to about 10 percent of the ABL, is characterized by nearly constant vertical turbulent transport and relatively large vertical gradients; in contrast to the rest of the ABL, where the transport can vary significantly, but the gradients are typically small. In this layer, wind shear caused by the interaction of the average wind with the surface, and with obstacles such as plants, buildings, hills, and ocean swell, is the dominant source of turbulence.

If turbulence generation by convection occurs in the ABL, it is known as an unstable or convective boundary layer (CBL); if the hydrodynamic stratification of the ABL acts to suppress or dissipate turbulence, it is known as a stable boundary layer (SBL). In the course of a typical diurnal cycle over land, the surface becomes warmer than the overlying air within a few hours after sunrise, and warms the lowest layer of air so that it is warmer and less dense than the air higher up. This relatively warm air rises and thereby converts its potential energy to kinetic energy in the form of turbulent fluctuations that deepen the boundary layer through the morning. By mid-afternoon, as solar heating begins to decrease, the boundary layer reaches a plateau of one to several miles in depth and turbulence decreases.

At night, infrared cooling of the surface suppresses turbulence, while wind shear near the surface can still generate it. As a result, the nocturnal SBL is much shallower—typically a few dekameters or less—and the temperature decreases less rapidly with height than the daytime CBL. The overlying air that was previously within the CBL, and therefore well mixed, is no longer turbulent. This residual layer may again become turbulent the following day when solar heating of the surface resumes.

This diurnal cycle is strongly dependent on the surface characteristics. A bare, dry surface, for example, will become warmer than a moist or vegetated surface. Therefore, the turbulence is likely to be stronger and the boundary layer deeper over a bare, dry surface. The moisture given off by vegetation will likely cause clouds to form at lower heights than over a bare, dry surface. If these differences occur over a large enough area, there may be significant differences in the mean temperature, humidity, and cloudiness. Horizontal variations in the surface can induce corresponding horizontal variability in the ABL. For example, on clear summer days, cumulus clouds are often observed to form preferentially over land, but a nearby lake may remain clear. Similarly, in mountainous terrain, clouds often preferentially form over ridges and elevated plateaus, rather than adjacent valleys.

Over the ocean, the diurnal cycle is quite different, and often scarcely noticeable. Because the ocean has a much larger effective heat capacity and heat conductivity than land, its surface temperature is hardly perturbed by the daily solar cycle. As a consequence, the ABL depth, typically about a kilometer, is much less variable. Furthermore, in daytime the boundary layer air is heated directly by the sun, which typically more than compensates for long-wave (infrared) radiational cooling. In this case, the boundary layer may be more stable (with less convection) in the daytime than at night.

When relative humidity reaches 100 percent within the ABL, clouds form, which can have dramatic effects on its subsequent evolution through generation of turbulence by release of the latent heat of condensation, shading of the Earth's surface, and precipitation. The resulting clouds may be confined to the ABL, or they may penetrate into the overlying atmosphere, depending on the change of temperature (density) with height across the ABL top; a large increase in temperature across the top suppresses cloud penetration and results in stratiform or layered clouds, while penetration leads to cumuliform or vertically-developed puffy clouds. Cumulus convection is an important mechanism for transporting ABL air, and, thus, trace constituents released at the surface, into the overlying atmosphere, thereby ventilating the ABL.

In the surface layer, which makes up about 10 percent of the ABL, turbluence is increased by surface features such as hills.

SEE ALSO: Atmospheric Absorption of Solar Radiation; Clouds, Cumulus; Clouds, Stratus; Convection; Ekman Layer; Radiation, Infrared.

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Atmospheric Component of Models

SCIENTISTS HAVE BEEN creating models of the climate and atmosphere on a systematic basis for more than a century. However, only with the development of powerful computational devices has a sophisticated simulation of the atmosphere started to become possible. The accurate modeling of turbulent liquids and gases, of which the atmosphere is of course composed, remains one of the most difficult tasks facing scientists studying the Earth. The problem is made more difficult by the lack of accurate and complete data dating back more than a few decades. Despite these difficulties, researchers have become able to create models that do represent the major features and changes of the atmosphere with a high degree of confidence.

The degree of sophistication inherent within the atmospheric component of climate models is revealed by the number of data points on the surface (the horizontal element) as well as the number of layers considered in the atmosphere (the vertical component). Currently, scientists are developing a third generation atmospheric circulation model that consists of 32 layers within the atmosphere. The coverage extends to 37 mi. (50 km.) from the surface of the Earth and the model also includes three layers of the Earth itself. Previously, a single soil layer was predicated across the surface of the Earth, but this is now supplemented by, when necessary, a snow layer and a layer of vegetative canopy.

Clearly, the rate of change of land cover across the surface of the Earth means that it would be impossible to create a model that is 100 percent accurate. However, models now represent the overall effect of the atmosphere to a satisfactory degree. For example, variables are included in the third generation models that include soil surface properties and heights, various types of surface albedo, and varying soil moisture conditions. Nevertheless, the central component of the model is the investigation of the heat exchange between the earth through the atmosphere and the ways in which this has an impact upon the climate. Understanding this has been a goal of scientists for more than a century, although it was not until the detailed observations first made in the middle of the 20th century that a real understanding of circulation became possible.

The discovery of the various wind systems and accurate mapping of them enabled a huge leap in understanding of the Earth's atmosphere as a whole. It revealed the need for more advanced understanding of the atmosphere than could be provided by a single equation, no matter how sophisticated that might be. The Norwegian meteorologist Vilhelm Bjerknes and the British physicist Lewis Fry Richardson were among the vanguard of scientists attempting to use a series of mathematical equations to represent weather changes over finite parts of the globe. This was to be achieved by dividing the surface of the earth into a grid of cells of such a scale that it was feasible to complete the equations with the tools then available. However, these attempts were unsuccessful and ultimately abandoned.

One particular problem was that it was necessary to compare results that had been calculated with real-world data and there were insufficient mechanisms to make those measurements. World War II was the impetus to measure climatic conditions (for inherently military purposes) that provided the amount of data necessary to refine and improve models. Contemporaneous improvements in computers made more rapid and wide-scale calculations possible, and a series of researchers, mostly based in the United States, were able to improve their models over the subsequent decades.

IMPROVEMENTS

Major improvements included the division of the surface of the earth into land and water, inclusion of topographical features and the integration of increasingly more layers in the atmosphere, which both improved the sophistication of the model and enhanced its scope to heights further from the surface of the earth. It took many years, nevertheless, for modeling to be completed faster than the weather elapsed in real time and the ability to make meaningful weather forecasts has only recently become possible. However, this is now possible and the geographical scope of the coverage has grown from regional to global in nature. Regional models may be more useful for state agencies to make forecasts across their territory, but the atmospheric system is global in scope and only models that include the whole globe can be really helpful in predicting the future.

Advanced modifications to the atmospheric component of climate models have included the dynamics of cloud and precipitation processes, radiation processes, and the impact of aerosols. Other areas of improvement have included the division of precipitation into frozen and liquid forms and the various forms of condensation involved with cloud formation processes. The modeling is not complete, but is advancing at a rapid rate.

SEE ALSO: Atmospheric Composition; Atmospheric General Circulation Models; Atmospheric Vertical Structure; Climate Models; Climatic Data, Historical Records.

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Atmospheric Composition

ALL LIFE ON Earth exists within a thin film of air, water, and soil about 9.3 mi. (15 km.) deep. This spherical shell of life is known as the biosphere. The biosphere can be divided into three layers: the atmosphere (air), the hydrosphere (water), and the lithosphere (rock and soil). The unique attributes of the Earth's atmosphere create a habitable place for humans, animals, and plants. It reaches over 348 mi. (560 km.) from the surface of the Earth. The atmosphere is a mixture of gases and particles that surround the planet. When seen from space, the atmosphere appears as a thin seam of dark blue light on a curved horizon. It is made of layers that surround the Earth like rings. About 99 percent of the Earth's atmosphere occurs within 31 mi. (50 km.) above the surface. The remaining one percent extends outward for several hundred km., fading gradually into interplanetary space.

The atmosphere serves several purposes: it provides habitants with the air to breathe, its gases retain the heat that warms the Earth, and its protective layer of ozone shields habitants from harmful ultraviolet rays emitted by the sun. The atmosphere also acts as a reservoir, or storehouse, for natural substances as well as emissions derived from human activities. Within the storehouse, physical and chemical actions and reactions take place. Many of these can affect climate and weather systems. Four distinct layers of the atmosphere have been identified using thermal characteristics (temperature changes), chemical composition, movement, and density. These are the: troposphere, stratosphere, mesosphere, and thermosphere. Beyond these atmospheric layers lies the exosphere.

Approximately 81 percent of Earth's atmosphere occurs in the troposphere, which extends about 3.7–10.5 mi. (6–17 km.) above the Earth's surface and is thickest at the equator. Temperatures in the troposphere generally decrease as altitude increases. Temperature in this layer is highest nearest the earth, in part because gases in the troposphere are warmed by heat radiated from the earth. The stratosphere extends beyond the troposphere to about 31 mi. (50 km.) above the Earth. Gases in the stratosphere are heated mainly by incoming radiation from the sun; temperatures in the stratosphere gradually increase as altitude increases. As a consequence of temperature differences between the troposphere and stratosphere, and the resulting circulation patterns, exchange of air between the two layers is slow.

The stratosphere is also known as the ozone layer. The distribution of ozone is closely linked to the vertical structure of the atmosphere. Approximately 90 percent of all ozone molecules are found in a broad band within the stratosphere. This layer of ozone-rich air acts as an invisible filter to protect life forms from over-exposure to the sun's harmful ultraviolet rays. Human activities have led to a depletion of the ozone layer observed since the mid-1980s.

The mesosphere starts just above the stratosphere and extends to 53 mi. (85 km.) beyond the stratosphere. In this region of atmosphere, temperatures fall as low as minus 135 degrees F (minus 93 degrees C). The thermosphere starts just above the mesosphere and extends 372 mi. (600 km.) beyond mesosphere. The thermosphere has two parts: the ionosphere (the inner part), and the exosphere (the outer part) that gradually merges into space.

The composition of the atmosphere has changed over time. The original atmosphere primarily consisted of helium and hydrogen. Heat from the still-molten crust and the sun, and probably from enhanced solar wind as well, dissipated this atmosphere. The surface cooled about 4.4 billion years ago, but was still full of volcanoes that released steam, carbon dioxide, and ammonia. This led to the early second atmosphere, which was primarily composed of carbon dioxide and water vapors, with some nitrogen, but virtually no oxygen.

The second atmosphere had approximately 100 times more carbon dioxide than the third, or current, atmosphere. As the atmosphere cooled, much of the carbon dioxide either dissolved in the seas or precipitated as carbonates. Bacterial forms of life began approximately 3.3 billion years ago, and were probably were the first oxygen-producing phototropic organisms. They were responsible for converting the Earth's atmosphere from an anoxic to an oxic state during the period 2.7–2.2 billion years ago.

As life evolved on the planet and more plants appeared, the level of oxygen increased significantly, while levels of carbon dioxide dropped, eventually giving rise to the modern atmosphere, which is also known as the third atmosphere. This modern atmosphere has a composition enforced by oceanic blue-green algae, as well as geological processes. Thus, oxygen does not remain naturally free in atmosphere, but tends to be consumed by inorganic chemical reactions, animals, bacteria, and even plants at night. Carbon dioxide is produced by respiration and the decomposition of organic matter.

Dry air near the Earth's surface consists mainly of Nitrogen (78.1 percent by volume) and oxygen (20.9 percent) with a small amount of argon (about 0.9 percent) and carbon dioxide (about 0.035 percent). Air in the troposphere also contains water vapor and small amounts of "trace gases," such as methane, nitrous oxide, hydrogen, and ozone. Even though many of these gases are present in minute amounts, they cause the atmosphere to act like an insulating blanket around the planet. Without this atmospheric blanket, the Earth's surface would be too cold to sustain life. Naturally occurring atmospheric gases play a key role in determining the climate, and the increase in their concentration, attributed to natural and anthropogenic causes, results in more dramatic climate changes. In addition to these naturally occurring gases, there are other gases such as halocarbons (a result of industrialization) present in the troposphere. The chemical composition of the atmosphere is very important and influences the climate; the addition of gases changes the composition of the atmosphere, complicating climate-change processes.

SEE ALSO: Atmospheric Vertical Structure; Mesosphere; Stratopause; Stratosphere; Thermosphere; Tropopause; Troposphere.

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Atmospheric Emission of Infrared Radiation

THE EARTH'S CLIMATE system is characterized by the energy balance of the Earth, the distribution of energy in space (or Earth's atmosphere), and temporal energy variation. The Earth's radiative energy balance is governed by the balance between the solar radiation and absorption by the Earth, and subsequent radiation from the Earth to outer space. The absorbed solar shortwave radiation by Earth is emitted back to outer space in thermal infrared or longwave radiation to maintain the Earth's heat energy balance. The imbalance (surplus) in the Earth's energy budget leads to global warming.

In the 20th century, according to global temperature records, the near surface of the Earth warmed by nearly 1.0 degree F (0.6 degrees C). This global warming is due to anthropogenic climate-forcing agents, such as greenhouse gases (GHG) including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), ozone (O_3), water vapor, and other gases. These climate-forcing agents block, trap, or absorb the thermal infrared energy radiated from the Earth to space. These agents also have energy-scattering ability. The absorbed thermal infrared energy is later radiated back to the Earth making the Earth warmer (the greenhouse effect). These climate-forcing agents also absorb solar shortwave energy and radiate that to the Earth in a later stage, thus warming the Earth's surface.

According to climatologic research, water vapor (without clouds), CO_2, CH_4, and O_3 cause about 36–70 percent, 9–26 percent, 4–9 percent, and 3–7 percent of the greenhouse effect on the Earth, respectively. The higher ends of the ranges quoted here are for the gas alone and the lower ends are for overlapping. Water vapor is a profound contributor to the greenhouse effect. Unfortunately, based on evaporation feedback, the amount of water vapor in the atmosphere is increasing with passing years.

Climate forcing is an imposed, natural, or anthropogenic perturbation of the Earth's energy balance with space. Anthropogenic greenhouse gases such as CO_2, CH_4, O_3, N_2O, chlorofluorocarbons (CFCs), and black carbon particles cause the largest positive climate forcing, warming up the Earth. CO_2 is the greatest climate-forcing agent as its absorptive and radiative power of atmospheric infrared energy is more than any other greenhouse gases. Black carbon produced by forest burning, emissions from thermal power plants, and volcanic activities has the next highest climate-forcing effect. CH_4 and O_3 also contribute significantly to global warming.

Climate forcing agents' ability to absorb and emit back to earth thermal infrared or longwave is also measured in terms of global warming potential (GWP). GWP is a relative scale: GWP of a climate-forcing agent is compared to the same mass of CO_2. GWP is mostly based on the radiative properties of the gases and how they impact the climate system, especially the warming of the surface of the Earth. Of course, each greenhouse gas does not absorb the Earth's radiated heat with similar potential. It also depends upon the rate of decay of each gas relative to CO_2. GWP is the measure of relative radiative effect of a given gas compared to another (CO_2) over a particular time horizon, such as 50, 100, 500, or 1,000 years. Hydrofluorocarbons (HFCs) and Perfluorocarbons (PFCs) are the most heat-absorbent. Methane and N_2O are more than 21 times and 270 times more heat-absorbent than CO_2.

It is essential to reduce the amount of positive climate-forcing agents, or GHGs, from the atmosphere to at least slow down the global warming process. The proposed Kyoto Protocol is designed to slow emissions of several of these positive climate-forcing agents.

SEE ALSO: Greenhouse Effect; Greenhouse Gases; Kyoto Protocol; Radiation, Absorption; Radiation, Infrared.

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Atmospheric General Circulation Models

GENERAL CIRCULATION MODELS of the atmosphere are computer-driven mathematical models that aim to represent the numerous actions within the atmosphere of the entire world and its interactions with the surface of the Earth. Initially intended to improve understanding of the movements of the atmosphere, with a view to predicting weather phenomena and preparing for adverse weather, circulation models have since provided further understanding of the impact of atmospheric warming and its implications for all forms of life on the Earth.

The atmosphere is an extraordinarily complex system—or set of systems—and modeling its actions is far beyond the ability of any single human brain. Indeed, its complexity is such that it even defeats the intuitive nature of the brain because second, third, and higher-order effects are, if not unimaginable, then at least incalculable. However, appreciating that level of sophistication and complexity was not possible until the expanded observations of the atmosphere that resulted from World War II.

These new observations opened the eyes of scientists to global interactions. Previously, only partial models, based on geographical regions, had been attempted. They also helped to demonstrate that processes such as cloud formation and other forms of meteorological physics were much more complex than had previously been imagined. Indeed, understanding the turbulent behavior of gases and liquids remains one of the most complex problems in modern mundane physics. For example, the influence of tropical and trade wind systems had not been fully integrated into worldwide models, while the circulation of the oceans has still not been comprehensively audited at all depths.

Attempts to create a model by experimental means, through, for example, heating gases around a spherical object, were crude approximations at best because of the lack of subtlety in defining the specific characteristics of the earth compared to a simple, homogeneous sphere. More success has been reached by identifying a series of simpler, lower-level equations and the ways in which they interact with each other from the bottom up have been more successful than approaches from the top down.

IMPROVEMENTS

The level of complexity of these issues meant that it was not until the development of digital computers in the 1950s that any serious attempt could be made to model the atmosphere as a whole. Early attempts treated the atmosphere and, indeed, the Earth's surface, as homogeneous composites of all possible values of the variables employed. Hence, there was little or no differentiation between land and sea or among the various layers of the atmosphere. Clearly, no model based on these initial conditions would be able to represent the complexity of the overall model.

The development of computer power has, on a rapidly accelerating trajectory, improved the accuracy of existing models and enabled integrating new variables into the overall model. As the model grows in its ability to provide satisfactory answers—that is, to provide increasingly better predictive power in forecasting actual weather conditions—scientists are able to identify new variables that may be included. On some occasions, practical issues preclude direct observation of the desired variables and, hence, proxy variables must be included instead. At the same time, researchers are adjusting their models by employing different variable weightings, varying certain initial conditions, and making other slight changes to determine the sensitivity of the models and their ability to replicate accurate simulations on a consistent basis.

No individual model is likely to provide a definitive answer, or to be qualitatively better than any other or to have one set of weightings that is consistently superior to any other. Prudence suggests, therefore, that researchers will search for a broad consensus of results before making claims for improved performance. This is facilitated by the peer-reviewing process in the academic world, which measures research findings against existing knowledge and information. The process tends to enhance accuracy, but delays reporting of some findings and tends to make researchers act with more equivocation than they might be asked to show by journalists or politicians. As the issues of global atmospheric warming and attendant climate change have taken an increasingly central role in political agendas around the world, climate modelers have found their methods and results questioned more stringently than ever before and there have, as a result, been some cross-cultural collisions that have done little, if anything, to improve aggregate understanding.

One of the first scientists successfully to make the link between the emission of carbon dioxide into the atmosphere at unprecedented rates with future climate change, was Syukuro Manabe. Manabe integrated oceanic and atmospheric climate models and identified the flows between them of momentum, heat, and water. His conclusion was that general atmospheric temperatures would rise by several degrees if the amount of carbon dioxide in the atmosphere doubled. A great deal of subsequent work on circulation models has been involved with either verifying or falsifying this initial conclusion. The main effect has been to refine the result and it has become apparent that, despite many (often well-financed) attempts to find flaws in the fundamental assumptions of such models, there can be no meaningful doubt that increasing levels of carbon dioxide and other greenhouse gases are having a measurable impact on current weather conditions and will have a greater impact in the future. The issue has been complicated for political reasons as powerful incentives exist to inspire certain people and interests to cast doubt on the findings. Media ownership issues in countries such as the United States mean that proper treatment of science in public discourse sometimes has been overtaken by partisan, and often uninformed, opinion.

FUTURE DEVELOPMENTS

Much remains to be done to improve the accuracy and sophistication of existing models, as well as to expand the range of data observations. The urgency with which this work should be completed has increased as the impact of global climate change intensifies. There is an urgent need for properly reviewed research to inform policy decisions in governments around the world to a much greater extent than occurs at the moment. Although many governments have committed themselves to international undertakings such as the Kyoto Protocol, their actual performance nearly always features as the lower end of target brackets and, at the same time, it has become increasingly clear that the existing targets are insufficient to deal with already forecasted changes in the atmosphere. There is a clear need for improved public education concerning the scientific method and ways of separating fact from obfuscation.

In technical terms, in addition to the continuous improvement of the treatment of variables and their integration into existing models, there is an important need to extend the time scales over which predictions of future weather phenomena take place. This will improve understanding of future changes. Second, there is also a need to improve understanding of the interaction among the different components of climate models and current understanding of past events.

Evidence from past ice ages, for example, provides a sound basis for understanding those conditions. However, there have been disparities between observed and predicted conditions, in the case of other factors such as sea temperatures. Even apparently small differences in conditions can significantly affect final results of these models.

SEE ALSO: Atmospheric Component of Models; Climate Models; Manabe, Syukuro; Modeling of Ice Ages; Modeling of Ocean Circulation; Modeling of Paleoclimates.

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Atmospheric Research and Information Centre

THE ATMOSPHERIC RESEARCH and Information Centre (ARIC) is an institution that works to educate citizens of Great Britain about environmental and geographical sciences. Established in 1984, staff at the Centre perform research and provide consulting in the field of atmospheric sciences.

The ARIC also maintained the Atmosphere, Climate & Environment (ACE) Information Programme, to educate people in Great Britain about the environment, specifically addressing pollution and air quality. The purpose of this program was to provide objective information to the public. It was supported financially until 2005 by the Department for Environment, Food, and Rural Affairs of the United Kingdom.

The ARIC is based at Manchester Metropolitan University, Manchester, England. Manchester Metropolitan University (MMU) was founded in the first half of the 19th century with the merger of the Manchester Mechanics' Institution (established in 1824) and the Manchester School of Design (established in 1838). Today the institution is spread over seven campuses. Five of these campuses can be found in Manchester, with two satellites in Cheshire, at Alsager and Crewe.

The ARIC is part of MMU's Centre for Air Transport and the Environment (CATE). CATE focuses on the sustainability of aviation and its intricate relationship with environmental maintenance. Researchers at CATE focus on the environmental impact of aviation. As a multi-disciplinary research center, CATE consolidates information from and shares information with all sectors: academia, industry, government, and nongovernmental organizations (NGOs).

The five major research branches at CATE are Climate Change, Local Air Quality, Noise and Community Impacts, Omega, and Sustainable Development. Climate Change researchers examine the impact of aviation on the global climate. Scientists in the Local Air Quality branch assist local airlines with reaching emissions standards and keeping British airports within national and international criteria. The Noise and Community Impacts team looks at the attitudes of local communities around airports and how these attitudes affect airport growth. Additionally, researchers study the impact of airports and their noise on these communities. In the research branch of Sustainable Development, while at the end of the year 2007 there were no projects underway, several had been completed. These projects examined a range of variables. such as the "Eco-footprinting of airports" and "Sustainability indicators."

SEE ALSO: Education; Nongovernmental Organizations (NGOs); Policy, International; Public Awareness; United Kingdom.

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Atmospheric Vertical Structure

THE ATMOSPHERE COMPRISES the thin envelope of gases held by the Earth's gravitational force. Extending for several hundred miles above the Earth's surface with no clear boundary, the atmosphere is often subdivided into vertical layers according to a distinctive physical properties. These properties include thermal characteristics, chemical composition, electrical attributes, or density. The vertical structure of the atmosphere is defined by changes in these physical properties, with each change determining a new layer.

The density of the atmosphere refers to the mass of atoms and molecules per unit volume of air. As with all gases, air molecules are not in a fixed, rigid arrangement, and can move randomly through space. No upper threshold to the mass contained per unit volume exists, and, as such, air density can fluctuate. The average density of air at sea level at a temperature of 68 degrees F (or 20 degrees C) is 1.2 kg. per cu. m. (or approximately 1.2 oz. per cu. ft.), decreasing rapidly at lower heights and more gradually with increasing altitude.

This nonlinear relationship between air density and altitude results from another common property of gases, compressibility: the atmosphere expands (and contracts) with decreasing (or increasing) pressure. Atmospheric pressure results from the force exerted by the mass of air molecules subjected to gravitational acceleration over a surface; in other words, the weight of the air above.

The average sea-level pressure of the Earth is 1011 hectoPascals (hPa), but can have considerable local variability. Because the atmosphere is compressible, air molecules are more compact closer to the surface, thereby increasing the density and pressure of the air at lower altitudes. As with air density, pressure decreases at a decreasing rate with increasing height. Approximately one-half of the atmosphere lies below a height of 3.5 mi. (5.5 km.), corresponding to a pressure of 500 hPa. Nearly 90 percent of the atmosphere lies below 10 mi. (16 km.) and a pressure of 100 hPa.

In comparison to density and pressure, the structure of the atmosphere according to thermal characteristics is more complex. Interactions among various atmospheric gases and radiant energy from the Sun and Earth result in distinct variations in the vertical temperature profile. Based on these thermal changes, the atmosphere is commonly subdivided into four major layers known as the troposphere, stratosphere, mesosphere, and thermosphere.

The troposphere encompasses the lowest portion of the atmosphere, from the surface to an average height of 7.5 mi. (12 km.). The temperature of the troposphere is primarily influenced by the radiant energy exchanges from the underlying surface. The further the air molecules are away from the surface, the less the atmosphere will warm. Tropospheric temperature decreases with height at an average rate of 3.5 degrees F per 1,000 ft. (6.5 degrees C per km.), a measurement termed the *normal lapse rate*. The top of the troposphere, known as the tropopause, has an isothermal layer, a zero lapse-rate region, where temperature does not change with altitude. The tropopause occurs at heights ranging from 5.6–9.9 mi. (9–16 km.), depending on latitude and season.

Beyond the tropopause lies the stratosphere. In this region, the isothermal layer gives way to a temperature increase with height or temperature inversion. This temperature increase occurs because of a localized concentration of ozone molecules (O_3) found 9–19 mi. (15 to 30 km.) above the Earth's surface. These molecules absorb ultraviolet solar radiation that warms the stratosphere.

Stratospheric warming terminates around 30 mi. (50 km.) at the stratopause, which marks the transition zone between the stratosphere and the much colder mesosphere. In the mesosphere, temperatures decrease rapidly with height. This layer contains the lowest temperatures of the atmosphere, averaging minus 130 degrees F (minus 90 degrees C) at 50 mi. (80 km.) above the surface. These lows are reached at the mesopause, the boundary between the mesosphere and thermosphere.

The thermosphere represents the outer layer of the Earth's atmosphere. Temperatures in this layer increase substantially with height from the absorption of solar energy by relatively few oxygen molecules (O_2).

While temperatures can register to values more than 1,800 degrees F (1,000 degrees C), the thermosphere holds an insignificant amount of heat due to the extremely low density of atmospheric gases. The thermosphere (and the upper mesosphere) also contains a large concentration of ions and free electrons in a sub-layer known as the ionosphere. Between 50–250 mi. (80–400 km.), these ionized molecules interact with charged particles from the sun to produce brilliant light displays at high latitudes known as the *aurora borealis* (northern lights) or *aurora australis* (southern lights), in the Northern and Southern Hemispheres, respectively.

SEE ALSO: Atmospheric Composition; Aurora; Mesosphere; Stratopause; Stratosphere; Thermosphere; Tropopause; Troposphere.

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Attribution of Global Warming

ATTRIBUTION OF GLOBAL warming refers to the recent effort to scientifically prove the cause of the warming effect. Many factors can cause changes in the Earth's heat balance, and changes large enough to cause major episodes of warming and cooling have taken place many times in the Earth's past. One cause of change of great concern to scientists is the amount of heat-absorbing gas in the atmosphere. Carbon dioxide, water vapor, and several secondary gases absorb thermal infrared radiation released from the Earth's surface and the lower atmosphere.

Greenhouse effect is the phrase for when a planet's atmosphere and surface are warmed by the absorption and emission of infrared radiation of atmospheric gases. When absorption takes place, the gas molecules take on heat and air temperature rises. If the atmosphere is heavy with water vapor and carbon dioxide, then heat tends to be retained in roughly the same way as the glass of a greenhouse contains longwave infrared radiation and heat. Hence, greenhouse effect is commonly used to describe the role of carbon dioxide (CO_2) and H_2O vapor and various secondary gases in holding heat within the atmosphere.

To illustrate the importance of the greenhouse effect, scientists estimate that if it were eliminated, the Earth's equilibrium surface temperature would fall 59 degrees F to 0 degrees F (33 degrees C to minus 18 degrees C). Global warming is one of the specific examples of climate change, referring to recent warming, and implying a human influence. Global warming is the status quo of the increasing average temperature of the Earth's near-surface air and oceans. It also refers to its projected continuation.

HUMAN-INDUCED CLIMATE CHANGE

The dominant mechanisms to which recent global warming and climate change have been attributed all result from human activity, such as increasing atmospheric concentrations of greenhouse gases, or aerosols. These attributions are supported by observations from the Intergovernmental Panel on Climate Change (IPCC). The IPCC concluded that most of the observed increase in globally averaged temperatures since the mid-20th century is "very likely" due to the observed increase in anthropogenic greenhouse gas concentrations via the greenhouse effect. It also concluded that it is "extremely likely" that human activities have exerted a substantial net warming influence on climate since 1700. These conclusions have probabilities greater than 90 and 95 percent, respectively.

Since the 1700s, the CO_2 content of the atmosphere has been increasing as a result of air pollution emitted by human activities. Pollution has also caused a significant increase in secondary greenhouse gases, namely methane from animal digestion and bacteria, ozone and nitrogen oxides from urban air pollution, and chlorofluorocarbons from spray cans and fugitive refrigerants. The increase in CO_2 and the four secondary greenhouse gases is a global trend. Since 1760, the atmospheric concentrations of CO_2 and methane have increased by 32 percent and 151 percent, respectively, compared to the pre-industry period. Therefore, the biggest root cause is worldwide population growth.

According to the IPCC, the projected increase of global surface temperatures is likely to be 2.1–11.7 degrees F (1.2–6.5 degrees C) between 1995 and 2100, based on the different scenarios of future greenhouse gas emissions and climate sensitivity. These conclusions have been endorsed by at least 30 scientific societies and academies of science, including all of the national academies of science of the major industrialized countries.

The argument related to global warming focuses on how much the greenhouse effect will be increased with the growing atmospheric concentrations of some greenhouse gases by human activities. Naturally occurring greenhouse gases consist of about 36–70 percent water vapor (not including clouds), 9–26 percent CO_2, 4–9 percent methane (CH_4), and 3–7 percent ozone. Comparatively small fractions of the greenhouse effect are caused by naturally occurring gases such as nitrous oxide (N_2O). Concentrations of N_2O are increasing because of human activity such as agriculture. CO_2 is produced mainly by natural processes such as volcanoes and rock weathering, and is recycled through the atmosphere by the biological processes of respiration and photosynthesis.

Over geologic time, atmospheric CO_2 has varied appreciably, causing shifts in the Earth's heat balance. Over periods of thousands of years, however, the CO_2 cycle can keep a fairly stable balance, thereby helping maintain a relatively stable global temperature regime. CO_2 from human sources, however, represents a surcharge on the natural system.

Human sources of CO_2 fall into roughly two major classes: fossil fuel combustion and open fires. Use of fossil fuels by humans contributes to three-quarters of the increase in CO_2 over the past 25 years. The fossil fuel sources are industry, power plants, automobiles, and households; the developed countries are the principal contributors. The open-fire sources are associated with the clearing of tropical forests, forest fires in general, grassland fires, household cooking and heating, and wars. The rate of increase in atmospheric carbon dioxide approximates that of global economic growth, about 2 percent annually. Current carbon dioxide levels are about 30 percent above the 18th century (pre-industrial) level.

It is crucial to scientifically determine mechanisms responsible for the observed warming of the Earth, and many efforts have been made to prove changes observed during the last 50 years, when human activity has grown fastest and observations of the upper atmosphere have become available. There are measurable signs that warming is underway, because the global atmospheric temperature has increased at least 0.9 degrees F (0.5 degrees C) in the last 100 years. This rise corresponds to the measured increase in atmospheric CO_2. Even though short-term temperature trends on the order of 50 or 100 years generally have little meaning with respect to global-scale warming, it is curious to note that studies of global temperature records dating from the late 1800s indicate that the 1980s and 1990s were the warmest two decades on record.

The IPCC has played an important role in providing the attribution of global warming, however, there are still several uncertainties that have to be resolved, including the exact degree of global warming expected in the future, and how changes will vary from region to region around the globe. One reason for scientists' uncertainty about how much global warming will take place is related to the rate of removal of CO_2 from the atmosphere. CO_2 is removed from the atmosphere by two main absorbing agents, vegetation and the oceans.

Under natural circumstances, it can be assumed that the oceans annually extracted 90 billion tons of CO_2 from the atmosphere, an amount equal to the quantity they put into the atmosphere yearly. However, with the rise of global air pollution, the oceans appear to have increased their CO_2 intake and now absorb a large part of the 7 billion tons of excess CO_2 put into the atmosphere annually from human sources. The amount may be as great as three billion additional tons a year. Therefore, the net amount of CO_2 left to accumulate in the atmosphere is about 4 billion tons a year.

At this rate, coupled with allowances for population growth, atmospheric CO_2 is expected to double by 2050. Whether the oceans and land vegetation will increase or decrease their intake of CO_2 in the future is difficult to claim at this point. Recent researchers concluded that the estimate of 3 billion tons of annual ocean intake may be high. The oceans may actually be taking in closer to 2 billion tons a year, and some other agency is responsible for extracting the remaining 1 billion tons of CO_2. Perhaps the world's forests might be a good candidate to increase the rate of intake. Some studies suggest that air pollutants such as CO_2 and sulfur dioxide may actually increase forest growth and intake CO_2 in some regions. The annual rate of rainforest destruction, as much as 65,000 sq. mi. (168,349 sq. km.) a year, is a considerable loss, especially when forests have very high annual CO_2 intake capacities.

FEEDBACK PROCESSES

The second category of the attribution of the warming is the various feedback processes caused by the forcing agents on the climate. Evaporation of water might be the most evident feedback effect that contributes to global warming. The initial warming generated by CO_2 will cause more water to be evaporated into the atmosphere. Then, water vapor acts as a greenhouse gas and causes more global warming. As a result, the global warming causes still more water vapor to be evaporated until the concentration of water vapor has reached the dynamic equilibrium, with a much larger greenhouse effect than that due to CO_2 alone. This increases the amount of the absolute moisture in the air, but the relative humidity of the atmosphere rarely changes because the air is warmer.

Cloud feedback effects are an area of ongoing research. In the air, clouds emit infrared radiation from the ground back to the surface and enforce the warming effect. The same clouds reflect sunlight and emit infrared radiation from sun to space and enforce the cooling effect. Because the type, altitude, and other variables are important factors in deciding the net effect of clouds on cooling or warming, it is very difficult to represent in climate models. Nevertheless, cloud feedback is reported as the second largest positive feedback that contributes to the global warming models that were used in the IPCC Fourth Assessment Report.

Ice albedo feedback is another feedback process that contributes to global warming. As global temperatures increase, the melting process of the ice near the poles increases rapidly. The resulting land and open water are, on average, less reflective than ice, and, thus, absorb more solar radiation. This causes more warming, which in turn causes more melting, and this cycle continues. Positive feedback due to release of CO_2 and CH_4 from thawing permafrost is an additional mechanism contributing to warming. Possible positive feedback due to CH_4 release from melting seabed ice is a further mechanism to be considered.

A COUNTERARGUMENT

In contrast to the scientific consensus, there is a counterargument by a few individual scientists who cast doubt on the global warming forecast. Their claims are based on the blocking effect on solar radiation caused by aerosols. Aerosols are particles of solids and liquids suspended in the atmosphere that backscatter incoming solar radiation. Aerosols are produced from both natural sources such as volcanoes, and pollution sources such as forest fires and urban emissions. They occur in both primary and secondary forms, meaning that some enter as particles, whereas others develop into particles from gaseous pollutants. In addition, pollutants increase condensation and cloud formation, thereby increasing reflection of solar radiation. Because aerosols and clouds reduce solar radiation receipt in the lower atmosphere and at the Earth's surface, they also reduce solar heating and may cause temperatures to decline as a result.

The effect of aerosols on solar heating of the lower atmosphere was dramatically demonstrated in the hours immediately after 9/11. The U.S. government ordered grounding of all aircraft, and for a short time, skies over the United States and Canada were clear of condensation trails from high-flying jetliners. During that time, a distinct rise in surface temperature was recorded over broad areas.

With the resumption of flying, temperatures fell back to pre-9/11 levels. With the dramatic increase in global air pollution in this century, the atmosphere has grown dirtier and less transparent to solar radiation. Less solar energy reaches the Earth's surface, and if there were no counterbalancing factors, the lower atmosphere would probably be growing cooler. But there are counterfactors in the form of CO_2 and warming gases.

EFFECTS OF GLOBAL WARMING

If global warming proceeds, Earth's equilibrium surface temperature will rise 3–11 degrees F (2–6 degrees C) over the next 100 years. Earth's equilibrium surface temperature will reach 62–68 degrees F (17–20 degrees C). This means that more thermal energy will be available to drive atmospheric processes such as winds, air mass movement, and evaporation. How all of this will interrelate to shape the broad picture of global climate is difficult to forecast. Based on computer simulation models illustrating anticipated changes in atmospheric circulation, scientists forecast that warming will not be geographically uniform; in some regions it will be significantly greater than others, and the climatic changes will likely be different in different parts of the world.

Specific examples of the modeling approach for change of global temperature scenarios are simple climate models (SCMs). SCMs are the simplified models used by the Intergovernmental Panel on Climate Change (IPCC) to provide projections of the atmospheric concentrations of greenhouse gases, global mean temperature, and sea-level change response, using as input emissions scenarios describing the future developments in the emissions of greenhouse gases.

The increased heat content of the troposphere will strengthen certain air masses, increasing their moisture content, leading to greater storminess in some regions. It is already known that that storminess and precipitation on the Pacific coast of the Americas increases substantially with only 1.8–3.6 degrees F (1–2 degrees C) of atmospheric warming associated with El Niño, the periodic buildup of warm water in the east Pacific near the equator. Increased ocean temperatures may also lead to increased magnitude and frequency of hurricanes. Hurricanes are driven by the energy of water vapor, called latent heat. Warmer ocean waters supply more vapor, and thus more energy, to the atmosphere to fuel storms. Hurricanes are the most powerful storms on the planet, and the greater their fuel supply, the bigger and more destructive they are.

Although it is difficult to connect specific weather events to global warming, an increase in global temperatures may, in turn, cause other changes, including glacial retreat and worldwide sea-level rise. Changes in the amount and pattern of precipitation may result in flooding and drought.

There may also be changes in the frequency and intensity of extreme weather events. Other effects may include changes in agricultural yields, reduced summer stream flows, species extinctions, and increases in the range of disease vectors. Some effects on both the natural environment and human life are, at least in part, already being attributed to global warming.

The broad agreement among climate scientists that global temperatures will continue to increase has led nations, states, corporations, and individuals to implement actions to try to curtail global warming or adjust to it. Many environmental groups encourage action against global warming, often by the consumer, but also by community and regional organizations. There has also been business action on climate change, including efforts at increased energy efficiency, and moves to alternative fuels. One important innovation has been the development of greenhouse gas emissions trading through which companies, in conjunction with government, agree to cap their emissions or to purchase credits from those below their allowances.

THE KYOTO PROTOCOL

The world's primary international agreement on combating global warming is the Kyoto Protocol, an amendment to the United Nations Framework Convention on Climate Change (UNFCCC), negotiated in 1997. The protocol now covers more than 160 countries and over 55 percent of global greenhouse gas emissions. As of 2007, the United States (historically the world's largest greenhouse gas emitter), Australia, and Kazakhstan had not ratified the treaty. China and India have ratified the treaty, but as developing countries, are exempt from its provisions. This treaty expires in 2012, and international talks began in May 2007 on a treaty to succeed the current one. Increased awareness of the scientific findings surrounding global warming has resulted in political and economic debate. Poor regions, particularly in Africa, appear at greatest risk from the suggested effects of global warming, while their actual emissions have been negligible compared to the developed world.

At the same time, developing country exemptions from provisions of the Kyoto Protocol have been criticized by the United States and Australia, and have been used as part of their rationale for continued non-ratification. China's CO_2 emissions, mainly from automobiles and coal power plants, are expected to exceed those of the United States within the next few years. China has contended that it has less obligation to reduce emissions, since its emissions per capita are about one-fifth those of the United States. The United States contends that if they must bear the costs of reducing emissions, so should China. India will also soon be one of the biggest sources of industrial emissions, and has made assertions similar to China's on this issue.

The world's primary body for crafting a response is the Intergovernmental Panel on Climate Change (IPCC), a UN-sponsored activity that holds periodic meetings between national delegations on the problems of global warming, and issues working papers and assessments on the current status of the science of climate change, impacts, and mitigation.

SEE ALSO: Carbon Emissions; Carbon Sinks; Evaporation Feedbacks; Greenhouse Effect; Greenhouse Gases; Hurricanes and Typhoons; Kyoto Protocol.

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Aurora

AN AURORA IS a colored display of light usually seen at night. They are natural, and occur more commonly in the polar regions than in temperate southern regions in the Northern Hemisphere or more temperate northern regions in the Southern Hemisphere. Auroras occur most frequently in the Northern Hemisphere around the time of the autumn equinox in September and October and at the spring equinox in March and April. Auroras are sometimes called polar auroras (*aurorae polaris*), or in the Northern Hemisphere, *aurora borealis*. A popular name in the Northern Hemisphere is the *northern lights;* in the Southern Hemisphere they are the *southern lights* or the *aurora australis* (Latin for southern is *australis*).

The *aurora borealis* begins with a magnetic storm on the sun. If the sun emits an extra mass of particles in a solar wind to the Earth, this can then produce a magnetic storm on earth. If the conditions are right, the *aurora borealis* can be seen not only at the poles, but far to the south in the Northern Hemisphere or far to the north in the Southern Hemisphere.

The light displays of auroras are caused by charged ion particles reaching the upper atmosphere of the Earth in solar wind. If the particles arrive as a cloud, they are called solar plasma. If the particles collide with one another when they are in an excited atomic state, light is emitted. This means that there may be more electrons surrounding an atom than normal. The excess energy can be emitted from the particle as visible light. Usually, the light is in wavelengths of 22 in. (557.7 mm.), which is in the visible light range of green. Some may be at lower or higher wavelengths and, thus, seen as red or other colors. The particles follow the Earth's magnetic field and may appear to glow as wavering sheets or curtains. Other forms of aurora activity occur as arcs of light, which can also be in folds that appear to have striations. Contributing to the shape of the *aurora borealis*

Aurora activity has been associated with sunspots since 1852; links to climate patterns are still being investigated.

are the rotation of the Sun and the rotation of the Earth. As the solar stream hits the Earth, it meets the Earth's rotation. The two combine to make a spiral shape.

Contributing to the frequency of the aurora is the sun's 11-year cycle. Sunspots and the emission of solar particles occur in a cycle that rises and falls in activity. Auroras are associated with a high number of sunspots. This relationship has been known since 1852, when Edward Sabine first identified it using sunspot and aurora spotting data that went back 100 years. This relationship seems to also correlate with climate patterns.

There is speculation that fluctuations in climate are closely related to the presence of aurora activity in Earth's atmosphere. The *Maunder minimum* is the term that was first used to identify the period 1645–1715. This was a time in which aurora activity was rarely seen, and sunspots were not observed with any frequency. In 1976, it was demonstrated that the Maunder minimum was associated with abnormal amounts of C_{14} in tree rings. When the Edda Period, a period of high sunspot activity in the 12th and 13th centuries was examined, numerous references to aurora activity were also found.

Some researchers have theorized that global warming may be associated with sunspot activity, or global cooling with its absence. Research is being conducted into the possibility that global warming is caused by solar emissions, rather than by the increasing presence of higher levels of carbon dioxide in the atmosphere due to pollution emissions since the Industrial Revolution.

SEE ALSO: Antarctic Circumpolar Current; Arctic Ocean; Atmospheric Vertical Structure; Solar Wind; Sunlight.

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Australia

AUSTRALIA IS A developed country in the Southern Hemisphere. With a landmass of 2,941,299 mi. (7,617,930 sq. km.), it is the sixth largest country in the world, but is sparsely inhabited, with a population of approximately 21 million. Prior to federation in 1901, the continent of Australia was comprised of separate colonies and territories. The Commonwealth of Australia is now divided politically into six states and two major territories. Australia is also responsible for a number of minor territories, including Christmas Island, the Cocos Islands, and Norfolk Island.

Most of Australia's population is concentrated in the southeast of the country, although there has been rapid population growth in the northeast (Queensland) and in the southwest (Western Australia). The national capital is Canberra. The largest cities are Sydney and Melbourne (each with about 4 million residents); and Brisbane, Perth, and Adelaide, each with 1–2 million residents in 2006. Most of the population lives close to the coast. There are inland agricultural and mining towns, but the interior of the country is semi-arid or arid with little human settlement.

Indigenous people have inhabited the continent for at least 40,000 years. European and Asian exploration and trade occurred for hundreds of years before the arrival of the English. Dutch explorers, particularly those associated with the

Dutch East Indies Company, are known to have landed on Australia beginning at least early in the 17th century. They gave the land the name *Terra Australis Incognita* ("unknown southern land"). Captain James Cook claimed the land for England in 1770, and English settlement began in 1788, in what is now Sydney. The colonies developed at different rates, boosted by gold rushes in New South Wales and Victoria in the 1850s, and in Western Australia in the late 1880s and 1890s. Mining booms have been significant, particularly coal mining in New South Wales and Queensland, and iron-ore mining in the northwest of Western Australia.

Climate change is an important issue for Australia, due to its position on the global political scene, its generation of greenhouse gases, and the potential impact of climate change for Australia. With regard to political positioning, in December 1992, Australia became the eighth country to ratify the United Nations Framework Convention on Climate Change, which had been signed by 155 countries in Rio de Janeiro. The most significant of the Conferences of the Parties (COP) held to develop and implement the framework was COP3 in Kyoto, Japan. At COP3 in 1997, the Annex One (developed) countries agreed to an average reduction of 5.2 percent of greenhouse gas emissions from a base year of 1990 by the period 2008–12.

Australia signed up to an 8 percent increase in emissions over the same time period, but also managed to insert a clause into Article 3.7 of the Kyoto Protocol to allow the emissions from land clearing to be included in the total emissions by Australia in 1990. Land clearing had decreased between 1990 and 1997. The baseline inflation gave room for Australia to expand other sources of greenhouse gas emissions and potentially remain within the 108 percent target.

Australia and the United States refused to ratify the Kyoto Protocol, citing the exclusion of countries such as China, India, and Brazil, plus Australia's unique economic structure (a large coal exporter and a very high greenhouse gas emitter per capita) and its national interest, as other reasons not to ratify the protocol. In February 2002, the U.S.-Australia Climate Action Partnership was established to work outside of the Kyoto Protocol framework. This concept was expanded in January 2006 into a new Asia-Pacific Partnership on Clean Development and Climate Change, comprised of Australia, China, India, Japan, the Republic of Korea, and the United States.

Australia is working outside of the Kyoto Protocol because of the political stance of the government, Australia's economic structure, its emissions generation, and because of the likely impacts of climate change for Australia. Australia produces approximately 2.3 percent of the world's greenhouse gas emissions, which is a very high rate per capita. Australia is also connected through the coal chain to global greenhouse gas emissions. At a global level, Australia is a rare example of a country that exports most of the coal it mines. Australia is the world's largest coal exporter, with markets mainly in Japan, South Korea, Taiwan, and other European and Asian destinations. The Port of Newcastle is the largest exporter of coal by tonnage in the world.

Stationary energy/power stations (68 percent), agriculture (19.5 percent), and transport (14.2 percent) generated most of Australia's greenhouse gas emissions in 2001. Industrial processes contributed only 4.6 percent of the total emissions. These aggregate figures do not account for the end use of the energy. The figures also highlight Australia's reliance upon fossil fuels. Australia's transport energy is predominantly petroleum; 84 percent of electricity in Australia is generated from coal.

The impacts of climate change will vary. Australia is vulnerable to drought, the ecosystems and biodiversity are prone to climate change in the long term, there are concerns that fires and insect outbreaks may be increased, and that coastal settlements are susceptible to flooding and erosion caused by sea-level rise. Inland temperatures are anticipated to increase more than temperatures in coastal locations, thereby making Australia very vulnerable to water shortages and threatening the health of rivers. By 2050, cities in northern Australia, such as Cairns, are likely to experience more intense tropical cyclones, with wind speeds likely to increase by 10 to 15 percent, the associated rainfall likely to increase by 20 to 30 percent; the area that is inundated by storm surges is likely to double.

There are innovative programs at federal, state, and local government levels in Australia that address the issue of climate change. These include Cities for Climate

Protection, which is coordinated and supported by the Australian Greenhouse Office and the International Council for Local Environmental Initiatives. There are also business initiatives and environmental groups campaigning about climate change. Unfortunately, Australia's greenhouse gas emissions have been rising steadily since the 1990s, and as of 2004 were reported at 25 percent above 1990 levels.

SEE ALSO: Drought; Economics, Cost of Affecting Climate Change; Economics, Impact of Climate Change; Energy, Renewable; Nuclear Power; Rainfall Patterns; Southern Oscillation.

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Austria

LOCATED IN CENTRAL Europe, Austria covers 32,383 sq. mi. (83,872 sq. km.) and has a population of 8,316,487 (2007 est.), with a population density of 257 people per sq. mi. (99 per sq. km.). Some 17 percent of the land in the country is arable, with a further 23 percent used for meadows and pasture. In addition, 41–47 percent of the country is forested, making it the most extensively wooded country in Europe.

As a wealthy country, Austria's population uses electricity and private cars extensively. However, use of bicycles has increased in recent years, and there is an extensive train service covering much of the country, in part duplicated by bus service.

The prosperity of the country has resulted in a relatively high rate of carbon dioxide emissions per capita: 7.5 metric tons in 1990, rising to 8.6 metric tons by 2003, significantly lower than that of the Czech Republic and Germany, but higher than its other neighbors. As for electricity generation in Austria, only 28.4 percent of it comes from fossil fuels, with 68.6 percent from hydropower. As a result, the country produces extremely low rates of emissions of sulfur dioxide, nitrogen oxide, and carbon monoxide.

The effects of global warming in recent years in Austria include the melting of some of the Alpine glaciers. The melting glaciers in the Ötztal Alps led to the November 1991 discovery of the preserved body of a frozen Stone Age person, nicknamed Ötzi, indicating that the glacial ice is smaller than at any period in the last 5,000 years. One study has shown that alpine plants in the Austrian Alps are now growing higher and higher on mountain slopes, in response to the rise in average annual temperatures. These changes, as well as an increase in development, have led to the endangering of the *Kaiseradler*, or Imperial Eagle.

A United Nations environmental report in 2003 claims that if global warming continues to raise the temperature in Austria, many ski runs, and even entire ski resorts, will have no snow by 2030. The expected rise of between 2.5–10-4 degrees F (1.4–5.8 degrees C) by 2100 would result in the snow line moving from 3,937–5,905 ft. (1,200 m. to 1,800 m.), which would mean that many resorts, such as Kitzbühel, might not have any snow. This also poses a threat to the fauna such as the chamois, the mountain goat, and the ibex.

The Austrian government of Fred Sinowatz took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, and the Global Warming International Conference & Expo (GW7) was held in Vienna on April 1–3, 1996. The government of Viktor Klima signed the Kyoto Protocol to the UN Framework Convention on Climate Change on April 29, 1998. It was ratified on May 31, 2002, and took effect on February 16, 2005. Focusing on a reduction on greenhouse gas emissions, the UN Framework Convention on Climate Change held a round of climate change talks in Vienna on August 31, 2007. During this period, there was a reduction in air and soil pollution from industrial chemicals, including the banning of leaded gasoline. Later government policies have encouraged wind power and solar power, with tax concessions given to people who install solar panels.

SEE ALSO: Climatic Data, Ice Observations; Glaciers, Retreating; Global Warming; Ice Ages.

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Automobiles

TEN BILLION METRIC tons of carbon dioxide and other greenhouse gases are spewed into the atmosphere each year by the fossil fuel-hungry transportation sector. Over the typical 124,000-mile lifespan of an automobile, the Toyota Prius will emit 32 tons of carbon dioxide from its tailpipe versus a Ford Excursion spewing 134 tons.

The type of transportation employed has a major impact on the amount of carbon dioxide and pollutants produced. People can choose their mode of transportation and whether or not to be a part of a growing community that wants to reduce the effects of global warming by cutting back on tailpipe emissions. The internal combustion engine (ICE) is a poor choice of power source. It dissipates 80 percent of its energy as heat, even before it reaches the vehicle's rear axle. Two major approaches to reduce the threat of global warming have emerged in the automobile industry. The first approach encompasses both conservation and new technology. A proven idea is increasing vehicle efficiency at a greater rate than has been done to date. The automobile industry can also develop new vehicle technology beyond the gas-electric hybrids. Introduction of Pluggable Hybrid Electric Vehicles (PHEVs) that double the range of current hybrids and further reduce greenhouse gas tail emissions is on the horizon. Utility operators already know that they can handle the additional demand expected of the power grid, since most PHEV owners would plug in their cars at night to be recharged, when demand for 120-volt supplies is low. All that is needed is improved battery technology and the will of automakers.

A second strategy is to develop alternative fuel supplies to power vehicles. Ethanol-blended gasoline, such as E85, is appearing on the market. New American cars work with this fuel which is 85 percent gasoline and 15 percent ethanol. Vehicles manufacturer-certified to burn E85 produce less carbon dioxide is produced combusting this fuel than burning regular gasoline, in spite of the CO_2 needed to produce the ethanol in the first place. Engine performance is boosted with E85, too, with some vehicles realizing a horsepower gain of up to 5 percent. One major advantage is lowered tailpipe emissions. Other mixtures are being developed, including the use of liquid hydrogen as an alternate source.

While many of these actions are voluntary, regulatory action is often required to raise mileage standards. In the United States, more stringent Corporate Average Fuel Standards (CAFE) spurs development of energy-efficient components and solutions for personal mobility. To achieve new goals for greater miles per gallon, and, hence, lower greenhouse gas emissions, more fuel-efficient engines and transmissions are needed for conventional gasoline-powered or diesel-powered vehicles.

BMW automobiles, a company that does not have a gas-electric hybrid on the market, is also contributing to better fuel efficiency. It developed a brake energy regeneration system as a result of an internal project to provide intelligent alternator control. Every car on the market uses an alternator to continuously generate power, regardless of the engine load. Known as "alternator drag," the alternator consumes energy even when the car is cruising or accelerating, a process referred to as freewheeling. If the alternator only generates power during the braking cycle, the amount of fuel consumed overall is reduced. BMW expects its brake energy regeneration system to cut energy consumption by 3 percent on every car that adopts the technology. The conventional energy cycle can be deconstructed,

A gas-electric hybrid, for example, a Toyota Prius, will emit only 32 tons of carbon dioxide from its tailpipe over a typical 124,000-mile automobile lifespan, while a Ford Excursion will discharge over 100 tons more.

analyzed, and subsequent innovations can deliver better miles per gallon for the driving public.

HYBRID AND ELECTRIC VEHICLES

Hybrid vehicles are available today and continue to gain market acceptance. Toyota's Prius has been the overwhelming favorite of the car-buying public interested in gas-electric hybrids. The first 100,000 Prius gas-electric hybrids were sold by September 2004, after the introduction of the car in Japan in 1997. While it took almost seven years to reach the first 100,000 sales, a five-fold increase was achieved in about 18 months. By April 2006, Toyota's worldwide sales passed 500,000 units. Momentum continued to build, and after another year had passed, Toyota exceeded the one million mark in sales. The Prius is a market hit, and the gas-electric hybrid technology for fuel efficiency and reduced greenhouse gas emissions has gained consumer acceptance. Electric vehicles that were popular at the turn of the 20th century are making a comeback in the 21st century. Two entrants come from Tesla Motors, the Roadster, a high-end sport car for the elite buyer, and Think, with their City car, a working everyday run-about. Think is working to fulfill a vision of producing a carbon-neutral vehicle. The Think City has a range of 112 mi. (180 km.) on a single charge, regulated at a maximum speed of 62 mi. (100 km.) per hour. It is ideal for local driving, easily exceeding the typical 50 mi. (80 km.) a day that most people drive.

Associated with an aspect of sustainability is the vehicle's battery, the major expense in any electric vehicle. It is expected that battery-leasing companies will appear to make vehicles like the Think City affordable to a wider audience. Utility operators can use batteries no longer suitable for transportation, but still retaining a useful charge, in their power facilities to store excess energy produced by renewable sources such as solar and wind. Many governments are offering some form of rebate incentive to go green and help improve local air quality, regardless of the type of gas-electric hybrid or electric vehicle driven. For example, the Canadian province of Manitoba initiated a $2,000 rebate program to offset the higher cost of gas-electric hybrid vehicles versus comparable “dirtier” vehicles. The objective was to increase the number of hybrid vehicles from a paltry .01 percent of vehicles operating, to some greater percentage that would help reduce greenhouse gas emissions.

A July 2007 joint study by the Electric Power Research Institute (EPRI) and the Natural Resources Defense Council (NRDC) reports that even with marginal reductions made to existing power plant emissions and acceptance of gas-electric hybrids on the order of 20 percent of the driving public by 2050, 163 million tons of greenhouse gas emissions would be cut. This worst-case scenario is great news for hybrid advocates, especially those pushing for PHEVs. In a better case scenario, where more aggressive pollution-control measures are invoked on utilities and where hybrids garner over a 60 percent share of the market, 468 million tons of greenhouse gases can be spared from the atmosphere. This translates into removing more than 80 million cars from the highways.

In early 2007, it was reported that a standard Prius converted to PHEV doubled its gas mileage range. One 51 mi. (82 km.) trip netted an efficiency of 124 mi. (300 km.) per gallon at a cost of a penny in electricity per mile. The conversion to PHEV delivered a huge reduction in gas consumption of just over 60 percent, while emitting about two-thirds less greenhouse gases. Total cost was $1.76 in gas and $0.51 electricity versus the $3.17 in gas it normally cost. PHEVs contribute lower CO_2 emissions, because they do not burn fossil fuels directly, but take electricity from a mix of sources produced by the utility. In a more typical comparison with conventional ICE vehicles, a standard Prius will release one-third less carbon dioxide than a large sedan into the atmosphere.

HYDROGEN-POWERED VEHICLES

In terms of reducing automobile pollution, each generation of new pollution control technology, since the days of the catalytic converter, has been pioneered by California. A recent plan for a California Zero Emissions Vehicle (ZEV) is spurring the development of new technologies, including hydrogen-powered automobiles. To run these, hydrogen fuel can be derived from fossil fuels (which defeats their purpose somewhat), biomass, or electrolysis of water. The most popular feedstock for producing hydrogen is natural gas. Using renewable alternatives, such as photovoltaics or wind to produce hydrogen, runs at three times the cost of other techniques. If the electricity for electrolysis comes from coal-fired plants, the CO_2 emissions are even greater than those from natural gas, unless the carbon can be sequestered. All things being equal, hydrogen produced from the electrical grid would produce a net increase in global warming for the next 20 years. Coal gasification can also be used to produce hydrogen.

Given that the economics to produce hydrogen dictate the selection of a fossil fuel feedstock, it makes a big difference how the carbon dioxide is produced. An internal combustion engine produces 248 kg. of carbon dioxide for each 600 mi. (966 km.) driven. Table 1 reflects the reduction in kilograms possible by using alternate forms of transportation:

Table 1

Propulsion type	CO_2 emissions	Reduced kg CO_2/600 mi.
ICE (internal combustion engine)	248	0
PHEV (coal-fired electricity)	237	11
FCV (onboard gas reformer)	193	55
FCV (onboard methanol reformer)	162	86
FCV (natural gas-derived hydrogen from a fuel station)	80	168
FCV (refinery-supplied hydrogen)	70	178

Hydrogen is used in fuel-cell vehicles (FCVs), which are a potential replacement for ICEs. Hydrogen is converted to electricity, without high temperature reactions and is done so very efficiently. Only water vapor is produced, a byproduct that is less harmful to warming global temperatures than carbon dioxide, methane, or chlorofluorocarbons (CFCs). Every major car manufacturer has a FCV prototype, and many have FCVs on the roads in places like California, Washington D.C., Japan, and parts of Europe.

It is expected that FCVs will appear when the following issues are resolved: high cost of fuel cells, overcoming poor fuel cell durability, improving onboard fuel storage to ensure comparable or better driving range, meeting and exceeding safety standards and demonstrating such, and ensuring there is an infrastructure to produce and distribute the hydrogen to large numbers of the driving public.

BMW's Hydrogen 7 or H-7 is a bifuel vehicle using an internal combustion engine that is propelled by either gasoline or hydrogen. It is a transitional vehicle that could be introduced to bridge the gap between the scarcity of hydrogen fueling stations today and their expected abundance by 2030.

INVESTMENT AND CHOICES

Chemical battery breakthroughs are needed to improve energy storage capacity and length of storage times, which are critical for hybrid vehicles to make the transition to PHEVs. Superior battery performance is also needed as electric vehicles begin to reappear after a more than 100-year absence. Continued investment in a hydrogen infrastructure that weans humanity from fossil fuel sources is a worthy long-term goal that can pay big dividends for the patient investor.

Furthermore, simply increasing fuel economy on existing vehicles can save millions of gallons of oil each year in the short term. This can be done without future hydrogen vehicles or all-electric vehicles making any contribution. Market pressure is making these types of investments happen faster than government regulations.

General Motors lost its position of market dominance by ignoring customer demands for gas-electric hybrids or evolving its early generation electric vehicle. No government bailouts are expected for American automakers, and there is little hope that continued lobbying for lenient mileage standards would be successful.

SEE ALSO: Alternative Energy, Ethanol; Alternative Energy, Overview; Carbon Emissions; Energy; Energy Efficiency; Technology; Transportation.

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Aviation

AVIATION IS ONE of the most significant drivers of global warming and climate change. The rapid development of economies around the world has increased the desire to travel by air, thus creating greater levels of pollution, both in the air and on the ground. However, aviation plays an important part within the global economy and, as a result, governments, aircraft manufacturers, airlines, and airports are working hard to reduce their global impact. The growth of air transportation has been frenetic due to technical advancements and economic development. The jet engine and wide-bodied jet aircraft, such as the Boeing 747, revolutionized the number of people who could be carried over greater distances at far lower unit cost. The result was cheaper and more frequent holiday and business trips.

The economic development of countries and higher standards of living have also allowed passengers to travel more frequently. Linked to these advances has been the desire of governments across the world to deregulate the aviation industry, thus helping to create additional competition. The introduction of new carriers, particularly low-cost airlines, such as Southwest Airlines of the United States and Ryanair of Europe, has helped increase mobility by air for groups of consumers who would have previously found it difficult to travel by air. Commercial aviation carries some 4.5 billion passengers per year. With continued growth by low-cost carriers and the traditional airlines, it is estimated by the Airports Council International that this figure will reach an estimated 7.4 billion by 2020.

Economically, aviation is of great importance, creating both wealth and employment worldwide. The International Air Transport Association (IATA) has highlighted that commercial aviation accounts for 8 percent of GDP globally. Aviation has helped drive globalization and allows greater communication between industries and friends and families. Added to this are the millions of jobs created in the aviation sector ranging from aircraft manufacturing, airline carriers, airport operators, and employment within the regulatory authorities.

ENVIRONMENTAL IMPACT

The impact of aviation on the environment is multifaceted. Aircraft expel numerous gases during flight, including carbon dioxide, nitrogen oxide, water vapor, and a variety of particulates. According to the Intergovernmental Panel on Climate Change, commercial aviation contributes 3 percent of all CO_2 emissions. This is still low compared to energy providers who account for 25 percent of all carbon emissions. However, the percentage contribution to CO_2 emissions from aviation continues to grow, while energy providers have been able to reduce their contribution. The Aviation Environmental Federation estimates that commercial aviation produces 700 million tons of CO_2 per year. A flight from New York to London, for example, is estimated to create two tons of CO_2 per passenger.

The production of nitrogen oxides by jet engines results in further environmental impact associated with global warming. Nitrogen oxides have resulted in an increase in ozone, which has led to an increase in temperature. The emission of water vapor (most noticeable by the condensation trails that often follow aircraft) may seem harmless, but contributes to warming the atmosphere and, therefore, trapping heat at the Earth's surface. The release of particulates by jet aircraft can also cause the formation of clouds, which contribute to global warming. Other chemicals that are released during flight include: sulfur dioxide, hydrocarbons, and carbon monoxide, all of which have been linked to global warming.

A growing concern within the scientific community is the evidence that aviation not only emits chemicals that are linked to global warming, but that it does so directly into the most sensitive parts of the atmosphere. Commercial airliners tend to fly between 30,000 and 42,000 ft. (9,144–12,801 m.) Here, the atmosphere is extremely sensitive to chemicals such as carbon dioxide and nitrogen oxide. Scientists believe that the actual damage caused by aircraft may be greater than estimates predict. This is, however, disputed by the IATA, which points to the fact that the carbon footprint for airliners in 2005 was slightly reduced with the introduction of efficiency improvements.

INCREASED AIR TRAVEL

The popularity of flying causes greater levels of greenhouse gases to be emitted, as congestion grows around the world's busiest airports and air routes. It is not uncommon for aircraft to have to wait in long lines with engines running before they can take off from airports in cities such at Los Angeles and New York. When airborne, aircraft suffer from congested airways, it results in flights operating at less than efficient altitudes, which, in turn leads to less than efficient operations. The airway navigation systems found in most countries also tend to be outdated, stopping aircraft from taking the most direct route to their destination. Furthermore, airports such as London Heathrow are operating at levels well beyond their original runway capacity, which results in aircraft having to circle the airport before they are cleared to land. When on the ground, it is common for aircraft arriving at London Heathrow to have to wait for air bridges to become available, as the lack of infrastructure extends to the terminal facilities.

Airports are subject to a variety of environmental considerations. One of the main problems surrounds the lack of public transportation to reach terminal facilities. For example, Washington Dulles Airport has no direct Metro connection, which results in passengers needing to either use car transportation or change from rail to bus transportation. Aircraft require a vast array of support vehicles to help turn them around for the next duty. These vehicles are powered by gas or diesel engines, which in turn leave a carbon footprint.

NEW TECHNOLOGY

Although international aviation was excluded from the 1997 Kyoto Protocol, the International Civil Aviation Organization (ICAO) arranged a summit in 2007 to look at how manufacturers, airlines, airports, and governments can work together to reduce aviation's carbon footprint. Boeing has created the next generation of aircraft from composite materials that weigh far less than their predecessors. The Boeing 787 Dreamliner is one such new development, with 50 percent of its structure made up of composite materials. Boeing estimates that the 787 will create 20 percent less carbon than the current aircraft operating on medium/long range routes. Airbus has promoted the development of aircraft that place greater emphasis on reducing their carbon footprint. The Airbus A380 Super Jumbo, while bigger than the jumbo jet, has a low fuel burn (12 percent lower than the jumbo jet) and is able to take more passengers, helping to reduce the number of aircraft required to fly on certain routes. The Airbus A380 is the first jet airliner to meet International Environmental Standard ISO 14001.

Airlines have also encouraged manufacturers to look at new methods of powering their aircraft. Virgin Atlantic's Chair Sir Richard Branson has highlighted his interest in powering his fleet of aircraft via biofuel or clean-fuel technologies. There are, however, a number of issues that need to be addressed before such initiatives could become reality. First, biofuels such as ethanol tend to freeze at high altitudes, and therefore chemicals would be needed to reduce this risk.

Second, large areas of land and water are required for producing such energy. The land needed would require further deforestation, which in turn would have major implications for climate change. The use of hydrogen has also been suggested as a means of powering airliners of the future. However, such fuels would require greater storage space and would still leave contour trails, that warm the atmosphere.

REDUCING IMPACTS

Airlines have looked at addressing concerns of global warming by educating passengers as to the consequences of their actions and allowing them to offset their carbon footprint. In the United Kingdom, flybe.com has produced an energy consumption chart that allows customers to compare their carbon footprint with other aircraft within their fleet. British Airways and easyJet have introduced sections on their websites where customers can pay to offset their carbon emissions for a specific journey by planting trees in the developing world. Airlines are further tackling the problems of climate change by producing annual environmental audits that look at reducing their impact on the environment, both in the air and on the ground.

Fully addressing aviation's impact on the environment require unanimous worldwide governmental consensus on what measures to take. Aviation fuel remains untaxed (apart from domestic air services within the United States), which, in turn, has allowed airlines to offer cheap travel options. The industry has lobbied successfully to stop such taxation being applied unilaterally by governments, as it is thought that such measures could have a detrimental impact on those country's airlines. Within Europe, the European Union has developed an Emissions Trading Scheme.

This initiative looks at companies trading credits based on the amount of CO_2 they create. Companies are given an initial allowance, and are then free to trade by selling unused credits or purchasing credits for emissions that are produced above their initial allowance. Airlines, including British Airways and Scandinavian Airlines (SAS), and the IATA have all agreed that this control would be preferable to taxation on aviation fuel.

The development of low-cost carriers has been seen as one of the main reasons for the continued growth in popularity of cheap flights. Many commentators have seen the development of airlines such as Jet Blue, easyJet, and AirTran as a major hurdle to the possible reduction in air travel. The low-cost carriers have, however, started to market their green credentials by highlighting that their aircraft fleets tend to be the youngest and most fuel efficient within the industry.

Furthermore, low-cost airlines point to the higher load factors that they are able to achieve onboard their aircraft, which, in turn, leads to a lower carbon footprint per passenger. The use of less congested airports by these carriers has also reduced significantly the need for aircraft to queue for take-off and landing slots. Low-cost operators have further reduced the weight of their aircraft by introducing extra costs for passengers wishing to place baggage into the aircraft hold. Such policies have helped minimize the fuel burned, while at the same time allowing aircraft to be turned around quicker, and requiring fewer support vehicles.

While aviation continues to grow at a furious pace, the industry is aware of its effects on the environment. The air transport industry is investing heavily in new technologies as the key to reducing its current carbon footprint. However, with the continued growth of cheap air travel, it may require global governmental action through taxation or emission-trading schemes to make passengers pay a more realistic price for their flights.

SEE ALSO: Carbon Footprint; Emissions, Trading; European Union; Tourism; Transportation.

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Azerbaijan

AZERBAIJAN IS SITUATED on the western coast of the Caspian Sea and has boundaries with Iran, Armenia, Georgia, and Russia. The area of Azerbaijan is 53,813 sq. mi. (139,375 sq. km.), with a variety of geographic regions including mountains, steppe, desert, and subtropical rainforest. Pastureland, broad leaf forests, farms, and orchards lie in the fertile lower slopes. The range of climate zones include: dry subtropical regions with mild winters and hot dry summers; forest zones with more precipitation and a moderate climate, with cold winters and warm summers; and the city of Baku, with desert conditions, short, cold winters, long, sweltering summers, and little rainfall.

Natural resources include oil, natural gas, grain, cotton, rice, tobacco, fruit, vegetables, grapes, and livestock. Agriculture in arid and semi-arid regions requiring irrigation accounts for approximately 80 percent of production. Exploitation of Azeri oil, dumping of toxic industrial waste, and agricultural practices including overuse of artificial fertilizer and chemical pesticides have resulted in soil damage and contamination of water sources. The impact of global warming is already seen with the rising level of the Caspian Sea. Though the sea level fell due to hydroelectric dam construction on the Volga River and diversion of water for irrigation, since 1978, the water level has risen 6.6 ft. (2 m.) at a rate of 5.9–9.8 in. (15–25 cm.) per year.

Caused by a combination of climate change, increased runoff from deforested land, and tectonic movement, the impact has resulted in coastal erosion with damage to roads and buildings, salinization leading to desertification of forests and farmland, and contamination because of flooding of oilfields and industrial areas. In September 2000, Azerbaijan ratified the Kyoto Protocol, an international and legally binding agreement to reduce greenhouse gas emissions worldwide, which took effect on February 16, 2005.

Countries that are parties to the United Nations Framework Convention on Climate Change (UNFCCC) are required to undertake "national communication" that can include assessment of the potential impact of climate change. To meet this challenge, the Initial National Communication of the Azerbaijan Republic was developed and submitted to the UNFCCC Secretariat. Proposed projects aimed at reducing greenhouse gas emissions include increased use of hydropower, solar energy, and wind energy; switching to compact fluorescent light bulbs; improved efficiency in oil production; introducing new technology for biogas production and methane collection; and the protection of agricultural fields with the planting of forests to mitigate the effect of frequent droughts and hot dry winds that cause crop failures. A reduction of demand for water by 10–15 percent and an increase of lines of productivity by 15–30 percent are expected as a result of project implementation.

SEE ALSO: Agriculture; Deforestation; Floods.

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Bahamas

LOCATED IN THE Caribbean, the Bahamas consists of an archipelago of more than 700 islands that cover about 100,000 sq. mi. (160,934 sq. km.) of ocean, and a land area of only 5,378 sq. mi. (13,878 sq. km.). It has a population of 323,000 (2003 est.), with a population density of 60 people per sq. mi. (23.27 per sq. km.), although on the island of New Providence in the capital of Nassau, there are 4,402 people per sq. mi. (1,693 per sq. km.). Much of the economy of the nation comes from tourism, with only one percent of the land arable, and 32 percent of the land covered in forest, mainly on the island of Andros.

Traditionally, the Bahamas have had problems with hurricanes and tropical storms. However, the major environmental problems facing the Bahamas through global warming and climate change are from the rising temperature of the seas around the Bahamas, and the possibility of flooding with rising water levels. Some 80 percent of the land area of the Bahamas is within 5 ft. (1.5 m.) of the mean sea level. This is especially true of Andros Island, which makes up nearly half the land area of the country, much of which is already swamp at high tide. Not only would flooding have an effect on housing, but it could also lead to the contamination of fresh water reservoirs, with a possible rise in malaria and dengue fever.

In terms of its contribution to climate change, the Bahamas ranks 63rd in the world for carbon dioxide emissions per capita, with emissions at 7.7 metric tons of carbon dioxide per person in 1990, falling steadily to 5.9 metric tons per person in 2001. However, this number rose to 6.7 metric tons per person in 2002, but has started falling again. Part of this comes through the tourism industry in the Bahamas, which caters to many tourists flying to the islands; the Bahamas has a total of 64 airports, although most tourists use the main one in Nassau.

Rising temperatures have already started to have an effect on the coral reefs in the Bahamas, which include the third-longest coral reef in the world. Accounts of their size vary, but there are between 900–2,700 sq. mi. (2,331–6,993 sq. km.) of reefs in the Bahamas. They serve as a focus for many types of fish and other marine life, which are endangered by the rising water temperatures.

To try to reduce global warming and climate change, the government of the Bahamas took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992. The Bahamian government was also the eighth country to accept the Kyoto Protocol to the UN Framework Convention on

Climate Change on April 9, 1999, which took effect on February 16, 2005.

SEE ALSO: Atlantic Ocean; Floods; Oceanic Changes; Salinity; Tourism.

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Bahrain

LOCATED IN THE Persian Gulf, the kingdom of Bahrain extends over three islands in the gulf, covers 253 sq. mi. (665 sq. km.), and has a population of 698,585 (2005 est.), with a population density of 2,556 people per sq. mi. (987 per sq. km.). About one percent of the land is arable, with 6 percent used for pasture. The largest agricultural products are fruits and vegetables. The soil has been heavily affected by salinity and the country has suffered from extensive soil erosion.

As with the other Gulf States, Bahrain has a wealthy population, largely dependent on the petroleum industry, a high Gross Domestic Product per capita, and heavy use of automobiles and air conditioning. With all of the electricity in Bahrain generated from using fossil fuels, gaseous fuels in particular, it had a per capita emission of carbon dioxide of 23.8 metric tons in 1990, rising 60 percent by 1998, and then continuing to rise gradually to 31 metric tons by 2003. This means that Bahrain has the fourth largest per capita emission level of carbon dioxide, with only Qatar, the United Arab Emirates, and Kuwait having higher per capita levels. In addition, Bahrain has significant carbon monoxide emissions.

The effects of climate change and global warming are reflected in even higher temperatures in Bahrain. A recent study has shown that these temperatures reflect an 11-year cycle owing to the effect of sunspots, although some variations are explained by the high level of carbon dioxide emissions in the region, as well as the extensive use of cooling gases for air-conditioning in Bahrain and its neighbors. Because of the country's small size, Bahrain has managed to maintain a good bus system to alleviate street congestion and link the towns and main residential areas.

Bahrain's government took part in the Vienna Convention of 1900, and also the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992. Bahrain accepted the Kyoto Protocol to the UN Framework Convention on Climate Change on January 31, 2006. It took effect on May 1, 2006.

SEE ALSO: Oil, Production of; Salinity.

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Bangladesh

BANGLADESH IS SITUATED in the northeastern portion of the Indian subcontinent on the Bay of Bengal. It borders India on the west, north, and south and Myanmar on the southeast. The area of Bangladesh is 56,977 sq. mi. (147,579 sq. km.). It is a low-lying country, with numerous rivers situated principally on the large delta formed by the Ganges and Brahmaputra Rivers, and scattered hills on the northern and eastern borders.

Approximately 10 percent of Bangladesh is still forested with teak, banyan, and kapok, and forests in the tidal zone along the coast include mangroves and sometimes hardwood. Mangroves blunted the destructive power of a cyclone and tidal wave that hit Bangladesh in 1991. Mangroves are able to grow in salt water, but depend on nutrients from silt from inland rivers, and have the ability to adapt to changing conditions (including salinity and rough waves). The extended roots stabilize coasts, preventing erosion.

The climate of Bangladesh is humid and tropical, with warm temperatures throughout the year. The average annual temperature is about 77 degrees F (25 degrees C). Rainfall is heavy, ranging from 55 in. (140 cm.) around the central eastern border to more than 200 in. (508 cm.) in the northeast annually. The majority of annual precipitation falls during the monsoon season, accompanied by flooding from June to October, and by cyclones with accompanying storm surge waves from April to May and September to November.

Bangladesh supports more than 143 million people, and the population is expected to double by 2050. The staple food and chief crop is rice. Other important crops include jute, tea, sugarcane, and cotton.

The principal energy resource, natural gas, is found in several small fields in the northeast. There is a coalfield in the northwest, and large peat beds underlie most of the delta. Electricity is generated in thermal plants burning fossil fuels (coal, natural gas, or petroleum) and hydroelectric facilities.

Bangladesh already faces complex environmental problems, including air, water, and soil pollution, and the overuse of natural resources, which causes deforestation, desertification, and energy and water shortages. Three percent of households lack access to improved water supply and 52 percent lack improved sanitation. The impacts of global warming could exacerbate already stressed conditions in some areas as the increasing population and scarcity of land drive occupation of marginal forest lands and temporary river islands. Agricultural practices including overuse of farmland and chemical pesticides have resulted in soil damage and contamination of water sources.

SEA LEVEL RISE AND CLIMATE CHANGE

Bangladesh is one of the countries most vulnerable to a rise in sea level. Estimates for future sea level rise vary from 3.2–43.3 in. (8–110 cm.) by the end of the century. A rise of 9.8 in. (25 cm.) or more in relative sea level would displace many residents of the delta region of the Ganges from their homes and livelihoods, while a 39 in. (1 m.) sea-level rise could inundate 11.5 percent of the land of Bangladesh. Extreme predictions of a 1 m. rise in the Bay of Bengal are that the Ganges Delta would lose 12–18 percent of its land. Loss of land (especially agricultural land) could be devastating, along with the displacement of coastal villages and people by severe flooding.

Seasonal flooding could increase and last longer, with higher sea levels decreasing the rate of drainage and increase the salinity of ground water. Also, as sea surface temperature rises, the ocean area capable of spawning tropical cyclones is expected to increase. Tidal waves during cyclones are likely to become more severe, as well. Climate change could translate into migration to urban areas or inland from the lowlands of the delta area. With transient populations, stress on sewage and waste systems could increase the spread of communicable diseases.

Warmer temperatures would increase the incidence of heat-related illnesses and lead to higher concentrations of ground-level ozone pollution causing respiratory illnesses and increasing risk of contracting certain infectious diseases from water contamination or disease-carrying vectors, especially for the malnourished. Flooding and storm surges associated with sea-level rise could increase the incidence of water-borne diseases, putting stress on limited health services.

In October 2001, Bangladesh ratified the Kyoto Protocol, an international and legally binding agreement to reduce greenhouse gas emissions worldwide that took effect on February 16, 2005. Strategies implemented to improve environmental conditions and human-induced climate change include assessment of the potential impact of climate change. Bangladesh began a National Conservation Strategy Implementation Project, assessed implementation of Agenda 21, established the Bangladesh Wetlands Network, conducted the case study "Sanitary and Phyto-Sanitary (SPS) Barriers to Trade and Its Impact on the Environment of Shrimp Farming in Bangladesh," established the International Dialogue on Water and Climate, completed the project design for "Integrating Economic Values into Protected Area Management in South Asia—Bangladesh Country Component" in collaboration with the Ecosystems and Livelihood Group (ELG), and executed another regional project titled "Sustainable Livelihood, Environmental Security and Conflict Management."

SEE ALSO: Climate Change, Effects; Hurricanes and Typhoons; Sea Level, Rising.

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Barbados

LOCATED IN THE Caribbean, Barbados has a land area of 167 sq. mi. (431 sq. km.), and a population of 331,000 (2006 est.), with a population density of 1,663 people per sq. mi. (647 people per sq. km.). More than a third of the population lives in Bridgetown, the capital. Thirty-seven percent of the land on Barbados is arable, with an additional 5 percent used for meadows and pasture. About 12 percent of the country is forested. Historically, Barbados has been reliant on the sugar industry, but now also relies on tourism. Because of this, Barbados has been at the forefront of the Caribbean Tourism Organization's role in discussing the adverse effects of climate change. Barbados is regularly threatened by hurricanes, and is facing real problems from global warming and climate change. Much of the country is low-lying, and rising water temperatures caused by global warming endanger the coastal fringe of coral reefs.

In terms of its carbon dioxide emissions per capita, Barbados ranks 83rd, with 4.2 metric tons of carbon dioxide per person in 1990, falling to 2.9 metric tons per capita in 1994, and then rising to 4.6 metric tons in 2001–02, before falling slightly. Because of its isolated location, most of the people traveling to Barbados, including over 500,000 tourists each year, come by air. To reduce carbon emissions, the Barbadian government has attempted to reduce power use on the island. It has maintained a well-run system of public transport, with buses covering most of the country.

Furthermore, the Barbadian government of Erskine Sandiford took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992. Barbados then hosted the Global Conference on the Sustainable Development of Small Island Developing States (SIDS), known as the Barbados Conference, in April–May 1994 when SIDS discussed the problems of global climate change and the impending rise in sea levels. The government of Owen Arthur accepted the Kyoto Protocol to the UN Framework Convention on Climate Change on July 8, 2000. It took effect on February 16, 2005. Soon afterward, Barbados launched its own national energy strategy. On September 24, 2007, Owen Arthur pleaded at the UN in New York that wealthier countries introduce policies to help reverse the effects of global warming and climate change, pointing out the responsibility of developed countries that have historically contributed heavily to the problem.

SEE ALSO: Atlantic Ocean; Hurricanes and Typhoons; Oceanic Changes; Tourism.

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Belarus

ONE OF THE former constituent states of the Soviet Union, the Republic of Belarus gained its independence in 1991. It has a land area of 80,155 sq. mi. (207,600 sq. km.), a population of 9,724,723 (2007 est.), and a population density of 127 people per sq. mi. (49 people per sq. km.). Although 29 percent of the land is arable, and a further 15 percent has been used for meadow or pasture, the nearby Chernobyl nuclear power plant in the Ukraine has contaminated some of the agricultural land in Belarus.

Suffering heavily from pollution during the Communist period, including the 1986 Chernobyl nuclear accident, Belarus has managed, since independence, to significantly reduce its per capita carbon dioxide emissions from 92 metric tons per person in 1992 to 7.6 metric tons in the following year, and then to 6.8 metric tons in 1994. Emissions have been between 5.8 and 6.4 metric tons per person since then. Belarus has a lower level of emissions per person than its neighbors, Russia and the Ukraine, largely because of the underdeveloped nature of the Belarus economy. However, there have been significant emissions of sulfur dioxide, nitrogen oxide, and carbon monoxide.

To reduce its effect on climate change, Belarus has embarked on an ambitious project of electrifying its train network, and investing more in public transport. However, it relies heavily on fossil fuels for the generation of electricity, which provides 99.5 percent of the power for the country, while only 0.08 percent comes from hydropower. With about a third of the country forested, Belarus lessens its effect on global warming, although there is the threat of deforestation with many cities becoming larger, and increasing demand for timber. The Belarus government of Vyachaslau Kebich took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, and the government of Syarhey Sidorski accepted the Kyoto Protocol to the UN Framework Convention on Climate Change on May 26, 2005. It took effect on November 24, 2005.

SEE ALSO: Deforestation; Nuclear Power; Pollution, Land.

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Belgium

LOCATED IN WESTERN Europe, the kingdom of Belgium has a land area of 11,787 sq. mi. (30,528 sq. km.), with a population of 10,511,382 (2006 est.), and a population density of 892 people per sq. mi. (344.32 per sq. km.). Twenty-four percent of Belgium's land is allocated for arable use, with another 20 percent used for meadows and pasture, and 20 percent still forested.

One of the earliest countries in the world to become involved in the Industrial Revolution during the 19th century, in recent years Belgium has focused heavily on the nuclear industry, which is now responsible for 57.6 percent of the country's electricity production, with fossil fuels accounting for 40.3 percent of the electricity, and only 0.5 percent generated from hydropower. Belgium ranks 46th in the world in carbon dioxide emissions per capita, with 10.1 metric tons per person in 1990. Most of these carbon dioxide emissions come from liquid fuel (36 percent), solid fuel (32 percent), and gaseous fuel (28 percent). Although emissions have risen slightly since 1990, there have been many government measures introduced since 2000 to reduce Belgium's impact on climate change and global warming.

The government has long had an extensive railway network, and in recent years has extended the public transportation network with an integrated transport system operating throughout much of the country, including tramway services in many of the major cities. There are also two prominent Green movements in the country, the AGALEV and the ECOLO, both of which have been involved in regional and national governments. They did very well in the 1999 national elections, but most of their gains were reversed in 2003.

Since 1999, the country has cleaned up some pollution, but as late as 2003, a UN report on water quality listed Belgium as the last of 122 countries in terms of its waste treatment, pollution control, and drinking water quality. The Belgian government of Jean-Luc Dehaene, during his first few months in power, took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, and in his last year in office, Dehaene's government signed the Kyoto Protocol to the UN Framework Convention on Climate Change. It was ratified on May 31, 2002, and took effect on February 16, 2005.

SEE ALSO: Nuclear Power; Pollution, Water; Transportation.

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Belize

BELIZE IS A small country in Central America south of Mexico's Yucatán Peninsula and east of Guatemala. Its eastern coast faces the Caribbean Sea. Belize is known as a small island developing state because of its low-lying seashore, coastal communities, and open and vulnerable economy. Small island developing states are considered extremely susceptible to the effects of climate change, including rising sea levels.

The small, open economy of Belize has historically been dependent on a narrow range of agricultural exports. Furthermore, it depends on foreign imports for most basic goods, and it relies heavily on a growing tourism sector for foreign exchange earnings to meet its import demand. These economic factors, along with its physio-geographic features, tropical environment, and coastal population centers increase the vulnerability of Belize to the impact of climate change.

Belize is a former British colony (known as British Honduras for most of the 20th century), and became an independent nation in 1973. Given its location, population, and cultural history, Belize is regarded as both a Central American and a Caribbean nation. Belize is a member of the Caribbean Community (CARICOM) and is the site of the Caribbean Community Climate Change Centre, which coordinates climate change research and regional responses for the nations of the Caribbean.

The coastline of Belize can be described as low-lying marshland and swampy plains. Tropical hardwood and pine forests in the western interior gradually rise to the forested Maya Mountains in southern Belize. The coral reefs and islands along the Caribbean coastline (known as *cayes*) form the Belize Barrier Reef. At approximately 200 mi. long, it is the longest reef in the western hemisphere. Tropical cyclones (hurricanes) and flooding regularly threaten human settlements during the rainy season, particularly in coastal areas. With a population of less than 300,000, Belize contributes very little to global greenhouse gas emissions, so its capacity to mitigate the effects of climate change is negligible. In a 2005 survey of residents' attitudes about climate change, nearly half responded that Belize is extremely vulnerable to the impacts of climate change, and 95 percent felt that Belize is not prepared to handle the impacts due to financial constraints.

Climate change poses five types of risk for Belize. First, a loss of coastal land may result from rising sea levels through erosion and increased flooding. Second, rising sea surface temperatures may increase the frequency and intensity of tropical cyclones, which pose risks to infrastructure and personal property. Third, warmer sea water and ocean acidification are expected to contribute to coral reef bleaching, and an increase in the extent and severity of coral mortality would threaten both the fishing and tourism sectors. Fourth, changes in temperature, rainfall, and sea level may increase the distribution and range of vector-borne diseases such as malaria and dengue fever, which already threaten public health. Finally, rising temperatures, increased salinity, and a shorter growing period may negatively impact the citrus, banana, and sugar cane industries, which already comprise more than half of major exports.

SEE ALSO: Alliance of Small Island States (AOSIS); Hurricanes and Typhoons; Oceanic Changes; Sea Level, Rising; Tourism.

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Benguela Current

THE BENGUELA CURRENT is located in the southern part of the Atlantic Ocean and moves northward from the western coast of South Africa, Namibia, and

Angola, merging into the Southern Equatorial Current. It takes its name from the Angolan port of Benguela, which was founded by the Portuguese in 1617. The current was quickly noticed by European seafarers, who initially had trouble navigating the region.

While the Benguela Current is cold, generated by water from the very deepest parts of the ocean moving in line with the rotation of the Earth, the Southern Equatorial Current is warm. The effect of the two merging is the subject of much research, starting with the English geographer James Rennell (1742–1830), whose book *Currents of the Atlantic Ocean* was published posthumously in 1832. From work by subsequent geographers, it has been found that the Benguela Current also includes subtropical water from the Indian Ocean. About 124–186 mi. (200–300 km.) wide in coastal regions, it becomes much wider as it reaches the tropics, and the cold current is responsible for some of the trade winds in the South Atlantic because there is a certain level of displacement of some of the waters on the surface of the ocean.

The problem facing the Benguela Current from global warming and climate change comes from a rise in the temperature of the water in the oceans, which has led to a rise in the temperature of the waters of the Benguela Current. A Benguela El Niño effect has already been detected. Not only has there been a rise in water temperature as far south as 25 degrees S, but the water has also become increasingly saline. This change may be generated by anomalous atmospheric conditions that have been seen in the western part of the tropical Atlantic Ocean.

Although each year some warm water from Angola has impacted the northern part of the Benguela Current, El Niño has caused this to happen further south. Although this may have occurred throughout history, there are accurate records of it taking place in 1934, in 1963, and in 1984. In 1963 the resultant temperatures off the Namibian coast were some 2–4 degrees higher than normal. The water pressure was also higher. Research by L.V. Shannon suggests that the problem is less frequent, and also has a lower intensity than the similar phenomenon in the Pacific Ocean.

The result of these changes from the Benguela El Niño is expected to have a serious effect on some of the lands in southern Africa, with a dramatic effect on marine life, on the southwest coast of Africa, and also on the trade winds, which are likely to affect marine life and shipping in the southern Atlantic.

Although the impact of the Benguela El Niño is not, at this moment, noticeable south of the Namibian port of Lüderitz, if the trend continues, it would have a major effect in the region off the Cape of Good Hope where the south-flowing Agulhas Current meets the Benguela Current. Throughout history, this has resulted in turbulence and storms on the surface of the sea off the southwest coast of South Africa, and the creation of a very rich marine ecosystem underwater. Off the coast of southwestern Africa, there has already been a fall in the catch of the fishing industry, including jack mackerel, sardines, and, off the coast of Angola, anchovies. Whether this is a result of over-fishing in the last two centuries or of less fish spawning because of the rising temperature has not been firmly established, although both are likely to be major contributory causes.

Although the marine ecosystem is likely to be affected, the most noticeable early impact of the Benguela El Niño will be changes in the trade winds. Although these changes will have a dramatic effect on journeys by yachts, it will have a much less important effect on container ships and tankers using the route than would have been the case during the 20th century. However, there will be an impact on the southern coast of Angola and much of the coastline of Namibia.

Over centuries, the current has led to the desertification of the coastline of southern Angola and Namibia, making the coastline extremely inhospitable. Some of the bushmen call it "The Land God Made in Anger." Because of the whaling industry, and the many shipwrecks there, it became known in Europe and North America as the Skeleton Coast. Although there is little flora or fauna along the coast, a number of plant and insect species have managed to adapt, making use of the dense sea fogs. Some desert birds also manage to survive. The small human populations that lived there many centuries ago seem to have survived heavily on seafood, with middens from the shells of white mussels still evident.

SEE ALSO: Agulhas Current; El Niño and La Niña; Namibia; Oceanic Changes; Southern Ocean; Southern Oscillation.

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Benin

THE REPUBLIC OF Benin covers 43,483 sq. mi. (112,620 sq. km.) on the West African coast, equivalent to the size of Pennsylvania. Benin has a population of 7,460,025 people (2005 est.), with nearly three million inhabitants living in the coastal stretch that links Cotonou, the economic capital, with Porto-Novo, the political capital. Benin's economy is dominated by agriculture, including the commercial production and export of cotton and palm oil. Most of the rural population earns its livelihood through subsistence farming of corn, beans, cassava, peanuts, and yams. The per capita Gross Domestic Product is $1,200 (2004 est.) and 33 percent of the population lives in poverty.

A coastal belt of lagoons, rolling hills in the central part of the country, rocky plateaus in the northwest, and savanna plains in the northeast characterize Benin. The climate is tropical Soudano-Guinean, with six months of rain and six dry months. Along the coast, it is hot and humid, while the inland climate is semi-arid.

Four environmental issues facing the country are: inadequate supplies of drinking water, poaching of wildlife, deforestation, and desertification. Benin is a party to the following international environmental agreements: biodiversity, climate change, the Kyoto Protocol, desertification, endangered species, environmental modification, hazardous wastes, law of the sea, ozone layer protection, ship pollution, and wetlands.

Climate change awareness among the general population in Benin is significant, as scientists have documented disturbing changes in rainfall patterns beginning in 1971. Farmers are also aware of climatic changes, such as shorter rainy seasons and longer dry spells. The contributions that Benin makes to human-induced climate change are minimal compared to the rest of Sub-Saharan Africa and the rest of the world. Per capita CO_2 emissions in 1998 were only 100 metric tons, as compared to an average of 800 tons for the subcontinent, and the global average of 4,100 metric tons. The burning of liquid fuels (petroleum products) represented 65 percent of the country's CO_2 emissions, while the remaining 35 percent was from cement manufacturing, according to the World Resources Institute. Other non-CO_2 air pollution in Benin is low compared to the rest of the continent and the world.

Possible impacts of climate change could have significant consequences for Benin's people and environment. With nearly half of the country's population living along the coast, a rise in sea level would threaten their livelihoods and well-being, since this zone would become subject to more frequent erosion and flooding. Climatic changes and drier conditions could accelerate deforestation in the central part of the country and desertification in the north. Also, changes in rainfall patterns are likely to have serious effects on soil erosion, while also leading to changes in cropping patterns and, ultimately, changes in the livelihood patterns of farmers and herders.

SEE ALSO: Deforestation; Desertification; Sea Level, Rising.

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Berlin Mandate

THE BERLIN MANDATE was a ruling reached at the first Conference of the Parties (COP 1) to the United

Nations Framework Convention on Climate Change (UNFCCC) in March 1995. It established a process for dealing with matters of climate change. The UNFCCC was adopted in 1992 at the UN Conference on Environment and Development (UNCED) held in Rio de Janeiro. Informally, the conference was known as the Earth Summit. It adopted an international treaty binding countries together in a common effort to meet the challenge of global warming by reducing its effects, or at least by preparing for higher temperatures. The treaty specifically aimed to stabilize greenhouse gas emissions to prevent anthropogenic interference with the climate system.

The UNFCCC was opened for signing on May 9, 1992. By March 21, 1994, enough countries had signed that it became a part of international law. The treaty as it was originally written did not set limits on greenhouse emissions by individual countries, lacked an enforcement provision, and was not legally binding. However, it did contain provisions that stated that updates, which were called protocols in the treaty, were to be issued that would set mandatory emission limits. The principal update was to be set at a new conference in Kyoto, Japan. The Kyoto Protocol was to become much better known than the UNFCCC. After each signatory nation conducted a greenhouse gas inventory, it was responsible for developing a plan for removing or reducing greenhouse gases to acceptable levels. The UNFCCC also named a secretariat that would be charged with supporting the work of implementing the treaty.

The COP 1 met in Berlin for its first session between March 28 and April 7, 1995. The participants concluded that the goals previously reached by those participating in the UNFCCC treaty were not sufficient to meet the challenge of global warming. Originally, the UNFCCC had a goal of returning greenhouse gas emissions to 1990 levels by 2000. It was decided that a process should be established for countries to take appropriate action well beyond 2000. COP 1 also called for legally binding standards and emissions limits to be set by international law. Participants in Berlin also created a separate body called the Ad Hoc Group on the Berlin Mandate (AGBM).

A second meeting of the Conference Parties took place at Geneva between July 8 and July 19, 1996. The meeting was styled COP 2. The meeting was a midpoint in the negotiations on greenhouse gas emissions that had begun with the Berlin Mandate. COP 2 acted in response to the IPCC Second Assessment Report issued December 1995 that stated that greenhouse gas concentrations had continued to increase, that the climate had changed since 1900, and that there was evidence that the change was anthropogenic. It also predicted that global temperatures would rise by 3.6 degrees F (2 degrees C) by 2100 and that the climate was expected to change in the future, adding that there were scientific uncertainties.

These Berlin Mandate negotiating sessions were held as follows: AGBM 1 (August 1995), AGBM 2 (October/November 1995), AGBM 3 (March 1996), AGBM 4 (July 1996), AGBM 5 (December 1996), AGBM 6 (March 1997), AGBM 7 (July/August 1997), and AGBM 8 (October/November 1997). The Berlin Mandate negotiations were concluded at COP 3 in Kyoto with the adoption of the Kyoto Protocol.

SEE ALSO: Greenhouse Gases; Kyoto Protocol; United Nations.

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Bhutan

LOCATED IN THE Himalayan Mountains and bordering India and China, the kingdom of Bhutan covers a land area of 18,147 sq. mi. (47,000 sq. km.), with a population of 672,400 (2005 est.), giving it a population density of 117 people per sq. mi. (45 per sq. km.). Gaining its independence in 1947, Bhutan has embarked on a program of modernization, trying

Bhutan's forests, such as this one, cover three-quarters of the country, and it has one of the lowest rates of carbon dioxide emissions per person in the world. In spite of this, it is imperiled by rising regional temperatures, which are melting nearby glaciers.

to foster greater harmony between various ethnic groups. Being landlocked, the main effects of global warming on Bhutan will be from melting of nearby glaciers. With average temperatures in the Himalayas having risen by about one degree C since the mid-1970s, there has been a glacial retreat in Bhutan estimated at 100–130 ft. (30–40 m.) annually, with the real possibility of serious flooding from swollen glacial lakes. Over time, this is expected to dramatically change the flora and fauna in the country, posing risks for some endangered animals such as takins (similar to gnus), wild elephants, and snow leopards.

Within the country, there is relatively low car use, with a somewhat overburdened public transport network that still effectively covers the entire country. This network includes the government Bhutan Post Express, the private Leksol Bus Service, and other companies. Although tourist flights into the country have contributed to global warming and climate change, the number of tourists is strictly limited. Also, 75 percent of the country is still forested, only two percent of the land is arable, and another six percent is used for meadows and pasture. Accordingly, the per capita emission of carbon dioxide by the people of Bhutan is one of the lowest in the world, with 0.1 metric tons per person in 1990, rising to 0.19 metric tons per person in 2003. A total of 99.9 percent of the electricity in Bhutan is generated by hydropower, resulting in one of the lowest rates of fossil fuel use of any country in the world. The country also has extremely low levels of emissions of sulfur dioxide, nitrogen oxide, and carbon monoxide.

The Bhutan government took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, and 10 years later, on August 26, 2002, it accepted the Kyoto Protocol to the UN Framework Convention on Climate Change, which took effect on February 16, 2005.

SEE ALSO: Climate Change, Effects; Floods; Forests; Glaciers, Retreating; Tourism.

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Biogeochemical Feedbacks

FEEDBACKS ARE PROCESSES in a system that can either amplify or dampen the system's response to external influences. When the concentration of a certain variable in a subsystem affects the behavior of the entire system, then changes in inputs or concentrations of that variable can result in multiple, coupled responses. It is possible that some of the responses enhance, while others mitigate, the initial response of the system to the external forcing.

In the case of the Earth's system, if a change in the environment leads to additional and enhanced changes in that system, it is said to have resulted in a positive feedback. When a large external forcing results in an even larger response from the affected system, the phenomenon is commonly referred to as a vicious cycle of positive feedback loops. In contrast, if a change in the environment leads to a process that mitigates the change, and results in smaller response from the affected system, it is said to be a negative feedback. Some systems have the ability to regulate their environment and maintain a stable condition by using multiple, interrelated dynamic mechanisms, known as homeostasis. Feedback processes regulate the response of the Earth's system to natural or anthropogenic forcings.

Biogeochemical feedbacks operate in the coupled biosphere-pedosphere-hydrosphere-atmosphere system. Biogeochemical feedbacks include changes in biological activity; atmospheric, water, or soil chemistry; and terrestrial and oceanic uptake of greenhouse gases that affect, or are affected by, changes in atmospheric dynamics. Some of the most important biogeochemical feedbacks include: changes in rates of plant productivity and carbon sequestration by soils due to altered patterns of air temperature and precipitation; changes in temperature that lead to faster decomposition of organic matter stored in peat lands; and changes in atmospheric conditions that may lead to altered patterns of oceanic temperature and circulation that ultimately lead to changes in ocean carbon storage. By modifying the fluxes of greenhouse gases to/from the atmosphere, biosphere, pedosphere, and hydrosphere, feedback processes in the climate system affect the residence time of the gases in the different spheres.

A study released by the National Academy of Sciences in 2001 estimates that half of the anticipated increase in air temperature over the next few years to decades will be attributable to internal feedbacks within the climate system, and the other half to the direct response of external factors that force change in the climate system.

An example of a positive feedback loop that results in amplification of the response of a system to an external influence is one in which increases in atmospheric concentration of carbon dioxide (CO_2) lead to increases in air temperature. This, in turn, results in higher rates of organic matter decomposition (respiration) that releases CO_2 to the atmosphere—further increasing the concentration of CO_2 in the atmosphere. In this case, a negative feedback loop would result in a chain of events leading to decreased concentrations of CO_2 in the atmosphere. For example, an increase in CO_2 in the atmosphere leads to increases in air temperature, which results in additional plant growth, which takes CO_2 from the atmosphere (acts as a sink for atmospheric CO_2), reducing atmospheric concentration of CO_2.

Another important biogeochemical feedback to climate change is the changes in production of dimethyl sulfide gas (DMS, a common atmospheric aerosol around oceans) by phytoplankton in the upper layers of the ocean. Increased plankton activity during warm atmospheric conditions leads to greater release of DMS from the oceans to the atmosphere. Consequent increase in density and concentration of aerosols in the atmosphere reduces the size of cloud droplets, resulting in increased albedo (reflection of solar radiation by an object) that leads to increases in air temperature—a negative feedback loop.

Biogeochemical feedbacks can be manifested at different spatial and temporal scales and may have significant control of short- and long-term changes in weather and climate at the level of leaves, stands, biomes, or ecosystems. Moreover, biogeochemical feedbacks can be direct or indirect. Direct effects are those processes that influence chemical composition and dynamics of the atmosphere or oceans, and normal functioning of the biosphere. Some of the most prominent direct feedbacks are increased plant productivity due to increasing concentration of CO_2 in the atmosphere, a phenomenon known as the CO_2 fertilization effect. Indirect feedbacks are those mediated by ecosystem responses to climate changes that result because of increasing concentration of greenhouse gases. Some examples of this include the change in ocean circulation patterns on phytoplankton productivity, which, in turn, affect the amount of CO_2 that biological processes in the ocean can sequester.

SEE ALSO: Albedo; Anthropogenic Forcing; Carbon Dioxide; Carbon Sinks; Climate Feedback.

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Biology

BIOLOGY, THE STUDY of life, has grown in complexity and comprehensiveness from its origins in antiquity. By the 20th century, biology was not a single science, but a group of subfields. Among the subfields was conservation biology, the discipline that sought to verify the reality of climate change and to stop it before it causes a mass extinction of species. In a number of ways, conservation is unique among the biological sciences. It is the science that is most conscious of global warming and of the need to arrest it.

Biology had its first stirrings among the ancient Greeks; Aristotle was the pioneer. The founder of anatomical studies, Aristotle likely performed the first dissections. His study of anatomy presaged the work of French comparative anatomist Georges Cuvier. Aristotle also appears to have been the first taxonomist. His classification of marine invertebrates anticipated the work of Swedish taxonomist Carl Linneaus.

As the founder of developmental biology, Aristotle sought to explain why, for example, an acorn always develops into an oak tree, and a frog's egg always turns into a frog. This line of research would lead to the 20th-century science of genetics. Aristotle sparked an interest in biology among his pupils, one of whom, Theophrastus, established the science of botany.

From this impressive beginning, the study of biology languished in the early Middle Ages, a period of theological, rather than scientific, study. In the 12th century, several universities in Italy revived the study of anatomy. Their focus was on human anatomy as a method of training physicians. The dissection of cadavers brought reproaches from the Catholic Church; but this work continued and, in 1543, Flemish physician Andreas Vesalius published his landmark study of human anatomy, *The Fabric of the Human Body*.

To an agnostic, the dissection of human cadavers implied that a person was nothing more than the sum of his or her parts: organs, muscles, bones, and the like. French philosopher and mathematician Rene Descartes wrote that purely mechanical forces animated the lower organisms. Humans alone had an immaterial soul. The idea that humans had a soul did not persuade everyone, and many biologists in the 20th century quietly banished the soul to the realm of superstition. Swiss alchemist Paracelsus had a more promising insight in supposing that chemical processes animated life. From this insight would emerge the science of biochemistry.

The 18th century was the age of taxonomy, one of Aristotle's lines of research. Among the systems of classification, Linneaus's work continues to influence the science of taxonomy. It was Linneaus, for example, who named humans *Homo sapiens*. Linneaus assumed that humans were special and deserved a genus apart from all other organisms. Natural theology, the study of nature for theological ends, agreed that humans were special among all other forms of life. The science of evolutionary biology, emerging in the 19th century, eroded the belief that humans were somehow special. Like all other organisms, humans were the result of natural selection, the product of nearly 4 million years of evolution.

Evolutionary biology requires that natural selection operate on a diversity of traits. Not all organisms of a species are identical; they vary in their particulars. Humans, for example, differ in height, eye and hair color, shape and length of the nose, and myriad other traits. The source of this variation puzzled British naturalist Charles Darwin, who was unaware of Austrian monk Gregor Mendel's work. Mendel was the first to understand that genes code for traits and that organisms differ because they have different assortments of genes. Mendel founded the science of genetics, which grew in scope during the 20th century.

CONSERVATION BIOLOGY

In the 20th century, biology multiplied into several subfields, among them conservation biology, a discipline that traces its origin to Eastern philosophies. The ancient Chinese, Japanese, and Indians posited a link between humans, plants, and animals. Given this link, harm could not come to the animal world without also harming humanity. Eastern philosophies believed pristine lands to be essential for people who desired a spiritual experience. In the Gospels, both John the Baptist and Jesus went to the wilderness for spiritual cleansing.

In the West, the dominant ideology favored exploitation, rather than conservation, of nature. To the Western mind, nature had no spiritual qualities. In the 19th century, the Transcendentalists, notably Ralph Waldo Emerson and Henry David Thoreau, challenged the belief that nature was nothing more than a commodity to be used for economic gain. Emerson and Thoreau affirmed that nature held a spiritual value and that humans could not degrade nature without degrading themselves. By his actions, Thoreau demonstrated that a person could live simply and in harmony with nature. Going beyond the musings of Emerson and Thoreau, conservationist John Muir recognized the value of political activism and formed an alliance with Theodore Roosevelt, who was also sympathetic to the aims of conservation.

As a science, conservation biology coalesced during the 1970s in the aftermath of the oil embargo by the Organization of Petroleum Exporting Countries, an event that underscored the fragility of an economy based on the burning of fossil fuels. The economies of the developed world relied on cheap fossil fuels and a quiescent public. Conservation biologists were anything but quiescent. In 1978, they held the First International Conference on Conservation Biology at the San Diego Zoo, a location that highlighted conservation biologists' commitment to protect Earth's biodiversity. In 1985, a trio of scientists formed the Society for Conservation Biology, and two years later, its members founded *Conservation Biology*, the society's scholarly journal.

Conservation biology concerned itself with, among other things, the relationship among climate, human activity, and the fate of Earth's biota. Conservation biology tracks changes in climate and the harm they cause organisms and ecosystems. In some cases, the changes in climate have brought organisms to extinction. Conservation biologists, aware that climate change imperils species, called attention to the greenhouse effect and deforestation. The greenhouse effect traps heat in the atmosphere. Human activity has increased the amount of carbon dioxide, a greenhouse gas, in the atmosphere, which has caused global temperatures to rise.

Plants absorb carbon dioxide during photosynthesis and so are natural checks against the accumulation of carbon dioxide. Deforestation, however, reduces the number of trees and plants and so weakens the capacity of plants to absorb carbon dioxide. The greenhouse effect and deforestation are, therefore, a mutually reinforcing feedback loop that intensifies global warming. Conservation biologists point to ranchers as contributors to the greenhouse effect. By overgrazing the land, cattle further reduce the number of plants and weaken their capacity to absorb carbon dioxide.

Conservation biology tracks changes in the chemistry of rain. Rainfall is an important aspect of climate because it determines the distribution and density of plants and, when rainfall is scant, the distribution and size of deserts. Conservation biologists noted with alarm that rainfall in the eastern United States and parts of Europe is acidic. Factories and power plants discharge sulfur dioxide, which combines with water vapor in the atmosphere to form acids. These acids fall to earth as acid rain, accumulating in streams and lakes.

Half the lakes in the Adirondack Mountains in New York have no fish because they were unable to reproduce in the acidic waters. Conservation biologists have devised a temporary solution to the problem of acidic lakes by adding large amounts of calcium carbonate to them to reduce their acidity. While effective, this solution is costly and only temporary. Acid rain returns lakes to acidic conditions three to six years after treatment with calcium carbonate. The long-term solution to the problem of acid rain requires humans to use renewable sources of energy rather than continue to burn fossil fuels.

Conservation biologists worried that the thinning of the ozone layer would change the climate. The ozone layer makes life possible by blocking out large quantities of ultraviolet light, which is lethal in high doses. As the ozone layer thins, due to the release of chlorofluorocarbons into the atmosphere, it screens less ultraviolet radiation. Increases in ultraviolet light kill photosynthetic algae in the ocean. Because algae absorb carbon dioxide during photosynthesis, their reduction in numbers weakens their capacity to absorb carbon dioxide, contributing to the greenhouse effect. The thinning of the ozone layer thereby contributes to global warming. This thinning, itself a manifestation of climate change, harms Earth's biota. The ultraviolet light that penetrates the ozone layer also damages amphibian DNA, causing fewer amphibians to survive. Consequently, the number of frogs and toads has declined in the western United States.

Conservation biologists warn that the climate is not only changing, but changing rapidly. The speed with which the climate is changing may mark some species for extinction. Some tree species, for example, take 20–30 years to reproduce. By then, the climate may have changed to such a degree that the tree species may die before reaching sexual maturity and will become extinct. Conservation biologists assert that climate change is causing a mass extinction greater than any since the mass extinction at the end of the Cretaceous Era in which the dinosaurs perished.

THE TRAGEDY OF CLIMATE CHANGE

According to one line of reasoning, the tragedy of climate change is that it imperils humanity. The number of people on Earth has surpassed 6 billion. As the number of people increases, so must the food supply. Climate change, in targeting species of fish for extinction, robs people of a valuable source of protein. Overgrazing of rangeland does more than alter the climate by reducing the number of plants. It reduces the capacity of the land to feed a burgeoning population. In the 1930s, decades of overgrazing and wheat monoculture caused soil erosion on a vast scale. Drought brought matters to a crisis, as huge dust clouds assailed the western United States. As humans heat Earth with greenhouse gases, cause acid rain to accumulate in lakes, and overgraze the land, they may find food in short supply, causing a Malthusian crisis.

According to another line of reasoning, the tragedy of climate change is that it imperils Earth's rich biodiversity. Plants and animals do not have value because they can feed humans. They have value simply by their uniqueness. Beyond that, they have an aesthetic value apart from any economic considerations. They have as much right to the Earth as do humans. This view accords well with the recognition that all life, including humanity, is a product of evolution. No species may claim superiority. All happen by chance to occupy Earth at the same time.

Conservation biology may be unique among the subfields of biology in advocating policy. As a rule, geneticists and molecular biologists, for example, do not advocate policy. Often, they pursue research without the expectation that it will influence policymakers. By contrast, conservation biologists go a step beyond these sciences in urging government, for example, to curb the emission of sulfur dioxide, carbon dioxide, and chlorofluorocarbons. Conservation biologists are not only scientists, important as the profession of science is; they are advocates. They work with legislators to fashion policy that protects plants and animals. Because of their role in advocating policy, conservation biologists court public opinion. In this sense, conservation biology is a public science.

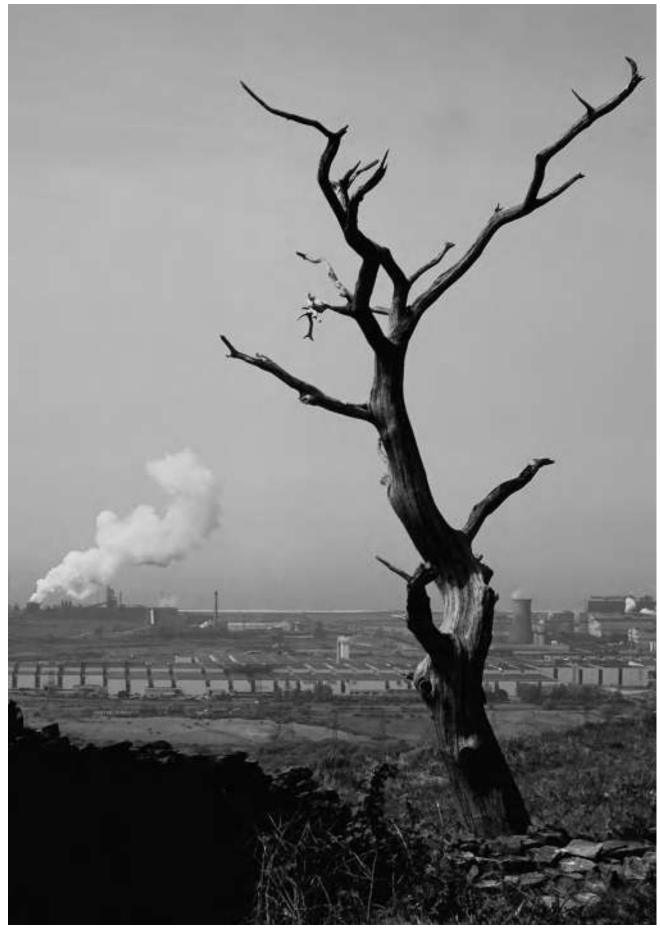
Conservation biology may also be unique in the breadth of its ties to other scientific disciplines and to nonscientific professions. By its nature, conservation biology is multidisciplinary. A full list of complementary disciplines may be difficult to construct, but conservation biology has ties to wildlife management, fisheries biology, the agricultural sciences, forestry, ecology, climatology, population biology, taxonomy, and genetics. In addition to working with scientists from these disciplines, conservation biologists work with journalists and newspaper editors. Some of the most influential conservation biologists—Aldo Leopold, for example—wrote in a journalistic vein.

Finally, conservation biology may be unique in seeking to protect the entire biota, the full range of species. Agricultural scientists are confined to crops and livestock, and the fisheries biologists to certain species of fish; but conservation biologists have every organism as their field of study. Conservation biologists believe that their central purpose is to protect Earth's biodiversity. Because climate change threatens biodiversity, conservation biologists aim, as one of their principal challenges, to stop, or at least slow down, climate change.

EVOLUTION AND EXTINCTION

The goal of biodiversity does not prevent conservation biologists from seeking to preserve evolution, a process that does not a priori favor biodiversity. Species compete for resources. The winners leave offspring to populate an ecosystem. The losers become extinct. Conservation biologists live with extinction as one outcome of evolution. However, they regret the current wave of extinction and pinpoint climate change as one cause of extinction. Humans are causing the current wave of extinction by warming the climate, acidifying rainfall, and thinning the ozone layer. The burning of fossil fuels, the cutting down of forests, the depletion of fisheries, and the overgrazing of ranchland are warming the climate and threatening the biota.

Conservation biologists have committed themselves to preserving land in as close to pristine condition as possible. In 1769, French colonialists legislated that one-quarter of the land on the island of Mauritius was to remain forest, that the island natives plant trees on denuded soils, and that the natives not cut down trees within 656 ft. (200 m.) of the ocean. In 1852, British scientists urged the East India Company, which oversaw the colony of India, to preserve forests in order to ensure abundant rainfall. Their report to the company was among the earliest to link the cutting down of trees with a reduction in rainfall. Before conservation biology had coalesced as a science, conservationists persuaded the U.S. Congress in the 19th and 20th centuries to create a system of national parks that would, in principle, remain unspoiled. Recognizing their role in protecting the habitats of innumerable species, conservation biologists aim to preserve the rainforests in Central and South America.



Conservation biologists battle problems like acid rain, which can result when factories and power plants emit sulfur dioxide.

By the early 21st century, conservation biologists, along with scientists from other disciplines, had established the fact of global warming and had enumerated the dangers of global warming for Earth's biota. Global warming is not a theoretical construct, but a biological reality. The greenhouse effect, the mechanism that causes global warming, threatens to extinguish innumerable species. Biologists, notably conservation biologists, urge political action to counteract global warming. Conservation biologists seek an alliance with policymakers and journalists, the one to implement laws and the other to inform the public of the dangers of global warming. Biologists acknowledge the difficulty of stopping global warming. People in the developed world must find an alternative to the burning of fossil fuels. People in the developing world must find an alternative to cutting down their forests. Biologists must think of innovative ways of protecting the biota while the rest of the world wrestles with the problem of global warming.

SEE ALSO: Animals; Climate; Climate Change, Effects; Cretaceous Era; Greenhouse Effect; Greenhouse Gases.

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Biomass

GLOBAL WARMING IS the increase in near-surface air temperatures as a result of the emission of greenhouse gases and particulate black carbon. Decaying biomass is considered to contribute to this. Biomass is living (or recently dead) plant and other biological material that can be used as fuel. Plant matter grown for use in biofuel (industrial production) is a type of biomass. Another type of biomass is crop residue, which comes from agricultural production and biodegradable waste. Grass species are the biggest contributors of biomass.

Biomass is known as carbon neutral. This means that it does not contribute to global warming, but does not reduce it, either. As plants that produce biomass grow, they absorb carbon dioxide (CO_2) from the atmosphere during photosynthesis. This is known as carbon sequestration, because carbon is removed from the atmosphere. Therefore, a living plant increases carbon sink, but when the plant dies and decays, the carbon is released back into the atmosphere as CO_2 and methane. This is known as the carbon cycle. Thus, the initial stage of carbon sinking through photosynthesis and the later stage of releasing carbon into the atmosphere through the decaying process makes the biomass carbon neutral. Even if the biomass is not burned, the same carbon must be released into the atmosphere by plant decay as a part of its natural life cycle. Therefore, when biomass is burned as fuel, scientists consider it carbon neutral.

Instead of allowing the biomass to decay naturally, the biomass decay process can be sped up by using it in biofuels. This also provides another positive effect toward global warming reduction. Methane is a natural byproduct of biomass decay, but when biomass is burned efficiently, no methane is released into the atmosphere. Therefore, scientists can argue that complete combustion of biomass for use in fuels benefits the environment. However, it can also be argued that biomass burning releases more carbon into the atmosphere instantly, whereas the natural decay process slows down the releasing process. Still, the acceleration of only a few years is not significant in the context of the entire carbon cycle, which takes hundreds of years.

However, controlled forest burning as practiced in developed countries, and slash-and-burn agriculture (shifting cultivation) in developing countries both contribute to global warming. According to M.Z. Jacobson, forest or biomass burning produces particles that cause short-term global cooling, but over decades the gases overwhelm the cooling effect to cause long-term global warming. Therefore, it is prudent not to burn biomass in the field, but to burn or use it in a controlled environment to produce biofuels.

Compared to biomass, fossil fuels act as a carbon positive because the fossil fuels exist in underground storage and they do not release carbon into the atmosphere unless used on the earth as an energy source. As most of the developing and developed nations have already mandated, or are in the process of mandating, 10 percent of fossil fuel use should be replaced by biofuels to reduce fossil fuel use. Thus, the consumption of biomass to produce biofuel will cut down on greenhouse gas emissions into the atmosphere.

Most mainstream environmental groups and environmental scientists support biofuels as a significant step toward slowing or stopping global climate change. However, if biofuels are not produced from biomass in a sustainable manner, they might be detrimental to the environment. Because the production of biofuel from biomass requires a lot of direct and indirect energy consumption, it emits more greenhouse gases into the atmosphere than the carbon released through biomass decay. The Roundtable on Sustainable Biofuels is working to define criteria, standards, and processes to promote sustainably-produced biofuels for global warming mitigation.

Plantation or afforestation to replace the used biomass can make the biomass burning process carbon negative, which is essential to reducing global warming and subsequent climate change. When sustainable biofuel production criteria are defined and properly followed, the use of biomass should contribute positively toward global warming and climate change mitigation processes.

SEE ALSO: Alternative Energy, Overview; Carbon Cycle; Carbon Dioxide; Carbon Emissions; Carbon Sinks.

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Blizzards

IN HIGH AND mid-latitudes, blizzards are some of the most widespread and hazardous of weather events. They are most common in Russia and central and northeastern Asia, northern Europe, Canada, the northern United States, and Antarctica. It is likely that climate change will give rise to changes in the number, severity, and geographical occurrence of blizzards. Although it is common for the term *blizzard* to be employed to refer to any disruptive winter storm, there is a more precise scientific usage. Blizzards are a winter phenomenon occurring when snow is blown along the ground surface by strong winds. In different countries, official definitions of blizzard conditions vary according to: high wind speed, high wind chill values, low visibility, the presence of falling or blowing snow, and the length of time the conditions persist. Although no particular temperature threshold is associated with these definitions, blizzard conditions may produce extreme wind-chill values through a combination of low temperatures and high wind speeds.

It is possible for blizzards to occur in conditions of clear skies when no snow is falling if conditions are conducive to the movement of existing surface snow, called ground blizzards. In many storms in continental interiors, it is not uncommon for little new snow to be associated with a blizzard, due to a lack of moisture associated with Arctic and Antarctic air masses in winter. In such circumstances, blizzard conditions are largely the result of winds blowing the existing snow cover. However, blizzards in some regions (for example, those in Western Europe and the Asian coast of the North Pacific, and "nor'easters" in the northeastern United States) are characteristically accompanied by heavy snowfall.

Blizzards are produced by strong winds: katabatic winds and those generated by steep sea-level pressure gradients associated with storms in high and mid-latitudes latitudes during winter. A single storm can occur over large areas of a continent and a severe blizzard may persist for a week or more. A blizzard that struck Saskatchewan, Canada, in 1947 lasted 10 days, burying a train in a snowdrift a kilometer long. The most severe blizzards occur in Antarctica, with winds exceeding 93.2 mi. (150 km.)/hour; at some Antarctic stations blizzard conditions occur on over half the days annually.

Historically, high death tolls have been associated with the most severe blizzards. A spring blizzard, in the United States in 1888, killed more than 400 people, and 277 died in a storm in 1993. In addition to the risks resulting from high wind chill values and exposure, blizzards generate other hazards. Whiteouts are often associated with blizzards, producing dangerous travel conditions. The blowing snow, limited visibility, absence of shadows, and lack of contrast between objects can cause a loss of depth perception and conditions in which even nearby objects may be rendered invisible. The persistent winds associated with blizzards may cause severe damage to buildings, and can block transportation links and bury structures in massive snowdrifts. Outdoor activities may come to a standstill. The resulting economic disruption can be extensive. Widespread deaths of domestic animals have occurred due to exposure and when sources of feed are cut off by blizzards. A reported 130,000 head of livestock died in Inner Mongolia as a result of a blizzard that began on New Year's Eve in 2000. However, very disruptive winter storms may not qualify as blizzards (for example, those involving high snowfalls, but without one or more other defining characteristics).

There are significant inter- and intra-annual variations in blizzard frequency and severity that make statistical analysis of past trends problematic. Detailed studies are limited. Nonetheless, at least in North America, historical evidence points to a decline in the frequency and severity of blizzards on the Canadian prairies and a significant decline in the frequency of blowing snow conditions in the Canadian Arctic. On the other hand, there is evidence for the occurrence of stronger blizzards along Russia's Pacific coast.

An increase in the vigor of winter storms in a warmer atmosphere may result in more frequent severe blizzards.

It may be reasonable to assume that in a warmer world there would be fewer blizzards. However, the occurrence of a blizzard is dependent on a specific combination of physical and meteorological factors. A systematic variation in one or more of these, as influenced by future climate change (for example, storm intensity, shifting storm paths, wind velocity, ambient temperature, the amount of snowfall, and the amount and condition of snow on the ground), may affect the number, intensity, and geographical distribution of blizzards.

An increase in the vigor of winter storms in a substantially warmer and energetic atmosphere may result in severe blizzard conditions becoming more frequent. A warmer climate may also be conducive to greater weather extremes. Regional differences in temperature variations in response to climate change (such as between ocean and continents, or between polar and mid-latitudes) may reduce or enhance temperature contrasts and thereby affect the frequency and severity of storms.

There is evidence from some regions that winter storms have increased in intensity; however, some modeling and empirical studies suggest a decrease in the frequency of winter storms. There may be considerable regional variation in the response to climate change (for example, potentially fewer blizzards in North America and more frequent and more severe storms in Western Europe). Storm tracks may also shift. Forecasts are speculative, as there is still a need to verify the conclusions derived from empirical studies of past blizzard patterns and projections from climate models.

SEE ALSO: Climate Change, Effects; Ice Ages; Ice Albedo Feedback; Ice Component of Models; Snowball Earth; Weather.

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Bolin, Bert (1925–2007)

BERT BOLIN MADE numerous contributions to the field of meteorology and its impact on the science of global warming and climate change. He was a Swedish meteorologist who worked globally and served on many international committees. Bolin was born in Nyköping, Sweden, on March 15, 1925, to two schoolteachers. He obtained his B.Sc. from the University of Uppsala in 1946, followed by an M.Sc. in 1950.

Bolin continued to study meteorology, receiving a Ph.D. from Stockholm University in 1956, at the age of 31. One of his mentors, Carl-Gustav Rossby, played an influential role in Bolin's career, when he encouraged the young scientist to enter the field of geochemistry. Bolin rapidly gained expertise on carbon dioxide and its role in biology and chemistry. From 1952–57, he served as executive editor of *Tellus*, a scientific journal publishing investigations in the atmospheric and oceanic sciences. In 1961, he returned to Stockholm University as a professor of meteorology, where he remained until 1990, and then became professor emeritus at that institution.

In 1967, the International Council of Scientific Unions (ICSU) and the World Meteorological Organization (WMO) joined forces to organize the Global Atmospheric Research Program (GARP), of which Bolin served as chair from 1968–71. GARP synthesized a new science that incorporated atmospheric physics, oceanic physics, mathematics, engineering, and other related fields, to study the weather and climate across the globe. Later, the WMO, along with the United Nations Environment Program (UNEP), formed the Intergovernmental Panel on Climate Change (IPCC), of which Bolin was chairman 1988–97. In 1990, he led the IPCC in its first assessment of climate change. The IPCC acts to review all relevant scientific investigations and observations regarding the climate and any human impact on the climate.

Between 1983 and 1986, Bolin acted on the Scientific Advisory Board, which advised the government of Sweden. He then became scientific advisor to the prime minister of Sweden until 1988, and then advised the vice prime minister until 1991. Bolin also served as the scientific director of the European Space Agency, as well as having membership in nine academies of science in different nations. In 1995, Bolin earned the Blue Planet Prize, established by the Asahi Glass Foundation in 1992 as "an international award that recognizes individuals and organizations who have made major contributions to solving global environmental problems." While Bolin's initial studies were on mathematics of atmospheric circulation, he is now recognized for his knowledge of greenhouse gases and his efforts to educate people about global warming.

SEE ALSO: Global Atmospheric Research Program (GARP); Intergovernmental Panel on Climate Change (IPCC); Stockholm Environment Institute (SEI); Sweden.

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Bolivia

THIS LAND-LOCKED SOUTH American republic has a land area of 424,163 sq. mi. (1,098,581 sq. km.), with a population of 9,119,152 (2007 est.), and a population density of 21.8 people per sq. mi. (8.4 people per sq. km.). Only 2 percent of the land in the country is arable, with 24 percent used for meadow or pasture, and 53 percent is forested. Largely underdeveloped, Bolivia had a per capita carbon dioxide emission rate of 0.8 metric tons per person in 1990, rising to 1.3 metric tons per person in 1997–99, and then falling to 0.90 tons by 2003. Most of the emissions come from transportation (39 percent), with manufacturing and construction accounting for 20 percent, and public electricity, heat production, and auto producers accounting for the rest. The relatively small part played by electricity generation comes from the heavy use of hydropower in Bolivia, which accounts for 50.1 percent of power generation. However, 48.3 percent comes from fossil fuels, mainly liquid (58 percent) and gaseous (24 percent) fuels.

The effect of global warming and climate change on Bolivia is significant; the average temperature in increased by about 0.18 degrees F (0.1 degree C) each decade since 1939, with the rate of warming doubling in the last 40 years, and then tripling in the last 25 years. With the small amount of agricultural land, global warming will continue to contribute to a declining food supply for an already poor population. Furthermore, it has been causing the ice on mountains in Bolivia to melt, leading to avalanches, occasional floods, and soil erosion.

The Bolivian government of Jaime Paz Zamora took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, and that of his successor Gonzalo Sánchez de Lozada ratified the Vienna Convention in 1994. On July 9, 1998, the government of Hugo Banzer Suárez signed the Kyoto Protocol to the UN Framework Convention on Climate Change, which was ratified on November 30, 1999, and took effect on February 16, 2005.

SEE ALSO: Agriculture; Floods; Global Warming.

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Bosnia and Herzegovina

ONE OF THE former constituent states of Yugoslavia, the Republic of Bosnia and Herzegovina has a land area of 19,767 sq. mi. (51,197 sq. km.), with a population of 3,925,000 (2007 est.), and a population density of 230 people per sq. mi. (76 people per sq. km.). Fourteen percent of the country is arable land, 20 percent is used for meadows and pasture, and 39 percent of the land is forested with mainly pine, beech, and oak trees.

One of the least developed countries in Europe, Bosnia-Herzegovina has one of the lowest rates of carbon dioxide emissions: only 1.2 metric tons per capita in 1992. However, in 1997 the per capita rate rose dramatically to 3.6 metric tons, and then 4.6 metric tons by 1998. Most of these emissions come from electricity production (63 percent), as 37.6 percent of the country's electricity production is generated from fossil fuels. The remainder comes from hydropower. Transportation accounts for 33 percent of carbon dioxide emissions. These figures are reflected in the fact that the use of solid fuels, primarily wood and coal, account for 47 percent of carbon dioxide emissions. Liquid fuels account for 38 percent. The manufacture of cement also has a role in the country's carbon emissions.

Despite the Bosnian War, the government was eager to join international forums, and took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, and ratified the Vienna Convention in the same year. On April 16, 2007, the Bosnian government accepted the Kyoto Protocol to the UN Framework Convention on Climate Change, becoming the 168th country in the world to do so.

SEE ALSO: Carbon Emissions; Coal; Serbia and Montenegro.

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Botany

BOTANY IS THE study of plants. Botanists study all aspects of plants, including their environment and how they grow. The discipline is one of the oldest sciences and has been closely associated with agriculture, horticulture, pharmacology, and other disciplines concerned with plants. Botany is related to many other sciences such as soil science, chemistry, geography, mathematics, and physics. All the sciences and businesses that use botanical knowledge benefit from pure botanical research.

Since prehistoric times, people have used plants for medicine, food, building materials, and making other items such as musical instruments. Plant knowledge was universal among cave dwellers or hunter-gatherers, whose folklore was passed on for generations. Medicine men or women practiced the development of remedies for diseases and injuries, as well as intoxicants. When settled farming communities arose about 12,000 years ago, horticultural plant knowledge also began to move toward a body of knowledge.

Ancient civilizations of the Egyptians, Indians, and Babylonians coined names for the plants they knew. The Greeks added to plant name descriptions. Aristotle, his student Theophrastus (*An Inquiry into Plants*), Galen the physician, and others gave descriptions to plant names. Aristotle sought the unique form or idea that is found in each plant. This basis would eventually aid the development of taxonomy of plants. He believed in the fixity of the species. This view was challenged by Charles Darwin's theory of evolution of the species, which was a naturalistic explanation for the enormous plant diversity in the plant kingdom.

There are hundreds of thousand of plants in the world. They vary widely, even when related. This creates a major problems for accurate identification. For example, there are a wide variety of plants named in the Bible and in other ancient literature. However, identifying the exact plants named by biblical names is problematic. The same problem occurs when plants are named by other ancient literature; because they were given local names, the specific plants named are hard to precisely identify. For example, in the Hindu *Vedas*, there is frequent mention of the soma plant that was used as an intoxicant. Today, scholars are not sure which plant is the soma plant because of the absence of a universal, standard terminology of identification.

A standard nomenclature was adopted after the voyages of discovery, when a rich new variety of similar and uniquely new plants confronted botanists. Standardized nomenclature was developed using a taxonomy derived from Latin names. Latin, the language of scholarship until the 20th century, was used to assign a universal name to plants with different common names or national names in the many European languages. The use of Latin, a dead language, prevents changes in names that would occur in a living language, thereby creating lasting scientific precision.

The scientific naming has a fixed pattern, in which the first name identifies the genus to which a plant belongs. The second name is the species name, which denominates precisely to which subgroup it belongs. Each genus is a unique class with each of its species being also unique groups. Many plants also have varietal names. For example, the orange tree has a scientific name of *Citrus sinensis*; Naval and Valencia oranges are varieties.

AREAS OF STUDY

As a scientific discipline, botany organizes plants observed in nature into an organized body of knowledge or taxonomy, giving each its unique scientific name in Latin. The features of plants help to identify and name them. These are studied in order to understand the nature and possible uses of plants. The features of plants studied by botanists include plant physiology, cytology and histology, morphology, genetics, pathology, plant ecology, and economic botany. Physiology in botany is the study of the kinds of things that plants do to stay alive. It includes study of how plants make and use food, how the cells of a plant enable it to grow, how they reproduce, and how they are influenced by heat, light, and moisture.

Plant morphology is the study of the form and structure of plants. Morphology is organized around the taxonomy of plants. Cytology and histology are sub-disciples of plant morphology. Histology is the study of how different types of cells are arranged in different plants. Cytology focuses on the specific nature of plant cells. Plants range from single cell to very complex arrangements of cells into soft green leaves, sea weed, or into very hard tropical trees such as mahogany. Plant genetics focuses on the laws of genetic reproduction to describe how plants transmit their characteristics to their offspring. This discipline is very important to many people, from gardeners to farmers.

Plant pathology is caused by a multitude of pathogens. The most damaging are viruses, bacteria, fungi, and molds. However, exhaustion of the soil, or weather, especially that associated with climate change, can cause the death of plants. To prevent crop loss, plant pathology includes the study of ways to fight or prevent plant diseases. Plant ecologists study the relationship between plants and their spatial location. Also important to plant ecology are studies of how plants grow (or do not grow) together. Knowledge of plant ecology can be very helpful in aiding recovery of an area that humans are trying to restore to health.

THE GREENHOUSE EFFECT

Botany is being brought into play in the effort to understand and respond to climate change. Global warming is climate change that is producing a dramatic rise in temperatures around the Earth. Carbon dioxide, methane, and nitrous oxide are naturally in Earth's atmosphere in small amounts; however, they act as greenhouse gases by absorbing some of the long wave radiation that is radiated from the Earth back into outer space.

Sunlight is mostly shorter-wave radiation. Although the layers of the upper atmosphere block some, the portion that strikes the surface of the Earth warms both the oceans and the Earth's surface. However, the polar ice caps and the alpine glaciers of the world reflect much of this radiation. That which heats up the rocks of deserts, or the concrete and brick buildings of urban areas, or even the masses of greenery in forests is absorbed, in part, and returned as a part of cooling as long-wave infrared radiation. Most radiated heat returns to outer space. However, some is retained by the greenhouse gases and radiated back to the surface of the Earth.

The greenhouse gas phenomenon is natural. Without it, Earth would be much colder, by 54 or more degrees F (30 or more degrees C), and would very likely be a block of ice. What is of great concern at the present is that humans are causing global warming. The term *anthropogenic* is used to describe the human emissions of greenhouse gases, mainly carbon dioxide, that are causing a rise in global temperatures, the melting of the ice caps and the alpine glaciers, and a change in wind patterns that bring rain.

CLIMATE ZONE CHANGES

Of particular concern to botanists, as well as others, are the global warming effects that are producing a shift in climate zones. For example, the warming of the Arctic regions is a threat to polar bears that need sea ice as a platform for their hunting, but it is also a threat to plants that are adapted to colder temperatures and are disappearing because of global warming. As global temperatures rise, plants in the latitudes away from the equator are affected. Many will spread northward or southward as temperatures rise; however, many species do not migrate well. This is especially true of plants (and animals that feed on them) that are located in mountainous areas. Adapted to cold temperatures in high elevation, global warming pushes them ever higher up the mountain sides until, for some, there is literally no place to go.

The changing temperatures are also affecting the hardiness zones used by farmers and gardeners to decide which plants to grow. However, global warming is not bringing a simple northward or southward movement away from the equator. The shifting flows of energy in the planetary weather patterns are making some places drier, some colder, others warmer, and others wetter.

Some botanists have hypothesized that if global warming continues, areas that have been agricultural zones for growing wheat, corn, or other crops may be lost and not easily replaced by other sufficiently warm, but less fertile, regions.

Many scientists are concerned that climate zones as they are currently known will vanish entirely by 2100. Using greenhouse gas emissions scenarios that range from low to high, it is possible that enough climate change will occur to cause major ecological transformations. Entire plant species will disappear, pine forests would become grasslands, and rainforests would become savanna. In places like Wyoming, grasslands would disappear. Higher temperatures would cause places such as Wyoming's grasslands to be much drier in the summer and to be much more threatened by fires. Researchers estimate that existing climates will disappear from almost half of the planet. New climates will develop in about 40 percent of the of the Earth's land mass. The places hardest hit will be the tropics, which have the most biodiversity.

Botanists report that many plants, including the cherry trees of Washington, D.C., are blooming days earlier than 30 years ago.

Duke University has conducted a study of the central plains of the United States in the areas where the plains have changed from grasslands and forest because of climate change in the geologic past. After the last ice age, periods of warming and cooling caused the grasslands and the forest areas to radically change. The grasslands would expand eastward into the eastern forests. Tree mortality would be affected by seed-eating predators and the ways in which seed dispersal affects biodiversity.

Botanical evidence of global warming is accumulating at a rapid rate. Botanists in Boston have found that plants are blooming over a week earlier than they did a century ago. The plants studied are in arboretums where long-lived plants or descendants of the same species of plants provide a standard of comparison. The flowers of living plants can be compared with museum specimens that were gathered at specific dates. These plants and dates have been compared to determine that plant life is showing evidence of global warming.

BOTANICAL EVIDENCE FOR GLOBAL WARMING

Botanical evidence for global warming is being extracted from the rich trove of journals and records kept by gardeners and farmers in areas such as New England. Henry David Thoreau's writings are an early version of this form of information that is allowing comparisons to be made with weather in prior decades and the current weather patterns. It takes at least 30 years of records to have sufficient data to make statements about the climate of an area. Those who have consistently kept records of the arrival of birds, of the blossoming of plants, for 30 or more years, have data that can be used to verify climate changes. Amateur naturalists, hunters, fishermen, bird watchers, and local nursery growers, as well as farmers, are supplying records that can demonstrate climate change. When compiled, if the field observations of amateur naturalists are close to the trends observed in scientifically collected data, then the scientific inferences of global warming and its effects gain additional support.

Another botanical observation that provides evidence of global warming is the famous blossoming of the cherry trees in Washington, D.C. Scientists from the Smithsonian Institute have produced evidence that the cherry trees are blooming seven days earlier than they did a mere 30 years ago. The change is apparently due to global warming. Studies by the Smithsonian's Department of Botany have found that records from the last 30 years show that between 1970 and 2000, almost all of the species of common plants studied bloomed earlier in 2000 than in 1970, by at least four and a half days.

Dutch botanists have begun studying epiphytes in order to understand the impact of climate change. Epiphytes are organisms that grow on living plants. They include algae, lichens, mosses, ferns, bacteria, and some fungi. Their specific focus has been on lichen species in the Netherlands. Lichen distribution and species diversity have changed significantly over the last 30 years. At first, the changes were because of reductions in pollution; later changes correlate well with temperature increases. Other European scientists have found that bryophyte species in central Europe are subtropical and are now expanding their range. The changes are indicative of botanical changes being wrought by global warming. In Costa Rica and in the Bolivian Andes mountains, epiphytes are also being used as indicators of global warming. A number of species of epiphytes have moved to higher elevations. Others in lower elevations have diminished, which suggests stresses caused by temperatures that exceed the species tolerances.

In Japan, studies conducted between 1981 and 2005 have found that 17 species and hybrids of cherry trees from Mt. Takao in Tokyo are flowering earlier previously. Each species is blooming between three to five days earlier for each one degree C increase in temperature. The effects of the changes on the gene flow and the pollination patterns are as yet unknown. Many botanists believe that Africa will suffer the most from increasing global warming and the resulting botanical changes. In Australia, the grasslands of Tasmania are also currently threatened, according to botanists studying the area.

SEE ALSO: Climate Zones; Climatic Data, Historical Records; Climatic Data, Tree Ring Records; Greenhouse Effect; Plants.

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Botswana

BOTSWANA IS A landlocked country in sub-Saharan Africa bordered to the south by South Africa and to the north by Zimbabwe and Namibia. It is a semi-arid country, dominated to the southwest by part of the vast Kalahari Desert. Only about 0.65 percent of the land is arable. Its main environmental issues are periodic droughts, limited access to fresh water, overgrazing, and desertification. The population is approximately 1.8 million people. Botswana has one of the world's highest rates of HIV-AIDS prevalence, with an estimated 37.3 percent of the adult population infected with the virus. This has put an enormous strain on the country's financial resources, and has made it even more difficult to deal with environmental issues.

Current climate models predict a regional decrease in rainfall of 10–20 percent by 2070. A 10 percent decline in rainfall would leave Botswana with just 23 percent of its current surface water flow; a 20 percent decrease would leave the country's few water sources completely dry. Researchers have also found that the dunes of the Kalahari Desert are beginning to shift for the first time in 16,000 years, reacting to vegetation loss and global shifts in wind patterns. This will push the dunes into Botswana's already stressed agricultural regions by 2100.

A study of crocodile populations along the Nile River near Okavango, Botswana, conducted by Alison Leslie, has shown that rising temperatures are leading to a decrease in the number of male crocodiles. Male offspring are produced only within a certain range of temperatures, and as the average temperature is increasing, more and more broods are all female, or female-dominated. This will eventually lead to a decline in the species.

Botswana is not a high CO_2 emitter, although studies show a 43 percent increase in emissions 1990–98. In 1998, per capita CO_2 emissions were 2.4 thousand metric tons, higher than the sub-Saharan average, but less than half the world average. About 66 percent of emissions came from the burning of solid fuels such as wood and charcoal, while 34 percent came from liquid fuel use. Botswana has signed a number of international environmental accords, including the Kyoto Protocol and conventions on biodiversity, climate change, desertification, protection of endangered species, the ozone layer, and wetlands. However, the government has ratified none of these conventions.

SEE ALSO: Desertification; Deserts; Diseases; Health.

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BP

BP (BEYOND PETROLEUM) is the world's third largest investor-owned oil company. At the close of 2006, it had nearly 97,000 employees, 18 refineries, 24,600 service stations, and proven oil reserves of 17.7 billion barrels of oil and gas equivalent, and it operated in over 100 nations. In 2006, BP's sales were $266 billion, with profits of $22.5 billion, compared to $19.3 billion in 2005, and $15.4 billion in 2004. It is also a major producer of solar and other renewable sources of energy. It is a significant contributor to greenhouse gas (GHG) emissions, but has also been a leading industry advocate of addressing climate change. BP is organized into three key segments: exploration and production; refining and marketing; and gas, power, and renewables.

BP is the product of numerous mergers during the 20th century. British Petroleum's retail operations were centered in Britain and Western Europe, with crude oil reserves predominantly in the Middle East until the late 1960s, when it discovered large oil fields in Alaska and the North Sea. At this time, it expanded into U.S. retailing through an ownership stake in Sohio (Standard Oil of Ohio). It bought full control of Sohio in 1987, rebranding the stations as BP and establishing its BP America division. That year, the British government completed selling its shares of BP. Amoco (Standard Oil of Indiana), a major Midwest U.S. retailer and the world's largest natural gas producer, was acquired in 1998, creating BP Amoco.

ARCO (formerly Atlantic Richfield) concentrated on the U.S. West Coast, and also held large Alaskan reserves, and British lubricant manufacturer Castrol and its parent, Burmah Oil, were acquired in 2000. That year the name was changed to BP and a new unified global brand was created, although the ARCO brand was retained on the U.S. West Coast. In 2002, BP bought Aral, a major German gasoline retailer, rebranding BP stations in several European nations under the Aral name. It also entered an $8 billion joint venture in Russia (TNK-BP) in which it has 50 percent ownership.

Under Lord John Browne, CEO 1995–2007, BP attained a reputation as an environmental leader in the oil industry. Browne publicly stated in 1997,

> the time to consider the policy dimensions of climate change is not when the link between greenhouse gases (GHG) and climate change is conclusively proven, but when the possibility cannot be discounted and is taken seriously by the society of which we are part. We in BP have reached that point.

BP then became the first company to withdraw from the Global Climate Coalition, an industry group opposing action on global warming. In 2007, BP was a founding member of the U.S. Climate Action Partnership, a coalition of over 25 corporations and several environmental groups advocating strong governmental action to reduce GHG emissions.

BP believes that addressing climate change involves several elements: precautionary action; urgent, but informed, action over the next 50 years; sustainable GHG emission reductions at the lowest possible cost; an inclusive approach involving many different parties, policies and regulations relying on market mechanisms, research and development; and public education. It is in favor "of mandatory emission caps and policies that set a price for carbon in a way that can change behavior and encourage innovation." The company has a related business strategy of engaging in energy efficiency, fuels switching; carbon sequestration; and solar, wind, biomass, and hydrogen power.

In 1998, BP began tracking GHG emissions and set voluntary reduction goals, which it met ahead of schedule. In 2004, a seven-year, $450-million energy-efficiency program began to cut GHG emissions and costs. BP estimates that customers' CO_2 emissions from use of its conventional hydrocarbon products were 606, 570, and 539 Mte in 2004, 2005, and 2006, respectively. One of the main ways BP is looking into further cutting GHG emissions is through limiting gas flaring and venting.

In 2004, BP Solar (a merger of solar companies previously purchased by BP and Amoco) had a 20 percent share of the global solar panel market, with 2,000 employees. BP currently has a $70 million project to expand solar casting capacity at a plant in the United States, and is tripling its capacity in facilities in Spain and India over a three-year period. BP currently operates two wind farms in the Netherlands and bought a leading wind producer in the United States. It intends to raise its wind generating capacity from 30 megawatts (MW) to 450 MW by 2010.

BP's hydrogen projects are more limited, derived from fossil fuels, accompanied by carbon sequestration and storage. BP is pursuing a relationship with

General Electric to develop new hydrogen technologies. Its natural gas operations include combined-cycle gas-turbine power stations and steam-turbine power generating plants. BP plans to invest $500 million in biofuels research and development over the next 10 years in a new Energy Biosciences Institute, and is funding many other external research projects into various low-carbon technologies and topics.

While generally lauded by environmentalists since 1997, BP has come under increasing criticism. BP's production of hazardous wastes is substantially higher than its industry competitors; a 2005 Texas refinery fire killed 15 persons and injured 170, and corrosion in an Alaskan pipeline managed by BP resulted in an oil spill of over 200,000 gallons and necessitated shutting down the pipeline for several months in 2006.

In 2007, a BP refinery received a permit from the state of Indiana to increase its discharge of ammonia and sludge into Lake Michigan coincident with a refinery expansion, resulting in tremendous negative publicity and calls for a consumer boycott. BP eventually announced that it would not increase its discharges, although the permit still remains valid. BP is alleged to have engaged in human rights abuses at various extraction and pipeline locations, including Columbia, West Papua, and Azerbaijan. BP has also been criticized for continuing to derive almost all its revenues from fossil fuels, despite the publicity it gives to its renewable energy business and its "beyond petroleum" slogan.

SEE ALSO: Oil, Consumption of; Oil, Production of; Royal Dutch/Shell Group.

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Brazil

WITH THE 10TH largest economy and fifth largest population in the world, Brazil is an important enactor of climate policy. Its energy matrix is relatively "clean"—80 percent of the generated electricity comes from hydropower, and 45 percent of the country's total energy consumption comes from renewable sources. Most of Brazil's CO_2 emissions come from biomass burning, as a result of deforestation. Deforestation is responsible for between 10 and 25 percent of the global human-induced carbon emissions and 60 percent of all Brazil emissions. Although total fossil fuel CO_2 emissions have increased steadily and reached 90 million metric tons in 2004, Brazil's per capita emission rate of 0.50 metric tons of CO_2 per year remains well below global average rates.

Climatic change is expected to impact Brazil in many different ways, from increases in semi-arid areas in the northeast, to higher rates of rainfall in the southeast. Lower rainfall rates in northeast Brazil will result in even more extreme drought spells and further challenge the availability of water in a region already historically ravaged by climate-related poverty. In addition, groundwater recharge may also decrease dramatically (by as much as 70 percent) further affecting the availability of water resources. Less water will also negatively affect irrigated agriculture and hydroelectricity production in the region.

Negative impacts are also predicted for Brazil's rich biodiversity, especially in areas such as the Amazon and Atlantic rainforests, or fragile ecosystems such as the Pantanal wetland, which may lose up to 40 percent of its species diversity with temperature increases of about 3.6 degrees F (2 degrees C) above pre-industrial levels. The Amazon forest may go

Deforestation, such as in this open pit mine in Minas Gerais, is responsible for 60 percent of Brazil's CO_2 emissions.

through a "savannization" process in which increases in temperature and decreases in soil moisture may lead to the gradual replacement of the tropical forest by vegetation similar to that in Brazil's savannahs. This savannization will be accompanied by possible extinction of species and loss of biodiversity. Drier weather may also increase the frequency of forest fires in the region, which, in turn, would contribute to further CO_2 emissions.

Other possible negative impacts include coastal cities and coral reefs being affected by rising sea levels, the expansion of vectorborne diseases, and possible increases in the frequency and intensity of weather-related disasters, such as flooding and cyclones. One sector of special concern is agriculture, because of its critical importance to Brazil's economy, and because of its role in the country's biofuel programs, essential to meeting mitigation goals for CO_2 emissions. Regarding human vulnerability to climate change, although, overall, Brazil fares relatively well when compared to other countries, the high level of socioeconomic inequality and large pockets of poverty suggest that significant portions of the population may be highly vulnerable to climate change and will need specific policies to increase their levels of adaptive capacity.

Brazil's climate policy, both domestic and international, has been, at times, aggressively proactive (as with the design and pursuit of Clean Development Mechanisms, or CDMs) and remarkably reactionary (as in the government's reluctance to support initiatives to curb deforestation as part of its climate policy portfolio). Brazil has been a leader in the Kyoto negotiations to introduce carbon-trading mechanisms such as CDMs, which allow for developed countries and businesses to count greenhouse gas (GHG) reductions generated by projects carried out in less developed countries (LDCs). Currently, Brazil is the country hosting the largest number of CDM projects.

Brazil has also sought to block initiatives to subject LDCs to stringent carbon emission reduction targets. Brazilian government representatives have been particularly sanguine in defending the historical contribution argument, which maintains that, because carbon dioxide remains in the atmosphere for more than a century, on average, climate change has been primarily caused by early polluters, or developed countries, that should be responsible for its mitigation. Another argument against emission targets for LDCs is that these countries have a long way to go to reach levels of per capita carbon consumption comparable to current levels of developed countries, and, therefore, should be exempt from carbon emission caps in the near/mid-term.

The Brazilian government has been particularly sensitive to any mitigation scheme that involves the Amazon rainforest, and has been reluctant to endorse initiatives such as Avoided Deforestation, which is supported by a coalition of conservation interests and rainforest-rich countries. This scheme would allow developing countries to participate in the Kyoto Protocol by electing to reduce their national emissions from deforestation. Forest-rich countries would be allowed to issue carbon certificates, similar to the Certified Emissions Reductions (CERs) of the CDM that could be sold to governments or private investors.

Domestically, Brazil has invested substantially in an energy matrix reliant on renewable resources. Brazil's flagship biofuel program is based on sugarcane and dual-fuel car technology (cars run on sugarcane alcohol and/or gasoline). The sugarcane biofuel program is worth over $8 billion a year and generates a million direct jobs. Brazil's bio-diesel program is based on oil seeds such as castor and sunflower crops that produce clean energy, absorb carbon monoxide, and are labor intensive.

SEE ALSO: Clean Development Mechanism; Deforestation; Forests.

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Broecker, Wallace (1931–)

WALLACE BROECKER IS an American oceanographer, Newberry Professor of Geology at Columbia University, and scientist at the Lamont-Doherty Earth Observatory who made major contributions to chemical oceanography, especially oceanic mixing based on radioisotopic distribution. Broecker set the research agenda for the field of paleoclimatology, thanks to his ability to devise coherent pictures of how all the different elements of the Earth shape the planet's climate. In particular, Broecker focused on the influence of oceans in triggering abrupt climate changes. His research has made him one of the most often-quoted scientists in contemporary debates about global warming. A *New York Times reporter* described him as the "iconoclastic guru of the climate debate."

Broecker was born on November 29, 1931, in Chicago, Illinois, where his father ran a gas station. He grew up in a fundamentalist Christian family and attended Wheaton College, a fundamentalist institution, before transferring to Columbia University in 1952. Broecker soon rebelled against his religious fundamentalist background. The skepticism that informs much of his scientific interest in the exceptions to general rules may be the result of this rebellion against the stifling religiosity of his family.

Broecker stayed at Columbia for his entire academic career. He earned his doctorate in 1958 and, a year later, became assistant professor. In 1961, he became associate professor, and in 1964, he was appointed full professor. In 1977, Broecker was named the Newberry Professor of Geology and, two years later, he was elected to the National Academy of Sciences and named chair of the Geochemical Society.

Broecker is the author of more than 400 articles and seven books. He began his research in the 1950s, developing techniques to measure the radiocarbon content of ocean water. He used his data to trace ocean circulation patterns over time. His researches connecting climate change with radiocarbon dating of marine shells found in sediment deposits on the sea bottom helped to date the abrupt end of the most recent ice age, approximately 11,000 years ago.

In the 1970s, Broecker was among the leaders of the Geochemical Ocean Sections (GEOSECS) program, which gathered information from the world's oceans through radiocarbon dating. In the mid-1980s, Broecker devised his theory of global ocean circulation, which is often called Broecker's Conveyor Belt. He theorized the circulation of chemical elements in the sea, the thorough mixing of surface and deep waters of the ocean that takes place every 1,000–2,000 years, and the rate of gas exchange between the atmosphere and the ocean.

Broecker came to the conclusion that climate is extremely volatile. It can cool down, as well as warm up very quickly, and these alterations can produce global changes. The Earth's climate is subjected to the on and off action (thus the conveyor metaphor) of deep ocean currents that transport great amounts of heat around the planet. Broecker used radiocarbon dating of samples of ocean water to study the world's oceans. He was one of the first scientists to stress the importance of the carbon cycle and to be able to work out its chemical processes. His research also pointed out the ocean's influence on atmospheric carbon dioxide levels.

While researching changes in the Earth's climate in the past 200,000 years, Broecker discovered that major climate shifts actually occurred much more rapidly than was previously thought. Focusing on the Younger Dryas, an event dating back 11,000 years when temperatures in northern Europe suddenly plummeted and remained low for about 1,000 years, Broecker concluded that the transition periods from warm to cold and back again may have taken as little as 20 years. This cold spell, Broecker explains, was due to a temporary disturbance in the global circulation of the world's oceans. Because this global current is linked to the atmosphere, the emission of greenhouse gases through fossil fuel combustion could cause a major interference in today's climate.

Broecker likens climate to "an angry beast" that "we are poking with sticks." He has had no qualms in explicitly stating that if world temperature continues to rise, the conveyor belt could slow down or stop, causing disruptive events throughout the world. The most disruptive of these events would be what he calls brief, but large ,"flickers" in global temperature as the climate readjusts itself in fits and starts. These flickers would be largely unpredictable and could produce drastic climate changes in periods as short as five years. This would lead to agricultural disasters.

Thanks to his investigation of oceanic cycles and the connection between the oceans and the atmosphere, as well as his research into chemical cycles such as the carbon cycle, Broecker has improved knowledge of how climate changes. He has also supplied fundamental information to devise possible strategies to deal with the problem of global warming.

SEE ALSO: Carbon Cycle; Carbon Sinks; Current; Global Warming; Oceanic Changes; Oceanography.

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Brunei Darussalam

LOCATED ON THE north coast of Borneo, Negara Brunei Darussalam has a land area of 2,226 sq. mi. (5,765 sq. km.), and is divided into two parts. It has a population of 383,990 (2007 est.), and a population density of 168 people per sq. mi. (65 people per sq. km.). The country has abundant petroleum and gas supplies, which produce most of the its wealth, with one percent of the land being arable, and another one percent used for meadows and pasture. Unlike most of the other major petroleum-exporting countries, some 85 percent of the country is forested, with logging restricted and largely for local consumption, such as in the making of furniture and other higher-value activities.

In spite of its abundant forests, Brunei has the 15th highest per capita emission of carbon dioxide in the world. In 1990, its emission rate was 33.7 metric tons per person, but this was steadily reduced to 10.7 metric tons per person in 1998, after which it rose dramatically, before being reduced to 12.7 metric tons per person in 2003. In terms of its carbon dioxide emissions by source, 55 percent is from gaseous fuels, 28 percent from liquid fuels, 13 percent from gas flaring, and 4 percent from the manufacture of cement.

Electricity production, which is entirely from fossil fuels, accounts for 38 percent of the emissions. With an extremely high standard of living, much of the electricity consumption is spent on household use and air conditioning. Until the mid-1990s, there was very limited public transport in the country (with the exception of the water taxis at Bandar Seri Begawen, the capital). The system has been greatly improved, although there remains a high level of private car ownership, with the result that transportation accounts for 16 percent of the country's carbon dioxide emissions.

The Brunei government sent observers to the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, but so far the government has not expressed an opinion on the Kyoto Protocol to the UN Framework Convention on Climate Change.

SEE ALSO: Forests; Natural Gas; Oil, Consumption of; Oil, Production of.

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Bryan, Kirk (1929–)

KIRK BRYAN IS an American oceanographer and Senior Research Scholar at Princeton University whose research has dealt with the construction of models for ocean circulation and the roles played by oceans in the climate system. Bryan is considered the founder of numerical ocean modeling. Climate models are computer-based simulations that use mathematical formulas to recreate the chemical and physical processes that drive Earth's climate. Bryan's original model is still considered an insight of enormous importance for climate science and weather forecasting. Earlier knowledge of the oceanic and atmospheric circulation, and their interactions, was based purely on theory and observation.

According to Bryan, the world's oceans are one of the least-understood elements in the climate system. His research aims to understand the role of ocean circulation in the Earth's current climate, and its variations over the recent geological record. To gain a better understanding of ocean circulation, Bryan has systematically compared data and has established a hierarchy of coupled models of increasing complexity. Bryan's work is geared toward a comparison of the atmosphere and the ocean, and their roles in the global heat and water balance.

THE BRYAN-COX CODE

Bryan started his research at the Geophysical Fluid Dynamics Laboratory in the 1960s. The laboratory was then located in Washington, D.C. (it has since transferred to Princeton University). With a team of colleagues, Bryan developed numerical schemes to calculate the equations of motion describing flow on a sphere. These schemes led to the "Bryan-Cox code," used in many early simulations, which allowed the development of the Modular Ocean Model currently used by many numerical oceanographers and climate scientists.

The "Bryan-Cox code" was used to create the first simulation models that calculate realistic circulation of oceanic regions. The models are often very complex, and their output is difficult to interpret. The Bryan-Cox model calculated the three-dimensional flow in the ocean combining the continuity and momentum equation with the hydrostatic and Boussinesq approximations, and a simplified equation of state. These models are called primitive equation models because they use the most basic form of the equations of motion. The equation of state allows the model to calculate changes in density due to fluxes of heat and water through the sea surface, so the model includes thermodynamic processes.

The Bryan-Cox model used large horizontal and vertical viscosity and diffusion to eliminate turbulent eddies of diameters smaller than about 311 mi. (500 km.). It also had complex coastlines, smoothed seafloor features, and a rigid lid. The rigid lid was necessary for eliminating ocean-surface waves, such as tides and tsunamis, which move far too fast to be accounted for by the time steps used by all simulation models. Criticism of the model concerns the lid. Islands substantially slow the computation, and the sea-floor features must be smoothed to eliminate steep gradients.

The Geophysical Fluid Dynamics Laboratory Modular Ocean Model (MOM) is perhaps the most widely used model that grew out of the original Bryan-Cox code. It is made up of a large set of modules that can be configured to run on many different computers to model many different aspects of the circulation. The source code is open and free. The model is commonly used for climate studies and to assess the ocean's circulation over a wide range of space and time scales. The Parallel Ocean Program Model also grew out of the Bryan-Cox code.

The Bryan-Cox code allowed scientists to understand how the ocean and atmosphere interact with each other to influence climate. The Bryan-Cox model also predicted how climate changes are determined by changes in the natural factors that control climate, such as ocean and atmospheric currents and temperature. This pioneering model included all the basic components of climatic factors (atmosphere, ocean, land, and sea ice), but covered only one-sixth of the earth's surface, from the North Pole to the equator and 120 degrees of longitude east to west. Bryan's most recent research, therefore, has focused on the development of more general models that will provide an accurate representation of the effect of mesoscale eddies.

Bryan is also interested in using coupled ocean-atmosphere models to determine climate predictability in middle- and high-latitude areas. Thanks to joint research with Stephen M. Griffies, Bryan has also concluded that the North Atlantic Ocean changes less rapidly than other oceans in terms of salinity and temperature, which are important factors in producing climate change. Bryan has been awarded the Maurice Ewing Medal of the American Geophysical Union for his contributions to the field of ocean science.

SEE ALSO: Climate Models; Ocean Component of Models; Oceanic Changes; Oceanography.

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Bryson, Reid (1920–)

REID BRYSON IS an American atmospheric scientist, geologist, meteorologist, and emeritus professor at the University of Wisconsin, Madison. At Wisconsin, he founded the Department of Meteorology, the Center for Climatic Research, and helped found the Institute for Environmental Studies, which he directed 1970–85. According to the British Institute of Geographers, Bryson is the most often quoted climatologist in the world. Throughout his long career, he has advanced general understanding of climate, linking it with human ecology. He has focused on anthropogenic climate changes (changes generated by human interventions) and has also dealt with paleoclimatology, which seeks to understand ancient weather patterns.

Bryson is perhaps most famous for his statement that global warming is not the result of human actions, which has sparked controversy even within his own department. He served on the council of the Smithsonian Institution and has written five books. He is a member of the United Nations' Global 500 Roll of Honor in which scientists are included for their outstanding achievements in the protection and improvement of the environment. In addition to his distinguished career as a scientist, Bryson is also a published poet, and his scientific book *Climates of Hunger* has won the Banta Medal for Literary Achievement, a prestigious literary award.

Born in Michigan in 1920, he received his B.A. degree in geology at Denison University in 1941, and obtained his Ph.D. in meteorology at the University of Chicago in 1948, the 30th in meteorological doctorate awarded in the United States. Before completing his postgraduate degree, Bryson had already developed an interest in climatology serving as a major in the Air Weather Service of the U.S. Army Air Corps. In this capacity, he prepared the weather forecast for the homeward journey of the Enola Gay.

He joined the faculty of the University of Wisconsin, Madison, in 1946 and was hired by the departments of Geography and Geology. In 1948 he was the founding chairman of the Department of Meteorology, now known as the Department of Oceanic and Atmospheric Sciences. Because his wide-ranging academic interests also included disciplines such as history and archeology, Bryson soon shifted the department's research in an interdisciplinary direction. He retired in 1985, but has continued to be an active researcher.

Bryson's research does not look only into the short-range phenomena that make up the weather, but also into climatic patterns over the millennia. He has also been fascinated by inherently unobservable predictions and discoveries. He worked out past climates from analysis of ancient tree rings. He came to the conclusion that arid parts of India had previously been much wetter through an analysis of primordial pollen gains. Consequently, he devised a system of land use that helped reduce the overgrazing that had caused the dryness.

Bryson has developed new approaches to climatology, such as air-stream analysis and quantitative, objective methods of recreating past climates. He has also pioneered the use of computers to study long-range climatic changes, setting up computer models concerning such topics as the past history of the monsoon in Rajasthan, model simulation of Pleistocene ice volume, and Pleistocene climatic history.

Bryson's role in contemporary debates on global warming is controversial. Although in the 1960s he was one of the first to point out the impact of human action on climate change, in 2000 the scientist claimed that the role of humans in shaping climate was minimal. Bryson claims that there is little evidence that humans and carbon dioxide (CO_2) cause global warming. According to Bryson, the Earth has been constantly warming up in the past centuries, even when the emission of CO_2 was extremely low. The phenomenon of global warming is, thus, due to emergence from an ice age.

In addition, Bryson argues that the data used for computer predictions about future climate overemphasize the role of CO_2 and do not account for the effects of clouds (water vapor) in absorbing radiation coming from the Earth. To Bryson, whose positions on the subject have made him a controversial figure in the scientific establishment, global warming is just a commercial concern for contemporary researchers seeking funding for their projects. He has described Al Gore's Academy Award-winning documentary, *An Inconvenient Truth,* as untrue and unscientific, going as far as saying, in his characteristically contentious style, that it made him throw up.

The scientific community has challenged Bryson's conclusions on global warming, pointing out that his argument is based on incorrect data and personal attacks against other climatologists. For example, his claim that humans have not produced much CO_2 in the past 300 years is countered by the fact that, from 1750 to 2005, atmospheric CO_2 concentrations increased by 35 percent. CO_2 emissions, scientists predict, will at least double this century, barring a switch away from fossil fuels. Moreover, climate models and paleoclimatic data show that the CO_2 effect on climate is not marginal, especially when amplified by positive feedbacks in the climate system.

SEE ALSO: *An Inconvenient Truth*; Carbon Emissions; Global Warming; History of Climatology; Paleo-Climates.

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Budyko, Mikhail (1920–2001)

MIKHAIL IVANOVICH BUDYKO was an environmental scientist who was internationally recognized for his pioneering work on the Earth's energy balance, surface hydrology, and climate change, and the role of climate in regulating Earth's biosphere. His work brought about the scientific discipline termed *physical climatology*, which, in contrast to *empirical climatology*, is based on the first principles quantitative analysis. Budyko strongly emphasized the importance of the Earth's surface and atmosphere thermal balances, which are at the heart of all scientific problems related to climate change. His approach allowed fast and successful development of the mathematical tools for analysis of recent climate changes, interpretation of past ones, and prediction of future changes.

Budyko was born January 21, 1920, in Gomel, a small Belorussian town (then in the Soviet Union), and before World War II moved to Leningrad (now St. Petersburg), Russia, to pursue his higher education. He received his Master of Science degree in Hydro-Aero-Dynamics in 1942 from the Division of Physics of the Leningrad Polytechnic Institute. Immediately following, he was employed as a scientific researcher in the Voeikov Main Geophysical Observatory (MGO), the oldest Russian meteorological research institution, which during World War II was evacuated from Leningrad to Sverdlovsk (near the Ural Mountains). Within two years (in 1944), Budyko earned his Candidate Degree (Ph.D.), and, in 1951, he defended his Doctoral Degree, the highest scientific degree in Russia.

In 1954, he became a head of the MGO, where he remained for the following 21 years. He was the youngest MGO head since its founding in 1849. His fast ascent in the scientific community gained Budyko a high level of scientific recognition both within and outside Russia, and inspired a new generation of scientists in seeking careers in climate change and radiative transfer.

Among Budyko's scientific achievements is the development of a procedure to calculate the components of the thermal balance of the Earth's surface. His method allowed for calculating the components of the heat balance from measurements of the lapse rate of atmospheric temperature and humidity of the surface layer of the atmosphere. Using these techniques, Budyko compiled the first maps of the annual thermal balance components in the southern area of the European part of Soviet Union, determined the latitudinal distribution of the thermal and moisture balance components of land and ocean surfaces for the Northern Hemisphere, and established the factors governing the characteristics of this distribution.

In his follow-up research, Budyko developed a method for calculating the radiation balance of land from data on the water balance. Based on this research, he introduced the "Budyko aridity index," which gathers and analyzes information on hydrothermal regimes of a particular Earth region. In 1956, with other Russian scientists, Budyko developed a "periodic law of climatic zonality," that the same values of the aridity index can be met in different geographical zones. For his work on thermal balance, Budyko was awarded the Lenin National Prize in 1958, the first among climate scientists.

In 1961, Budyko recognized anthropogenic (human-induced) global warming. Primarily through analysis and interpretation of observational data, Budyko developed a quantitative relationship between surface temperature and incoming solar radiation, using it to formulate the energy-balance global change model, one of the earliest developed. Using it, he deduced that the Earth's climate might be sensitive to small disturbances in the radiative balance.

In 1964, Budyko became a Corresponding Member of the Academy of Sciences of the Soviet Union. In 1970, Budyko became interested in understanding interactions among the climate system, biosphere, and human agricultural activities. He and his colleagues carried out theoretical and experimental investigations to explore the dependence of the photosynthetic productivity of agricultural crops on the principal meteorological factors. Also, he was interested in how to calculate the thermal balance of a person's body when adjusting to the thermal conditions in different climates. For this research, Budyko received the Professor Lithke Gold Medal of the Russian Geographical Society in 1972.

GLOBAL WARMING, SNOWBALL EARTH, AND NUCLEAR WINTER

Beginning in 1972, Budyko played an important role in studies of the greenhouse effect under the auspices of Working Group VIII of the U.S.-Soviet Union Bilateral Agreement on the Protection of the Environment. He believed that, in spite of the then observed cooling, an increase in greenhouse gases would bring the climate system back to the warming tendency because, as he showed, the formation of the Earth's ecosystems is strongly connected to periodic changes in atmospheric concentrations of oxygen and carbon dioxide. Based on this, he pushed for the development of three important concepts: global warming, snowball earth, and nuclear winter. The latter played an important role in understanding of global consequences from possible nuclear war and helped in accelerating the process of ending the Cold War.

In 1975, Budyko moved his research to the State Hydrological Institute (Leningrad), where he created a new department for Investigating Climatic Changes and the Hydrologic Cycle of the Atmosphere. In 1980, he took the lead in applying the paleoanalog approach to project future anthropogenic global warming. Thus, he introduced the possibility of estimating climate sensitivity via reconstruction of greenhouse gas radiative forcing and retrieving past global temperature changes for the same periods.

In 1987, Budyko was awarded the International Meteorological Organization (IMO) Prize by the World Meteorological Organization. In 1989, the Russian Academy of Sciences awarded him the A.P. Vinogradov Prize, and, in 1991, he received a Diploma of the First Degree from the Russian Knowledge Society. In 1992 Budyko become an Academician of the Russian Academy of Sciences and, in 1995, he won its A. Grigoryev Prize. In 1994, Budyko received the Professor R. Horton Medal of the American Geophysical Union for his contribution to the study of the hydrologic cycle, and, in 1998, he was awarded the prestigious Blue Planet Prize.

In 1998, Budyko became a scientific leader of the Research Center for Interdisciplinary Environmental Cooperation (INENCO) of the Russian Academy of

Sciences, which was established to promote basic scientific research in the fields of environmental protection, rational exploitation of natural resources, and relevant ecological issues. Mikhail Ivanovich Budyko died in 2001, at the age of 81, in St. Petersburg, Russia.

SEE ALSO: Global Warming; History of Climatology; Russia; Snowball Earth.

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Bulgaria

BULGARIA IS A country in southeastern Europe that lies between Romania and Turkey and has a population of about 7.3 million. Projections warn of its significant vulnerability to climate change. It participated in the U.S. Department of Energy's Country Studies Program Department, creating an inventory of greenhouse emissions and potential mitigation. A defining event took place in 1997; a global change conference integrated efforts of scholars across a wide range of disciplines and established the Scientific Coordination Center for Global Change (SCCGC) in the Bulgarian Academy of Sciences. The conference summarized climate change research about emissions, climate variability and change, hydrology, agriculture, water resources, economics, demographics, data acquisition, and policy-making.

Severe water rationing in the capital of Sofia, due to mismanagement and drought, triggered a serious water conflict 1994–95. The SCCGC initiated a project studying drought from 1982 to 1994 as an analogue of future climate change. This seminal work explored impacts on environmental elements, society, economy, and human health, including computer models of climate scenarios and recommendations to policy-makers. Introducing drought- resistant crops is imperative, as well as increasing the altitude of artificial forests. Studies demonstrate future seasonal change in watersheds, and pollution during low summer flows.

A 1997–98 public opinion survey compared concerns and knowledge about climate change and emissions in the United States, Bulgaria, and Japan; such issues did not rank high among Bulgarians. A recession after 1989 led to a reduction of carbon dioxide emitted by energy and industry, the latter now surpassed by transportation, with a growing number of old and inefficient vehicles. Another nuclear power plant and a gas network for heating are in the works. Energy efficiency is improving by changing windows and adding insulation, although growing affluence results in larger homes and air conditioner usage.

The media in Bulgaria have not given persistent attention to climate change. Extreme events such as floods, droughts, and storms are treated as sensational, but quickly forgotten. Communication from scientists does not seem to effectively reach policymakers. Agriculture and tourism have come to the forefront of the economy, and increase the country's vulnerability to climate change. Agriculture was marked by intensive irrigation until 1989 (10 percent of nation's area was irrigated), but recurring droughts, such as in 2007, threaten harvests.

Warmer winters cause losses for ski resorts, while droughts lead to water scarcity in Black Sea resorts and inland. Floods occurred repeatedly in 2005 and 2007, amid prolonged droughts and extensive forest fires. Landslides were triggered in traditionally vulnerable areas, and in newly-constructed ski runs. According to the Intergovernmental Panel on Climate Change's 4th assessment, Bulgaria, like much of the Mediterranean, will face increasingly severe summer droughts in future decades.

SEE ALSO: Agriculture; Drought; Floods; Tourism.

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Burkina Faso

BURKINA FASO IS a landlocked country in West Africa with a population of about 14.3 million. The terrain is mostly savanna and relatively flat. Three major river systems cut through Burkina Faso: the Mouhoun, the Nakembé, and Nazinon; only the Mouhoun, along with the smaller Comoé, flows year-round. Access to clean water has been stressed in recent years, leading to tension between communities, especially in the north of the country. Only 18 percent of the land is arable, and recent decades have brought recurring droughts and increased desertification, along with overgrazing and soil depletion.

Current climate models indicate that Burkina Faso, like much of West Africa, is drying up and flooding at the same time. After a decades-long dry spell punctuated by severe droughts, the country is now moving into a new cycle, where hot, dry periods are broken by heavy, unpredictable rains. This has led to catastrophic flooding, most recently in August 2007, when at least 6,000 Burkinabe were left homeless after two days of heavy rains. This unpredictability is expected to put pressure on crops and livestock, and lead to increased incidence of disease among animals and humans.

The Burkinabe government has taken several steps to mitigate and cope with climate change. Recently, they have changed the laws in such a way as to grant farmers ownership of the trees on their own property. As a result, fewer trees are being cut down. They have also joined in a regional initiative to enhance biodiversity by encouraging farmers to use more sustainable farming methods.

Burkina Faso is not a significant contributor to carbon emissions. CO_2 emissions produced by the Burkinabe dropped 30 percent 1990–98, with annual emissions at just 0.1 thousand metric tons per capita. Of this, the burning of liquid fuels produced 98 percent. The country is a signatory to a number of international environmental conventions, including agreements on biodiversity, ozone protection, wetlands protection, endangered species protection, and the Kyoto protocol; however, the government has not formally ratified any of these conventions.

SEE ALSO: Desertification; Drought; Floods.

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Burundi

BURUNDI IS A landlocked country in Central Africa, south of Rwanda. It is home to about 8.4 million people, most of whom live in abject poverty; annual income is about $100 and life expectancy is just 45 years. About 36 percent of the land is arable. Natural disasters include droughts, alternating with rains, often causing landslides in the mountainous interior of the country. Overgrazing has led to soil depletion, while clear-cutting of the forest has caused erosion and loss of habitat.

Most climate experts believe that Burundi will be one of the countries hardest hit by global warming, as temperatures rise and stress an already weakened population. Burundi lies on the eastern shore of Lake Tanganyika, which contains about 18 percent of the world's liquid fresh water and is vital to the survival of millions of people across Central Africa. In the past four years, the lake has receded about 50 ft. (15.2 m.) from the shore as feeder rivers have slowed.

Aside from being a key source of drinking water, Lake Tanganyika is crucial to the region's food supply: fish from this lake supply 25–40 percent of the region's protein needs. However, fish yields have been dropping as a direct result of global warming. A 2003 study found a 0.6 degree C temperature rise along the lake, combined with a decrease in local wind speeds. This has decreased circulation within the lake, negatively impacting the its unique ecosystem. This is likely to grow worse, with most estimates indicating a temperature rise of 2.7 degrees F (1.5 degrees C) in coming years. Farmers throughout the country note that weather has grown more erratic in recent years, resulting in diminished crop yields. Some models estimate that crops could decline by as much as 50 percent by 2020. In a region already plagued by civil and cross-border wars, there are fears of increased violence over resources as food and water supplies diminish.

Burundi is not a significant contributor to carbon emissions, with total CO_2 emissions in 1993 at 231,000 metric tons. This was a 19 percent increase over 1990 totals, but still considerably lower than regional averages. An estimated 92 percent of their emissions come from liquid fuel sources, and only 8 percent from solid fuel. The country is a signatory to a number of international conventions on climate change, including biodiversity protection, desertification control, protection of the ozone layer and endangered species, and the Kyoto Protocol.

SEE ALSO: Agriculture; Ecosystems; Food Production; Global Warming.

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Bush (George H.W.) Administration

THE ADMINISTRATION OF President George H.W. Bush has received mixed reviews from historians and environmentalists for its handling of the global warming issue. Bush, the 41st president of the United States, came into office in 1988, having promised during the campaign that he would be the "environmental president." Over the next four years, Bush won praise from the environmental community for pushing needed revisions of the Clean Air Act through Congress. However, Bush was also criticized for his handling of several environmental issues, in particular, wetlands conservation, the *Exxon Valdez* oil spill, and global warming. Faced with mounting scientific evidence for human-caused global warming and calls from European allies to take strong steps to reduce carbon emissions, Bush warned against the likely economic impact of mandatory reduction programs, and called for further study of the nature and extent of global climate change.

Bush's cautious position on global warming surprised many, because his campaign rhetoric had appeared to signal an intention to take a more aggressive stance. In one of his most famous campaign speeches, Bush stood in front of Boston Harbor and contrasted his environmental credentials with those of his opponent, Massachusetts Governor Michael Dukakis. On the subject of climate change, Bush declared:

> those who think we are powerless to do anything about the greenhouse effect are forgetting about the White House effect. As president, I intend to do something about it.

Specifically, Bush pledged to host an international conference on global warming within a year of taking office. Bush's apparent resolve was remarkable, in particular because his predecessor in the White House, Ronald Reagan, had been reluctant, until his tenure as president was nearly over, even to acknowledge global warming as a potential problem.

As president, however, Bush charted a significantly less-ambitious path on climate change than environmentalists had hoped. The United States did not host a global warming conference in 1988, despite proposals put forth by Environmental Protection Agency Administrator William Reilly. As calls mounted for Bush to keep his campaign promises on global warming, White House officials went on the offensive against critics of the president. Spokesman Marlon Fitzwater repeatedly warned of potentially drastic consequences for the U.S. economy posed by proposed solutions to global warming, such as a carbon tax or restrictions on coal-fired power plants. Fitzwater's comments reflected a growing tendency within the Bush administration to see the economic costs of an aggressive stance on global warming as too high for comfort.

Chief of Staff John H. Sununu, a noted mechanical engineer, also questioned the veracity of global warming science, in particular the ability of computer models to predict long-term changes in climate. In a scandal that outraged many in Congress, including Senator Al Gore of Tennessee, a junior official at the White

House Office of Management and Budget secretly edited the congressional testimony of National Air and Space Administration (NASA) Institute of Space Studies Director James Hansen, to weaken Hansen's conclusion that global warming was accelerating. Most significantly, the White House initially eschewed international efforts to develop a comprehensive strategy to fight climate change under the auspices of the United Nations. This last development, though less sensational than the editing of Hansen's testimony (an incident from which the Bush Administration immediately distanced itself), portended that little action on global warming would be taken while Bush was in office.

A steady stream of criticism ultimately moved the Bush Administration to take a more active role in international efforts to study and address global warming, but the president still fell short of satisfying the demands of most environmentalists in the United States and abroad. The White House hosted a conference on global warming in Virginia in 1990, and agreed to take part in international negotiations on a climate change treaty, starting with talks in Geneva in 1989. These negotiations ultimately produced the Framework Convention on Climate Change, signed by 154 nations at the United Nations Conference on Environment and Development, also known as the Earth Summit, at Rio de Janeiro in 1992.

The Framework Convention was a step forward in efforts to combat global warming, but many blamed Bush for the treaty's relative toothlessness. The Bush Administration engaged in Cold War–style brinkmanship with the rest of the international community over the Framework Convention, a strategy that epitomized all that environmentalists found most frustrating about the Bush presidency. Though the Earth Summit was to be attended by over 150 heads of state, including those from each of the world's major industrialized nations, Bush claimed that the United States would not attend unless its demands were met. Well aware that the conference would be all but meaningless without the participation of the United States, treaty negotiators acquiesced to many of Bush's demands. At the insistence of the Bush Administration, the Framework Convention did not require specific reductions in carbon emissions from any nation, but, rather, directed each nation to reduce its emissions in such a manner, and by such an amount, as suited its own circumstances.

This lack of mandatory cuts in carbon emissions was a severe disappointment to many of the parties involved in producing the treaty. However, the convention also mandated annual Conferences of the Parties, in order to continually update efforts to address global warming. The Kyoto Protocol, which established legally-binding emissions reduction targets for the first time, was the result of the 1997 Conference of the Parties in Kyoto, Japan.

Though more engaged with the issue of global warming than his predecessor in the White House, George H.W. Bush proved a disappointment to many environmentalists. However, Bush's actions against global warming nonetheless paid important dividends. Bush's leadership on revisions to the Clean Air Act indirectly aided in the fight against global warming, by making it harder to build coal-fired power plants. Most importantly, the Framework Convention, though weaker than many had hoped, created a framework for future negotiations through which nations could work together to address global warming. The Kyoto Protocol would not have happened without the foundation of the Framework Convention, and future international efforts may also rely on channels laid down through this treaty, which Bush helped to bring to fruition.

SEE ALSO: Economics, Cost of Affecting Climate Change; Framework Convention on Climate Change; Hansen, James; Kyoto Protocol; United Nations.

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Bush (George W.) Administration

GEORGE WALKER BUSH (b. July 6, 1946) was the 43rd president of the United States, serving two terms between January 2001 and January 2009, with the first inauguration taking place on January 20, 2001. During his presidency, Bush would be both sharply criticized and highly praised for his stance on environmental issues and, over the years, would be seen to accept global warming verbally while politically denying it. Nevertheless, Bush would eventually come to support research into alternative energy means, if not for environmental preservation, for national security measures.

In his first year in office, Bush retreated from the Kyoto Protocol, which had been established as a way to limit emissions of greenhouse gases from global, economically-leading nations. Bush chose not to support the Kyoto Protocol despite that fact that the United States Senate had voted 95–0 in favor.

REJECTING THE PROTOCOL

Bush gave several reasons for choosing not to support the Protocol. First, that it would have been traumatically expensive for the nation's economy to follow the Protocol, because only one fifth of the world's population was to be held accountable for it. Second, he nations of China and India had not yet signed the Protocol. Third, Bush didn't feel there was enough scientific evidence for human-caused global warming. In the year 2005, Department of State documents that were revealed that showed a strong influence of the ExxonMobil Corporation on domestic environmental policy. Additionally, the Exxon-led anti-Kyoto Protocol group Global Climate Coalition (GCC) was noted for influencing President Bush's decision to reject the Kyoto Protocol.

The year after Bush retreated from the Kyoto Protocol, the Environmental Protection Agency (EPA—an agency of the United States federal government) issued a Climate Action Report stating that recent decades' global warming was, in fact, most likely due to human impact. Despite this report, Bush continued to doubt the science behind global warming and claimed that the EPA's report was not to be trusted.

Next, in the year 2002, Bush attempted to weaken the Clean Air Act of 1963 (which was amended in 1967, 1970, 1977, and 1990) with his Clear Skies Act (eventually presented to, and rejected by, the Congress as the Clear Skies Act of 2003). The Clear Skies Act proposed to raise the caps on mercury, nitrogen oxide, and sulfur dioxide emissions by large amounts, to postpone pollution standard enforcement until the year 2015, and to permit companies to modernize using including non-compliant equipment.

Several people in high positions in the U.S. government have publicly denounced Bush's repeated denial of global warming and his consistent dismissal of the scientific evidence. For example, James Hansen, the Director of the Goddard Institute at the National Aeronautics and Space Administration (NASA), in the year 2004, accused Bush and his administration of hiding the dangers of greenhouse gases from public awareness. Joseph Romm, formerly an official at the Department of Energy, accused Bush and his administration of consistently denying and delaying steps that could reduce carbon dioxide emissions and global warming.

Another federal employee, Rick Piltz, of the U.S. Climate Change Science Program co-wrote climate reports. He, along with other employees, claimed that climate reports were repeatedly edited by Bush administration officials to lessen the appearance of a global warming threat. Piltz gave the example of a review draft that was returned from the White House with handwritten edits by Phil Cooney, chief of staff of the Council on Environmental Quality and former lobbyist for the American Petroleum Institute. In the report cited by Piltz, a statement about global warming being enhanced by energy production was crossed out by Cooney. In another section, the review draft warned of rapid changes in the Earth; Cooney changed this line to read "may be undergoing change". Piltz claims these examples are only two of the many unscientific, but political, changes that Cooney made to the review draft.

Despite Bush's repeated denial of global warming and the need for political action, individuals in the United States recognized the value of the Kyoto Protocol and its suggestions and chose to follow the regulations, anyway. A 2005 article from BBC News of the United Kingdom, cited nine American states, 187 mayors (not necessarily only from those nine states), and several American-based international companies that signed up to heed Kyoto-based recommendations.

During his two terms in office, Bush eventually seemed to accept global warming as a fact and the necessity of public policy supporting alternative strategies. On August 8, 2005 Bush signed the Energy Policy Act of 2005, passed by Congress on July 29 of

An oil pipeline in Alaska. The Bush administration sought to open the Arctic National Wildlife Refuge to oil drilling.

that year. The Energy Policy Act supports alternative energy production and research, with tax incentives and loan guarantees.

Despite his repeated attempts to weaken regulations for environmental protection, not all Bush's actions were detrimental to the environment. For example, in 2006 Bush declared that the 84 million acres comprising the Northwestern Hawaiian Islands a national monument. This marine habitat holds 7,000 species of marine animals, including fish and birds. Out of these 7,000 species, greater than 1,500 species are unique to Hawaii. The area of land mass protected totals 139,000 sq. mi. (223,699 sq. km.).

Additionally, although the decision to do so was not related to global warming, but rather to national security and the relief from our dependence on foreign oil, Bush pledged in his 2007 State of the Union Address to reduce the consumption of fossil fuels and to expand research into alternative energy sources.

In preceding years, the Bush administration tried several times to open oil drilling in the 19-million acre Arctic National Wildlife Refuge (ANWR) in Alaska, an area that ANWR supporters call the "last untouched wilderness" of the United States. There is a 2,000-acre plot where the proposed drilling would take place. Although the House of Representatives has repeatedly approved the bill, the Senate has repeatedly blocked its passage.

Under President Bush, the position of Secretary of Energy was held by Spencer Abraham (2001–05) and later by Samuel Bodman. Administrators for the EPA were Christine Todd Whitman (2001–03), Michael Leavitt (2003–05), and later, Stephen L. Johnson.

SEE ALSO: Alaska; Alternative Energy, Ethanol; Alternative Energy, Overview; Alternative Energy, Solar; Alternative Energy, Wind; Attribution of Global Warming; Bush (George H.W.) Administration; Carbon Dioxide; Clean Air Act, U.S.; Clinton Administration; Department of Energy, U.S.; Department of State, U.S.; Goddard Institute for Space Studies; Greenhouse Gases; Hawaii; Kyoto Mechanisms; Kyoto Protocol; National Aeronautics and Space Administration (NASA); Oil, Consumption of; Oil, Production of.

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California

IN SEPTEMBER 2006, California's governor signed a landmark piece of legislation intended to reduce the state's vulnerability to global warming and climate changes. Arnold Schwarzenegger intended to take California back to 1990 levels of carbon production. California has long been considered a trailblazer for the nation. The first tuition-free public colleges and universities were in California, as were the first significant tax revolts. California has the world's fifth or sixth largest economy, with 36 million citizens.

The 1960s, which witnessed such social and economic changes in California, were also nearly the peak of California smog. Geographically, the state is divided into a cool and wet northern area and a hot and dry southern one. The southern part, especially around Los Angeles, became home to the nation's worst smog in the 1970s. There were times when athletes, playing on sunny California shores, could not see the San Bernardino Mountains because of the air pollution. With its intricate network of freeways, some of them boasting 16 lanes of traffic, the Golden State had a new, foggy horizon, and some people wondered if it was still the last refuge for Americans wanting a freer way of life.

Southern California's troubles with smog and air pollution improved considerably during the 1980s with greater use of unleaded gasoline and prohibitions against carbon emissions, but the state was simultaneously beginning another social change. Millions of immigrants, some legal and some illegal, were crossing the Mexican border with California. The state in 1962 had surpassed New York as the most populous of the 50 American states. Around 1999 California population reached 34 million, and it was considered the first true minority-majority state, meaning that people of Anglo-Saxon descent had become a social minority.

The fact that California had more people than any other state, as well as more cars, led to increased emissions from automobiles. Though the smog and air pollution had been contained, there were an increasing number of natural disasters that alarmed Californians. The 1994 Northridge Earthquake was followed by mudslides; the summers of 1995 and 1997 brought serious forest fires; and autumn 2007 saw one of the most destructive firestorms of all, carried by the notorious Santa Ana Winds. After Hurricane Katrina hit New Orleans, Californians were acutely aware of the dangers posed to their coastal cities. A comparable typhoon or hurricane, both of which are rare on America's West Coast, would have wreaked extensive damage. In the summer of 2006, Governor Schwarzenegger pushed for a new law to require California and its people to reduce carbon emissions.

The timing was fortuitous. Former Vice President Al Gore's documentary, *An Inconvenient Truth,* debuted at the box office in the summer of 2006, making the painful facts about global warming more apparent than ever. In the wake of Hurricane Katrina, citizens and legislators alike felt a pressing need to address the problems of global warming, and on September 26, 2006, Schwarzenegger signed Assembly Bill No. 32, which was designed to reduce carbon emissions to 1990 levels by 2020, set mandatory caps in 2012, and reduce emissions to 80 percent of 1990 levels by the year 2050. All these were to be implemented by the California Air Resources Board (CARB).

Critics emerged from the right and the left. Conservatives lamented the amount of power given to the state regulation board, and declared that global warming was a scientific hoax, put over on an unsuspecting population, while liberals (at least with respect to an environmental point of view) said that the levels of 1990 were anything but healthy: that it was insufficient to use as a benchmark. The bill went into law just the same, marking the boldest step implemented by a single state to that date.

SEE ALSO: California Institute of Technology; Carbon Emissions; Hurricanes and Typhoons.

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California Institute of Technology

THE CALIFORNIA INSTITUTE of Technology, also known as CalTech, or simply Tech, is a private university and research institute located in Pasadena, California. Established in 1891, it offers graduate and undergraduate instruction, and research, in pure and applied science and engineering. CalTech maintains a strong emphasis on the natural sciences and engineering. CalTech also operates and manages the National Aeronautics and Space Administration's (NASA's) Jet Propulsion Laboratory (JPL), an autonomous spaceflight complex that oversees the design and operation of most of NASA's space probes. Staffed by a faculty of some 1,000 distinguished and creative scientists, CalTech is considered one of the world's premier scientific research centers.

The Division of Geological and Planetary Sciences offers a number of undergraduate and graduate programs in geophysics, planetary science, and environmental science and engineering. They also offer research programs that focus on global issues such as climate change, environmental problems, glacier movement, evolution of atmospheres, and global change. The Environmental Science and Engineering (ESE) Program offers a coherent program of education and research spanning global climate studies, engineering solutions, and environmental problems, such as toxic waste remediation. Scientists from the Division of Chemistry and Chemical Engineering, Division of Engineering and Applied Sciences, and Division of Geological and Planetary Sciences collaborate on many topics involving the environment, atmosphere, hydrosphere, biosphere, and lithosphere.

Professor of Planetary Science Yuk L. Yung has authored two books and more than 100 scientific papers. His research focuses on atmospheric chemistry and global change. Dr. Yung and his team have developed a two-dimensional model description of chemistry interacting with global-scale dynamical fields for studying the terrestrial atmosphere and other planetary atmospheres. Such a model is necessary for analysis of global data sets. They are also developing a three-dimensional chemical tracer model.

An effort has been initiated between CalTech and JPL to utilize global data sets for the study of global environmental change. John Seinfeld, the Louis E. Nohl Professor and professor of Chemical Engineering, has performed extensive research in atmospheric chemistry, physics, and aerosols. Professor Seinfeld's research has made a major effort in atmospheric modeling aimed at urban and regional air pollution and global climate.

CalTech also offers a series of seminars known as Caltech Public Events. They offer an event sponsored by the Engineering and Applied Science Division called Global Warming: Science and Solutions.

This free event is a one-hour school day performance offered to children grades 3–12 to improve their understanding of global warming.

SEE ALSO: California; Global Warming; National Aeronautics and Space Administration (NASA).

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Cambodia

THIS SOUTHEAST ASIAN country was a French colony until it gained independence in 1953. The country was devastated by war from 1970–75 and 1978–91, leading to the destruction of much of the country's infrastructure. It has a land area of 69,898 sq. mi. (181,035 sq. km.), a population of 13,971,000 (2006 est.), and a population density of 201 people per sq. mi. (78 people per sq. km.). Altogether, 13 percent of the land in the country is used for arable purposes, with a further 11 percent used for meadows and pasture. Officially, about 74 percent of the country is forested, but there has been massive deforestation since the 1980s, in spite of government claims to have limited the problem. This, in turn, has led to soil erosion, made worse by flooding of some areas. In fact, the flouting of environmental laws by government officials and businesses has long been a major problem in the country.

A poor and undeveloped country, Cambodia has little electricity production, with 62.1 percent generated from fossil fuels and 37.8 percent from hydropower. Cambodia's per capita carbon dioxide emissions have been extremely low, with negligible rates recorded, and 0.04 metric tons per person generated in 2003. Cambodia ranks 205th in the world's CO_2, emissions, only slightly less than Mali, and a rate only higher than Burundi, the Democratic Republic of the Congo, Afghanistan, Chad, and Somalia. Of Cambodia's carbon dioxide emissions, 77 percent comes from liquid fuels, which is due to cars or buses. The remaining 23 percent come from cement manufacturing. There is also a reasonably high per capita emission of carbon monoxide.

With much of Cambodia low-lying, parts of the country have regularly faced problems from floods, and with the rising water levels, the floods have become more frequent. Flooding could increase mosquito-borne diseases such as malaria and dengue fever. Most of the country's fishing industry is located in the Tonlé Sap Lake in central Cambodia and the Mekong River, and thus is less likely to face problems related to the warming of the Indian Ocean, with overexploitation causing a far bigger problem. The Cambodian government took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, and ratified the Vienna Convention in 2001. It accepted the Kyoto Protocol to the UN Framework Convention on Climate Change on August 22, 2002, which took effect on February 16, 2005.

SEE ALSO: Deforestation; Floods; Transportation.

BIBLIOGRAPHY. "Cambodia—Climate and Atmosphere," www.earthtrends.wri.org (cited October 2007); *Cambodia: First State of the Environment Report 1994* (Cambodian Ministry of the Environment, 1994); Robert Turnbull, "Reconciliation and Conservation in the Cardamons," *Geographical* (v.77/5, 2005).

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Cameroon

LOCATED IN CENTRAL Africa, the Republic of Cameroon has a land area of 183,568 sq. mi. (475,442 sq. km.), a population of 17,795,000 (July 2005 est.), and a population density of 97 people per sq. mi. (37 people per sq. km.). With 80 percent of the population involved in agriculture, arable land accounts for 13 percent of the country. A further 4 percent is used for meadows and pasture. Fifty-four percent of the land is covered in forest. The forestry industry specializes in tropical hardwoods such as mahogany, ebony, and sapele.

With an underdeveloped economy, Cameroon has a low rate of carbon dioxide emissions, with 0.1 metric tons per capita in 1990, rising to 0.23 metric tons in 2003. About 87 percent of Cameroon's carbon dioxide emissions come from the use of liquid fuels, 4 percent from solid fuels, and 13 percent from the manufacture of cement. Most of these carbon dioxide emissions are generated by transportation (61 percent), with 21 percent from residential use. The public transport network in the country is not well-developed, although there is an efficient train service connecting the northern and southern parts of the country.

The Cameroon government of Paul Biya ratified the Vienna Convention in 1989, and took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992. The government accepted the Kyoto Protocol to the UN Framework Convention on Climate Change on August 28, 2002. It took effect on February 16, 2005.

SEE ALSO: Deforestation; Forests; Transportation.

BIBLIOGRAPHY. "Cameroon—Climate and Atmosphere," www.earthtrends.wri.org (cited October 2007); Germain Gros, *Cameroon: Politics and Society in Critical Perspective* (University Press of America, 2003); Paul Scholte, Saidou Kari, and Mark Moritz, *The Involvement of Nomadic and Transhumant Pastoralists in the Rehabilitation and Management of the Logone Flood Plain, North Cameroon* (International Institute for Environment and Development, 1996).

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Canada

CANADA IS OFTEN seen as one of the coldest places in the world. It is the second largest country in the world (after Russia), located at the top of the North American continent. The United States and Canada share the world's longest unprotected border (known as the 49th parallel of north latitude). In December 2007, Canada's population reached 33,091,228, most of whom live in the southern parts of the country, mainly near the St. Lawrence River and in the Great Lakes regions. The most well-known Canadian cities are Montreal, Toronto, Vancouver, and the nation's capital, Ottawa. Many tourists and visitors visit Canada's natural landscapes and rivers, rather than its cities and museums.

There are 10 provinces and three territories, including the newly named Nunavut province. Canada is surrounded by three oceans: the Pacific, Atlantic and the Arctic. The magnetic North Pole is located in Canada. A member of the Commonwealth and an active member of the G7/G8 summits, Canada is also one of four regions to be part of the Inuit Circumpolar Conference (ICC), along with Greenland (Denmark), Alaska (the United States), and Russia. Canada has been the site of international conferences and agreements pertaining to global warming, including the Montreal Protocol.

The average temperature in Canada varies according to season and location. Winters are long and snowy in almost all Canadian regions, usually lasting from November until April. In Canada's capital Ottawa, the yearly average temperature is 43 degrees F (6.3 degrees C), although in winter weather can get as low as 6 degrees F (minus 14 degrees C).

THE KYOTO PROTOCOL IN CANADA

Canada signed the Kyoto Protocol on April 29, 1998, and it was ratified by the Canadian government on December 17, 2002. However, when the Conservative Party of Canada won the 2006 election (after four terms of the Liberal Party), the leadership of Steven Harper realized that the Kyoto targets had not been met. Canada was, in fact, far from its objectives. Between 1993 and 2005, greenhouse gas emissions in Canada rose about 25 percent higher than under the previous Liberal-led government.

As a consequence, the new Canadian government recognized in 2006 that the goal of the Kyoto commitments was not achievable until 2050 (missing the initial deadline of 2012). In 2007, the federal minister of environment, Rona Ambrose, explained that promises made by the previous government (the Liberal Party of Canada) were impossible to meet, and asked for a realistic compromise that would not disrupt the Canadian economy: "In the real world, the emissions reductions needed in Canada to achieve the Kyoto target are not technically feasible in that time frame," said Conservative minister Ambrose, adding: "That is why we need new targets and a new Kyoto framework."

In 2007, John Baird was named as the new Conservative environment minister by Steven Harper, although no changes in policy were decided in regard to the Kyoto target. The ministery at least acknowledges the existence of climate change as an important issue for Canadians.

In December 2007, Baird made a statement after the United Nations Climate Change Conference in Bali (Indonesia): "Climate change is a global problem requiring global solutions, and we've seen that with today's agreement. We have a track record of leadership on the environment at the G8, APEC, the Commonwealth and the United Nations." In early 2008, Baird also made a commitment in order to take action to help developing countries fight climate change.

As a political response, many provincial governments (equivalent to a state government in the United States), such as Quebec and British Columbia, declared they would independently strive to reach the initial target. Moreover, the establishment of a carbon exchange in Montreal (known as the Montreal Climate Exchange) has existed since 2003, including a special agreement with the Chicago Climate Exchange (CCX).

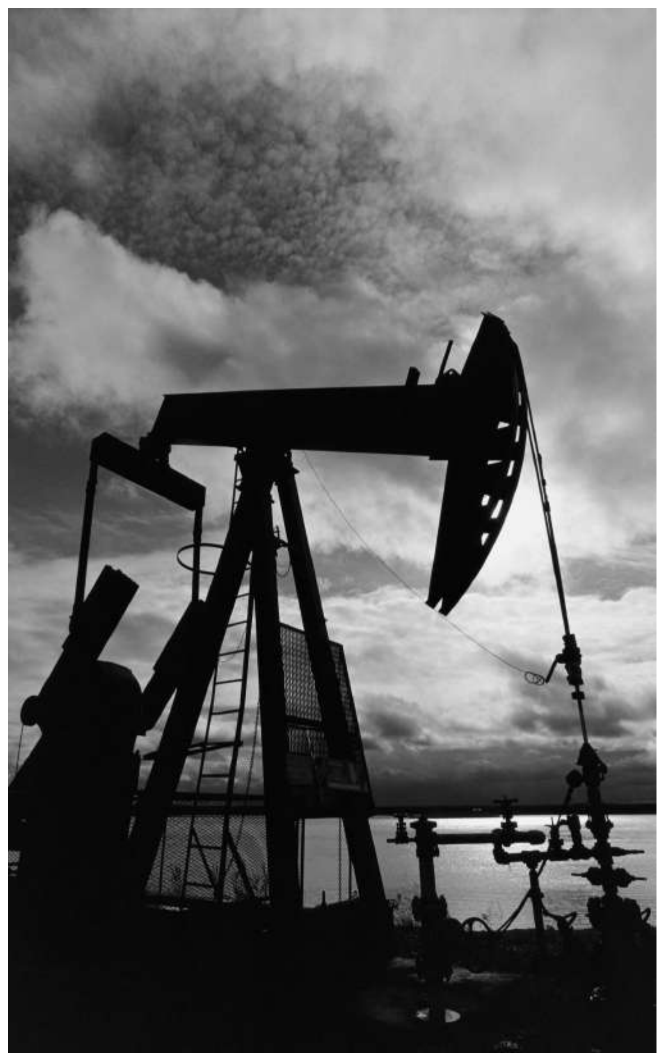
In 2008, polls confirmed that a majority of Canadians wanted their federal government to act in the spirit of Kyoto, although they do not always have a clear idea of the terms of the agreement.

Things might change in the future, as the former Liberal environment minister before 2006, Stéphane Dion, was leading the Liberal Party in 2008, the second-most popular party in Canada. An experienced politician, Dion cultivates an image of himself as a "Canadian Al Gore," dedicated to environment; he even named his dog "Kyoto."

According to the numbers from the Carbon Dioxide Information Analysis Center (at Oak Ridge National Laboratory, Tennessee), Canada produced 133.9 millions of tons of CO_2 in 1997, 4.42 tons per person. Comparative statistics show that countries, such as Japan and Russia, produce more CO_2 overall, since their population is higher in number, but their average per capita is less than Canada. This perhaps because Canadians live in very cold regions and enjoy a high standard of living. The Organisation for Economic Cooperation and Development (OECD) stated that the CO_2 emissions in Canada were 17.49 per capita in 2003. Only two countries, the United States and Luxembourg, had a higher ratio.

ENERGY IN CANADA

Since 2004, Canada has been led by minority governments, which means a more difficult position in terms of negotiating with other parties and the private sector. The protection of the environment has to rely on consensus. Each new initiative is often seen as "too little, too late," by environmental groups and leaders. On April 5, 2005, the government of



An oil derrick in operation in Canada's Northwest Territories. Oil has been drilled in Canada since the 1850s.

Peyto Lake, in Banff National Park, Alberta, is fed by the meltwaters of Peyto Glacier. Glacial silt floats on the lake, giving the water a bright turquoise color. The Canadian Rockies that nestle the lake are widely visited by tourists.

Canada and the automotive industry reached a landmark voluntary agreement to reduce annual greenhouse gas (GHG) emissions from Canada's vehicle fleet by 5.3 megatonnes (Mt) in 2010, according to the Joint Government-Industry GHG MOU Committee, October 2007.

According to the Ministry of Energy of the Government of Ontario, Canada produces a third of the world's uranium. However, Canadians are not always in favor of nuclear power, which remains controversial, even among environmentalists. The province of Quebec uses only one nuclear plant and relies mainly on hydropower (Hydro-Quebec), while in the neighboring province of Ontario, nuclear power provides half of the power. Also located in Ontario, the Nanticoke coal-fired power plant is the largest station of its type in North America.

The Alberta oil sand deposits became an issue in the 1990s. Production costs are very expensive and oil can only be produced at a profit when a barrel is worth more than $60, which has been the case for more than a decade. Despite the controversy over energy resources, Alberta and Saskatchewan have become increasingly populated, requiring more energy supplies, and there are more interprovincial migrations toward these two provinces.

CANADA AND THE UNITED STATES

Issues and diverging conclusions regarding environmental problems and pollution have often caused diplomatic conflicts between Canada and the United States, especially in the early 1980s. The Canadian government stated that air pollution in the Great Lakes region was mainly caused by U.S. industries, and the action of winds, which brought pollution from the south to the north of the border.

Moreover, three short Canadian documentaries took the position that air pollution and acid rain occurring in central Canada were partly caused by U.S. factories located near the Canadian border. These three films were officially labeled as political propaganda by the U.S. State Department.

These film essays, bringing environmental issues to light, were: *Acid From Heaven* (1982) by George Mully; *Acid Rain: Requiem or Recovery?* (1982) by Seaton Findlay; and *If You Love This Planet* (1982) by Terri Nash. The latter was about nuclear hazards in the United States. The U.S. government required U.S. theatres or movie rental stores showing or loaning any of these controversial films to report the usage to the State Department.

A PARADISE LOST: THE CANADIAN ARCTIC

Since most Canadians have not visited the Arctic region, they only know the area from images seen on television and in the media. As climate appears to be warming up, the Canadian arctic region is becoming more attractive for neighbors like Russia, the United States, and Scandinavian countries, which see a possible road for transportation of commerce. The Canadian government reaffirmed its right to that region, but it is becoming more contested by countries that would like to change the Canadian route into an international zone, as has always been the case for Antarctica. Most Canadians do not agree with that international suggestion.

Davis Guggenheim's film, *An Inconvenient Truth,* (starring Al Gore) was a huge success in Canada. It was presented in English and French in many Canadian schools, and was sometimes screened more than once. Furthermore, the DVD of the film *An Inconvenient Truth* was often lent for free by video stores in Quebec, in order to make the film's message more accessible.

Other films about climate change had similar success, such as the documentary *The Arctic Mission* (2004), coproduced by the National Film Board of Canada (NFB). An important Canadian documentary film, titled *The Refugees of the Blue Planet* (2005), and directed by Hélène Choquette and Jean-Philippe Duval, showed the environmental refugees who left their home because of the rising water levels in Brazil, the Maldives, and even in Canada. Another poetic film essay, directed by Pierre Perrault and titled *Cornouailles* (1994), explored the tundra and musk-ox in the Arctic region near the Elsmere Islands, in the north of Canada.

Debates about climate change and global warming are still ongoing in Canada. A few Canadian universities have programs in environmental education, such as the Université du Québec à Montréal, Université Laval in Quebec City, and also in Yellowknife (Yukon).

SEE ALSO: *An Inconvenient Truth*; Energy, Renewable; Energy Efficiency; Kyoto Protocol; Oil, Production of.

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Canadian Association for Renewable Energies

INCORPORATED IN 1998, the Canadian Association for Renewable Energies is an organization dedicated to the promotion of feasible applications of renewable energy in Canada. The objectives of the association are to promote greater awareness of the benefits of renewable energies to Canada's economy, environment, and society; advance the adoption of renewable energies; and undertake research that will optimize renewable energy technologies. Membership is open to institutions, corporations, and individuals.

At the peak of the association's activity, it provided a range of services to members, including information dissemination, access to information requests, domain hosting and email services, public relations services, and participation on expert advisory committees. Funding for the association is private, primarily from contracts and membership fees. One of the first projects of the association was an electronic daily news service, TRENDS in Renewable Energies. This service later partnered with the International Solar Energy Society as part of Refocus Weekly.

The association maintained extensive websites, featuring information on the theory and application of renewable energy technologies, particularly those related to heat-pump applications. They maintained their online news feed until December 2006. The association is closely tied to the Earth Energy Society of Canada, formerly the Canadian Earth Energy Association, which was formed in 1989 to promote ground source/geothermal heat pumps. It administered a $20 million program during the 1990s devoted to installing ground heat-pump systems.

The association has been involved in a variety of projects. They began offering the first green internet hosting service in Canada in September of 2001. The service is powered by green energy produced by wind turbines in Alberta; the electricity from the turbines is distributed by ENMAX and both generation and distribution are certified under Canada's Ecologo program. This initiative can thus be seen as a carbon offsetting program. A slight premium is charged to cover the extra cost of the green energy. A related program that provided green domain tagging is no longer in operation. The program is a good example of innovative use of the bundled green power available in parts of Canada. Bundled green power allows customers to pay for green power directly on their electricity bill. Though the specific electricity used by the consumer is not necessarily being generated by a green power method, their payment ensures that a certain percentage of the total power generated will be green. Another option is the "Green Power Certificate," which is billed separately. This approach supports the development and use of green electricity.

The Green Heat Partnership was formed in 2001 to encourage the adoption of space and water heating applications that use renewable energy technologies. Partners include the Earth Energy Society of Canada, the Canadian Solar Industries Association, the Canadian Biomass Association, and other private partners. Technologies being showcased by the initiative include heat pumps, solar thermal water heaters, solar thermal air heaters, and biomass combustors.

Geothermal heating and cooling systems work well in the Canadian climate. They collect and transfer heat from the ground using a series of pipes filled with fluid. Operating the systems in reverse provides air conditioning, eliminating the need for separate heating and cooling systems. The systems are very energy efficient, providing significant cost savings to users. The systems can also be used to heat hot water.

In 2006, both the Earth Energy Society of Canada and the Canadian Association for Renewable Energies were named in a lawsuit over the ownership of the term *GeoExchange*. As a result of the costs of this suit, the Earth Energy Society ceased operation in November 2006.

SEE ALSO: Alliance to Save Energy; Canada; Energy, Renewable; Energy Efficiency; International Solar Energy Society; Nongovernmental Organizations (NGOs).

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Cantor Fitzgerald EBS

CANTOR FITZGERALD EBS (CF EBS) was a division of Cantor Fitzgerald, a leading investment and brokerage services company in the United States. While Cantor Fitzgerald is based in New York City, CF EBS was based in Los Angeles, California. It is now CantorCO2e, based in both Great Britain and California. As emissions caps are set for companies and enforcement is strengthening, a novel business has emerged: emissions trading. If a company cannot reach emissions levels at or below the cap, it can purchase the right to have the difference of emissions (or credit) from a company with a lower emissions rate. In effect, the company exceeding emissions is fined, while the company with lower emissions receives a financial benefit.

Bernie Cantor and John Fitzgerald established Cantor Fitzgerald as a bond brokerage firm in 1945. The company expanded with a division of Equity Capital Markets 20 years later. In 1972, Cantor Fitzgerald provided the first electronic marketplace to manage U.S. government securities by developing the field of screen brokerage. That same year, the company acquired a controlling interest in the smaller company, Telerate.

As screen brokerage continued to develop, Cantor Fitzgerald opened an office in London in 1983, offering screen brokerage to clients around the globe. The following year, they opened an office in Japan, managing the brokering of Eurobonds. Cantor Fitzgerald acts as a mediator between buyer and seller for the purchase of Eurobonds, which are in a currency of a specific country, but are traded and regulated outside of that county in a different currency. To specify the initial country's currency, the name of that currency is found in the name of the Eurobond. For example, a Eurobond in Japanese currency is called a Euroyen. In 1998, Cantor Fitzgerald traded U.S. Treasury futures via electronic exchange. Two years later, a new branch of investment banking was created. The company continued in its pioneering of electronic services by staging the first wireless bond trade, using a BlackBerry® handheld device.

Cantor Fitzgerald offers multiple financial services, including brokerage services, investment services, sales and trading, news distribution, and mobile gaming, whereby patrons of a casino can use a personal digital assistant (PDA) to gamble outside of the casino in approved areas such as the casino pool. In the brokerage services sector, Cantor Fitzgerald offers Cantor Clearing Services (CCS), CantorCO2e, Cantor LifeMarkets, Cantor Fitzgerald Telecom Services (Cantor Telecom), and Cantor Spectrum & Tower Exchange (CS&TE). CCS deals with equities, fixed income, and futures transactions.

Cantor LifeMarkets, established in 2004, deals with life insurance and its benefits to the financial sector. For example, Cantor LifeMarkets manages an online marketplace for life insurance policy trading. Cantor Telecom deals with wire line telecommunications as well as wireless communication. CS&TE brokers unused radio frequencies, along with rooftop space and other goods in communications infrastructure. CantorCO2e is the current version of what was initially Cantor Fitzgerald EBS.

CF EBS began making headlines in 2006 when it joined the market for crude oil products. Then, in 2007, CF EBS joined with CO2e.com LLC, becoming CantorCO2e. CantorCO2e headquarters are in London as well as San Francisco, California. The company has partnered with Price Waterhouse Coopers to create the website CO2e.com. This website serves as a carbon marketplace accessible around the clock, as well as access to Cantor associates who act as consultants to help companies blueprint their emissions reduction investment plans.

Brokerage services offered by CF EBS include brokerage of emissions, as well as biodiesel, ethanol, and renewable energy; these latter three are considered new forms of energy. Additionally, CF EBS brokers renewable energy certificates, and runs an Institutional Trading Department for brokerage of energy securities. CF EBS also provides consulting services to clients looking to switch to cleaner technology. For example, CF EBS works with clients that produce biodiesel and are looking to establish the infrastructure to sell this biodiesel as fuel. The slogan of CantorCO2e is "Energy. Environment. Innovation." On October 3, 2007, CantorCO2e established an online marketplace for global CO_2 emissions trading, allowing clients around the globe to trade emissions voluntarily.

SEE ALSO: Carbon Dioxide; Emissions, Baseline; Emissions, Trading.

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Cape Verde

A CHAIN OF islands in the mid-Atlantic, the Republic of Cape Verde was a Portuguese colony until it gained independence in 1975. It has a land area of 1,557 sq. mi. (4,033 sq. km.), with a population of 420,979 (July 2006 est.), and a population density of 326 people per sq. mi. (126 people per sq. km.). The country is very poor. Only 11 percent of the land arable, and a further 6 percent is used for meadows and pasture.

The soil is largely volcanic. Owing to a large population, and compounded by overgrazing and deforestation, there have been regular food shortages in the country from droughts. These may not all be due to global warming, as droughts have been recorded in the area since the 17th century. Over many centuries, Cape Verdeans have migrated overseas. Electricity production comes from fossil fuels. The country's carbon dioxide emissions are very low, ranging from 0.2 metric tons per capita in 1990, rising to 0.30 metric tons per capita in 2003. This is entirely due to the use of liquid fuels, and in spite of the small size of the islands, public transportation in Cape Verde is extremely limited.

The government of António Mascarenhas Monteiro took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, and ratified the Vienna Convention in 2001. It accepted the Kyoto Protocol to the UN Framework Convention on Climate Change on February 10, 2006, making it the 158th country to accept the Kyoto Protocol; it took effect on May 11, 2006.

SEE ALSO: Climate Change, Effects; Desertification; Drought; Volcanism.

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Capitalism

CAPITALISM IS AN economic system of market-driven services and production carried out by private individuals and business firms. Karl Marx coined the term *capitalism* as an opposite to communism/Marxism. Other terms that refer to this economic system include *free enterprise* and *market economy*. The term *mixed economy* refers to the combination of a market economy and taxation for governmental spending. Adam Smith originated the philosophy behind capitalism in his treatise *An Inquiry into the Nature and Causes of the Wealth of Nations* (1776). He argued that societal well-being could be the secondary result of the combination of self-interest, private ownership, and consumer-driven competition.

Capitalism is a socioeconomic system where the infrastructure for production is privately owned; the market coordinates buyers and sellers; everyone involved in the system has the freedom to look out for their own self-interest with maximum return from the invention of resources, labor, and time; consumers are free to spend money as they choose, creating competition for their business and as a whole; and government supervision is minimal.

Trade over long distances to procure goods was the stimulation throughout history for such developments as overland caravans to the Middle East and Asia; shipping routes from Asia to Europe and from the Americas to Europe; and the colonization of Africa, Asia, and the Americas. Emphasis on production came with industrial advancement. Before that time, however, an important figure in the capitalist system began to emerge: the entrepreneur, or risk taker. A key element in capitalism is the undertaking of activity in the expectation that it will yield gains in the future. Because the future is unknown, both the risk of loss and the possibility of gain exist.

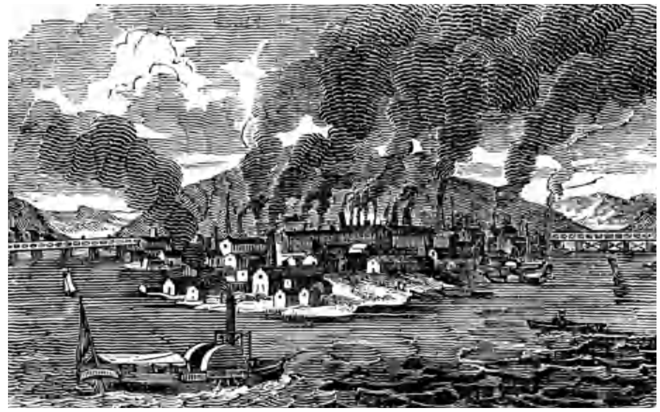
The assumption of risk involves the specialized role of the entrepreneur. The Renaissance and Reformation brought about social change, as people demanded a right to be involved in their government and to control their personal destinies. With this emerged contemporary forms of government, with judicial, legal, and organizational structures necessary for economic growth and capitalism.

Governments began to take advantage of this form of trade to make a profit. They saw that the influx of gold and silver from a favorable trade balance would stimulate to economic activity, thus enabling the state to levy more taxes and gain more revenue. The Industrial Revolution changed the face of business, moving from small enterprises to large enterprises that employed many workers to produce large quantities of goods, and used machines for work previously done by humans or animals. Production became more specialized and factory units became the prime producers, while entrepreneurial activities became part of peripheral economic activities.

Situations for workers declined as big business demanded child labor, long working hours, and dangerous workplaces. These conditions were the impetus for Karl Marx to develop his treatise promoting communism, with business owned collectively by society, and with collective sharing of goods, services, and profits. Capitalism also experienced setbacks, with cycles of expansion, as well as economic collapses and unemployment. Corporations sought control of manufacturing with monopolies and trusts.

Public involvement led to antitrust legislation passed by the U.S. Congress to make monopolies illegal, and to the use of government power to force competition. Capitalism continued to expand and prosper because of the potential for individuals to create wealth and improve living standards. However, as the Cold War came to an end in the 1980s and the former Soviet Union nations turned to free enterprise (though with mixed success at first), nations with a free economy rose to the challenge of the changing times and adapted.

Democratic governments intervened in the economy to correct the worst abuses inherent in capitalism. Action was taken to encourage collective bargaining and build a strong labor movement in order to offset the concentration of economic power in large industrial corporations. The foundation for the modern welfare state was laid through the introduction of Social Security and unemployment insurance, measures designed to protect people from the economic hazards endemic to a capitalist system.



Early capitalist industry left its mark. Current atmospheric CO_2 is about 30 percent above pre-industrial 18th-century levels.

Social welfare spending by governments continued to grow; in the United States, these expenditures (along with those for defense) account for the overwhelming proportion of all federal spending. Economic growth slowed, and many nations, particularly the United States, where national, corporate, and personal debt had reached record levels, dropped into recession, with rising unemployment. The early 21st century situation needs to be seen from the perspective of the long history of capitalism, particularly its extraordinary versatility and flexibility. New demands imposed on the economic system include ending environmental pollution, as the unregulated growth of industry and the use of fossil fuel as a primary energy source have led to global warming and climate change.

SEE ALSO: Economics, Cost of Affecting Climate Change; Economics, Impact from Climate Change; United States.

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Carbon Cycle

THE CARBON CYCLE describes the biogeochemical cycle, or routes by which carbon atoms are exchanged through nested networks of environmental systems from the atmosphere into the biosphere, through photosynthesis and back again with respiration, decomposition, and biomass burning. Elemental carbon is a traditional component of the hydrosphere, the atmosphere, the geosphere (rocks, such as limestone; coal; and soils), as well as the biosphere (all living things).

The carbon cycle also involves the process of removal and uptake of carbon on a global scale. This process involves components in food chains, in the atmosphere, as carbon dioxide; in the hydrosphere; and in the geosphere. The major movement of carbon results from photosynthesis and from respiration. Carbon is present in the planet in the following major reservoirs: as the gas, carbon dioxide (CO_2) in the atmosphere; as organic matter in soils; as organic molecules in living and dead organisms found in the biosphere; in the lithosphere as fossil fuels and sedimentary rock deposits such as limestone, dolomite and chalk; and in the oceans as dissolved atmospheric CO_2 and as calcium carbonate shells in marine organisms.

The carbon cycle has a large impact on Earth, both globally and locally. At the global scale, the carbon cycle influences Earth's climate by regulating the amount of CO_2, a principal greenhouse gas, in the atmosphere. Terrestrial ecosystems store as much carbon as the atmosphere, so plants and soils play an important role in regulating climate. The carbon cycle also plays a primary role in keeping ecological systems in balance, since it is involved in basic ecological processes such as plant growth and accumulation, and the death and decay of plant material.

As a principal building block of organic matter, carbon is utilized by biotic components of an ecosystem, especially by organisms for structural growth: a portion of elemental carbon that a living thing takes in is usually incorporated into its tissues. Thus, the carbon cycle is one of the most important biogeochemical cycles to humans, because it is a vehicle through which one of the primary elements required for the formation of human tissues is cycled, and also because it is a means through which elemental carbon is introduced to plants, the basis of human food.

The carbon cycle is also important to the human climate system because it sets the background for the environment, through CO_2 and methane (CH_4), which are major drivers of global climate temperatures. The carbon atoms present in the atmosphere, hydrosphere, biosphere, and the geosphere are able to move from one of these environmental systems to another as part of the carbon cycle.

The carbon cycle is sometimes conceptualized as four major carbon sinks, interrelated by nested systems of pathways for transport of carbon atoms. The carbon reservoirs are the air (atmosphere), considered as the starting point of the cycle; the sea water and oceans (hydrosphere), which include biotic and abiotic marine biota; the sediments (fossil fuels); and the terrestrial biosphere, which includes fresh water systems (lenthic or lotic), as well as nonliving organic substances, such as soil carbon. The carbon cycle is primarily controlled by a series of biological, physical, chemical, and geological processes within the environment.

In the atmosphere, carbon exists primarily as the gas CO_2. It is this form that plants transform into carbohydrates via photosynthesis, releasing oxygen in the process. This process is mainly carried out in autotrophs (terrestrial and aquatic plants such as algae and cyanobacteria). They produce their organic compounds using atmospheric CO_2, with solar radiation providing the source of energy for the process. However, a minor group of autotrophs harness chemical energy sources for the production of their organic compounds through a process called chemosynthesis. Through the food chain, carbon is transferred as autotrophs (producers) and eaten by heterotrophs or as heterotrophs feed on other organisms. When the plants and animals die, their carcasses, stems, or leaves decompose, releasing the carbon trapped in them into the geosphere. Some could be buried, and over time, will become fossil fuels. Food webs serve as part of a carbon atom's journey through the carbon cycle. Carbon is returned to the biosphere during cellular respiration.

Biomass burning has the ability to transport substantial amounts of carbon into the atmosphere. When humans burn fossil fuels to run industries, power plants, cars, airplanes, and jets, a significant portion of carbon is transferred directly into the atmosphere as CO_2. When autotrophs and heterotrophs die, their remains may settle as sediments in fresh water and marine ecosystems. The carbon trapped in sediments is eventually released into the aquatic environments through geological and chemical processes. Marine animals use the released carbon to build their skeletal materials. Ultimately, the stored carbon compounds in these organisms up the web are broken down by decomposition, and the carbon is released as CO_2 back into the cycle to be used by plants.

The world's oceans act as sinks for CO_2, and, in general, contain more than 90 percent of the carbon involved in the global cycle. The concentration of atmospheric CO_2, which is an important driver of climate change, influences the temperature of the Earth's surface, which is largely determined by the ocean. The levels of CO_2 in surface water, and, hence, in the atmosphere, are usually kept lower than that in deep water by two principal natural processes: the solubility pump and the biological pump.

SEE ALSO: Carbon Dioxide; Carbon Sinks.

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Carbon Dioxide

CARBON DIOXIDE IS a naturally occurring gas. Chemically, it is stated as CO_2, which means that each carbon dioxide molecule has two oxygen atoms bonded to a single carbon atom. CO_2 has many practical applications. CO_2 measurements are now being used as a way to test the cardiovascular system. This new tool has the promise of not being as invasive as other diagnostic methods. CO_2 can be frozen into dry ice, and has numerous chemical uses. It is often a byproduct from chemical reactions. It has a number of common uses, such as providing the fizz in soft drinks.

Humans and other animals also expel CO_2 when they exhale. In the respiratory processes of humans, mammals, birds, reptiles, and fish, oxygen is breathed into the lungs and CO_2 is exhaled. Their breath contributes to the CO_2 cycle. In the CO_2 cycle, plants take in CO_2 and in the photosynthesis process make chlorophyll and oxygen from the CO_2 as it combines with water, minerals, and other products in the plant's chemistry.

Plants are able to store huge quantities of carbon in hydrocarbon compounds. CO_2 plays a vital role in plant growth. There are also tremendous quantities of CO_2 locked in fossilized hydrocarbons, such as coal and oil. In addition, peat bogs and the plant material frozen in the Arctic tundra are repositories of vast quantities of organic material and, thus, of carbon and CO_2.

The Earth's atmosphere is composed of a number of gases, including: nitrogen, oxygen, CO_2, water vapor, argon (an inert gas), methane, varying amounts of ozone, and other gases such as nitrous oxide. The greenhouse effect is a natural phenomenon that is caused by these gases. Without the greenhouse effect, the biosphere of Earth would either never have existed, or it would die because the Earth's climate would be too cold. CO_2 and other gases such as methane, ozone, and others act as a thin blanket that retains heat that would otherwise be radiated out into space. Instead, these gases capture some of the long-wave infrared radiation and return it to the Earth's surface.

Sunlight enters the Earth's atmosphere as white light of all wavelengths, from ultraviolet to infrared waves. Some wavelengths of energy, such as gamma rays and x-rays, are adsorbed or reflected in the upper levels of the atmosphere and do not affect the surface of the Earth. Most of the sunshine that strikes the surface of the Earth is white light sunshine. It is in the visible light spectrum, which is seen by human eyes, and ranges from purple to red in a spectrum of increasing wavelengths. Just beyond the visible red spectrum is infrared radiation. About 60 percent of the sun's radiation is infrared, which is radiation invisible to humans and most animals. The tongues of snakes have infrared sensors to detect the heat of animals in the dark. Camera film can be designed to detect infrared radiation, making it visible to humans.

Carbon dioxide and other gases, such as methane and ozone, act as a thin blanket that retains heat that would otherwise be radiated out into space. Without this natural greenhouse effect, Earth's climate would be too cold for much life.

As sunshine strikes the Earth, much of it is reflected away by clouds, the polar icecaps, desert surfaces, and other bright surfaces. When the Earth, buildings, plants, or other objects adsorb it, some of it is emitted from surfaces as heat. Radiant heat is composed of infrared wavelengths. There is a range of infrared wavelengths radiated skyward. Most of these infrared wavelengths pass through the atmosphere and emerge to vanish into outer space. However, CO_2 adsorbs some infrared wavelengths.

CO_2, water vapor, and trace gases all absorb some of the heat energy of the Earth. Carbon dioxide absorbs infrared waves that are from 13–100 micrometers (.0004–.004 in.) in length. Water vapor absorbs infrared waves that are between 4–7 micrometers. The infrared waves that are between 7–3 micrometers, on the other hand, are not usually absorbed. Instead, they pass easily through the atmosphere and into space. The major infrared window is the infrared wave range between 7–3 micrometers. This means that the major work of the greenhouse effect is accomplished by CO_2. In contrast, although methane absorbs 30 times as much energy per molecule compared to a molecule of CO_2, the amount of methane in the atmosphere has not increased as dramatically as the CO_2. While other gases have increased, none have increased as much as has CO_2.

THE KEELING CURVE

Charles David Keeling of California developed a device for measuring the amount of CO_2 in the atmosphere in parts per million. During the Geophysical Year 1957–58, he took many readings at different locations on the surface of the Earth. These included the top of Hawaiian volcanoes that were (at the time) far from industries. He also took readings in all manner of other places and used these to construct the Keeling Curve. The Keeling Curve shows that the amount of CO_2 in the atmosphere has increased dramatically since the beginning of the Industrial Revolution in the late 18th century. In addition, his readings show that the amount of carbon dioxide is increasing rapidly.

Keeling's readings were supported by major studies of ice core samples taken from Greenland and Antarctica. The ice core samples were drilled from deep within the ice caps at opposite ends of the globe. The upper limits of the ages in these cores were estimated to be as high as 160,000 years. What they show is that, on average, the amount of carbon dioxide in the atmosphere until the Industrial Revolution was 270 parts per million (ppm). However, the current reading for carbon dioxide is now 380 ppm and rising. It is estimated that 450 ppm may be a kind of trigger for major weather changes that may be permanent and cause not just global warming, but also permanent climate change that melts the ice caps and causes other long-term climatic changes.

SEE ALSO: Atmospheric Composition; Atmospheric Emission of Infrared Radiation; Attribution of Global Warming; Carbon Cycle; Carbon Emissions; Carbon Footprint; Carbon Permits; Carbon Sequestration; Carbon Sinks; Emissions, Trading; Global Warming; Greenhouse Effect; Greenhouse Gases; Keeling, Charles David.

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Carbon Emissions

CARBON IS A widely distributed element on the Earth. Pure carbon in one form is graphite. It can also take the form of diamonds after undergoing tremendous pressures and heat in volcanic pipes. Carbon is the basic atom in organic chemistry. Because carbon has four electrons, which can be joined to other atoms, it is able to form an enormous number of compounds. Some are simple and some are complex. The ones that matter the most to the issue of global warming are those that become involved in the chemistry of climate change.

The most common carbon compound that is involved in global warming is carbon dioxide (CO_2). It is a very common emission from a wide variety of sources. Humans and animals, including birds, all exhale CO_2 when they breathe. On the other hand, plants use CO_2 as an essential part of the process of photosynthesis. Plants lock up tremendous amounts of carbon in trees, shrubs, grasses, and other plant materials. When these are buried, they can, under the right conditions of heat and pressure, become natural gas, oil, coal, peat, or other carbon remains.

Most carbon emissions come from natural sources. Volcanoes give off CO_2, as do decaying plants. The Earth naturally has had an abundance of CO_2 in its atmosphere. Without it, the Earth would become a block of ice. CO_2 is the main compound involved in the greenhouse gas effect. This is the effect of sunlight striking the Earth, where it is either reflected immediately from bright surfaces such as the polar ice caps, or it is radiated in infrared wavelengths back into the atmosphere. CO_2 and other carbon compounds such as methane, absorb and reflect back to Earth certain infrared wavelengths. Without this effect, all of the energy would return to outer space and the Earth would be much cooler.

The problem with carbon emissions in the current era is their volume. The rise of China and India as global producers and markets has followed on the huge volume of CO_2 and other compounds that industrialized North America and Europe have spewed into the atmosphere for decades. It is anthropogenic (human-made) increases in the global atmospheric levels of carbon compounds that are blamed for the rises in temperatures globally in recent decades. Burning fossil fuels is probably the greatest source of carbon emissions. The use of oil and its derivatives is a major contributor. Oil is used to make fuel for airplanes, and in automobiles and trucks as gasoline or diesel fuel. In addition, coal has been burned for fuel for centuries. Today, coal-fired power plants burn whole trainloads of coal almost daily. The emissions, unless controlled, add huge quantities of smoke, much of which is CO_2, to the atmosphere, where it increases the temperature of the planet through the greenhouse gas effect.

In addition to the burning of gasoline and coal, natural gas is a major, and still growing, fuel. To this is added the flaring of natural gas at refineries and at oil wells that have an excess of natural gas. It is mostly methane, but when burned, it becomes CO_2 and water vapor. The consumption of huge quantities of natural gas produces CO_2 in large quantities. Other liquefied petroleum gas products used for fuel are propane and butane. These also produce CO_2 when burned.

Carbon emission sources also include livestock, rice paddies, deforestation, and the warming of the arctic tundra where decaying vegetation that has been thawed turns into a natural form of carbon emission. Researchers have concluded that livestock account for 18 percent of current levels of carbon emissions. The emission of cattle and many other farm animals produce gas in the form of methane. However, methane reacts with oxygen in the atmosphere to form CO_2. Modern septic tanks that vent gases produced in their biodegradation of waste material emit methane, which is a gas that adds to the greenhouse gas stocks. Agricultural chemical fertilizers, as well as decaying vegetation, add vast amounts of carbon emissions on the Earth's surface and in the atmosphere. Cement production is another human source of carbon emissions.

The goal is to control global warming by controlling pollution from carbon gases produced by entities such as power plants. One idea is to develop a market in carbon-offset vouchers. Such programs seek to offer an economic incentive for a cleaner environment and a reduction in global greenhouse gases. Carbon emissions can be managed through a combination of government controls and market forces.

SEE ALSO: Automobiles; Carbon Cycle; Carbon Dioxide; Carbon Footprint; Carbon Permits; Carbon Sequestration; Carbon Sinks; Emissions, Trading; Methane Cycle.

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Carbon Footprint

A CARBON FOOTPRINT is defined as the total amount of carbon dioxide (CO_2) and other greenhouse gases such as methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6) emitted directly and indirectly to support human activities such as the burning of fossil fuels, deforestation, livestock raising, and agricultural production. Calculating a carbon footprint is a tool for understanding the amount of global warming gases everyday activities create. For example, when heating a living space with oil, gas, coal, or electricity, a certain amount of CO_2 is emitted. In addition, when buying consumer items from a store, the production, transportation, and packaging of these products also create a certain amount of CO_2 and other greenhouse gases. A carbon footprint is the sum of the total amount of CO_2 produced by human activities in a given time frame (typically a year's time). Carbon footprints are generally expressed in annual tons of CO_2.

The carbon footprint is not only a method of estimating the amount of CO_2 and greenhouse gases humans are producing, but a way to understand the chemical nature these substances have in different parts of the atmosphere. CO_2 and other greenhouse gas molecules created from the burning of fossil fuels have different chemical behaviors than their original fossil fuel molecules. Many greenhouse gas molecules produced from human activities accumulate in parts of the atmosphere where they have an undesirable effect. For example, the production of ozone gas (O_3) is desirable in the stratosphere (upper atmosphere) where it protects humans from harmful ultraviolet radiation; however, production of an abundance of O_3 in the troposphere (closer to where humans live) is undesirable because it acts as a lung irritant for people with respiratory illnesses (such as emphysema, asthma, and chronic bronchial inflammatory diseases), and contributes to smog production.

The largest sources of CO_2 from the burning of fossil fuels are: liquid fuels (such as gasoline or diesel), 36 percent; solid fuels (such as coal and wood), 35 percent; gaseous fuels (such as natural gas), 20 percent; international bunkers, four percent; and cement production, 3 percent, according to research by M.R. Raupach. The most common human activity that produces an abundance of CO_2 in the atmosphere is the use of liquid fuels in driving an automobile. Other greenhouse gases that are produced from the burning of liquid fuel in engines include, but are not limited to, methane and ozone gas (CH_4 and O_3).

One method for estimating the amount of CO_2 and other greenhouse gases produced by human activities is determined from a balanced chemical equation (for example, stoichiometry) and then converted to an equivalent amount of CO_2, which allows it to be added together to determine an individual, household, city, state, national, or total global carbon footprint. Human activities on the entire planet produce approximately 27,500 million tons of CO_2 annually.

In 2006, China passed the United States as the number one emitter of CO_2 with 6,200 million tons annually. The United State's emission of CO_2 was 5,800 million tons, according to the Netherlands Environmental Assessment Agency. However, in a per person comparison, the average Chinese citizen is responsible for 10,500 pounds or 4,763 kilograms of CO_2, while the average U.S. citizen is responsible for 42,500 pounds or 19,278 kilograms of CO_2 as a result of heating and electricity for living spaces, driving, traveling by airplane, and purchasing manufactured products.

There are a number of groups and organizations working to create a more scientifically literate population and proposing and implementing programs and policies that reduce CO_2 and other greenhouse gases. A provision in the Kyoto Protocol is the Clean Development Mechanism (CDM), which is an offset that allows more developed countries to invest in lower emission-producing facilities in developing or less-developed countries to avoid reducing emissions in their home countries.

Another proposal is a carbon tax, or the taxation of burning fossil fuels (such as liquid, solid, and gaseous fuels) to reduce CO_2 emissions. Some groups are proposing a carbon label, where consumer products would report their carbon footprint on the label. Other practical methods for reducing carbon footprints are to reduce driving (for example, to use public transportation or bikes), reduce household heating by a couple of degrees, purchase green energy, plant a tree, recycle, and buy products with reduced packaging.

SEE ALSO: Carbon Cycle; Carbon Dioxide; Carbon Emissions; Carbon Permits; Public Awareness.

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Carbon Permits

CARBON PERMITS MAY be issued to companies through governmental agencies, and allow companies to emit up to a specified level of CO_2. The total number of issued permits from governmental agencies equals the national limit on emissions. CO_2-generating companies may reduce emissions by using lower-carbon coals, or increasing the use of cleaner-generating plants. Generators that reduce emissions below their allotted levels can sell excess emissions permits to other generators. Other generators who exceed the limit of the permit may purchase permits at the market price, instead of reducing emissions, if it is more cost effective. Thus, companies that can easily reduce emissions will do so, and those for which it is harder will buy credits that reduce greenhouse gases at the lowest possible cost to society. Emissions permits can also be banked for future use.

EMISSION TRADING SYSTEMS

The European Union Emission Trading Scheme (ETS) is an example of a carbon permits trading system. The test phase of ETS operated from 2005–07, and is slated for operation in the European Union (EU) during the Kyoto commitment period 2008–12. In the system, the aggregate cap on emissions is set by each EU government agency, and the total number of emissions allowances is defined to provide the owner the right to emit units of emissions. The amount of emissions is capped, whereas the permit prices are uncertain.

These permit prices are determined by economic conditions, generally, stronger economic growth means a higher permit price. Critics claim that the ETS has done more for power-generating companies, than it has curbed pollution. First, power generators emit a tremendous amount of pollution and monopolize the carbon market. Also, permit holders find they have unexpectedly valuable property rights because carbon permits are usually handed out for free, rather than auctioned. Second, there are no signals that the carbon permit is helpful in switching to cleaner fuel. That is not just because gas has been so much more expensive than coal, but because the first phase of the ETS lasts only three years. Because investments to reduce emissions have payback periods of five or more years, investors are wary.

The ETS was originally designed to meet the targets set by the Kyoto Protocol. The Kyoto Protocol was an international treaty negotiated in Kyoto, Japan, in December 1997 that took effect on February 16, 2005. As of December 2006, a total of 169 countries and other governmental entities had ratified the agreement. Its objective is to stabilize the greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. In the Kyoto Protocol, mechanisms such as International Emissions Trading (IET), Joint Implementation (JI) and the Clean Development Mechanism (CDM) provide options for members to fulfill their targets. IET provides the trading of assigned amount units (AAUs) between Annex I Parties in the Kyoto Protocol, JI enables Annex I parties to get credits for join projects to reduce emissions, CDM enables Annex I parties to get credit for projects resulting in emissions reductions in non–Annex I parties.

In the United States, the example of a successful emission trading system to date is the SO_2 trading system under the framework of the Clean Air Act (CAA). Under this program, SO_2 emissions are expected to fall by 50 percent 1980–2010. Compared to the proven success of the SO_2 trading program in the United States, carbon trading has some specific features that make it more complicated.

Carbon emissions are an international issue, rather than a domestic one. Complexities may arise in setting up baseline projections against which to monitor and verify net emissions reductions, particularly with regard to the CDM. Usually, large amounts of SO_2 come from coal-burning generation plants, making it relatively easy to monitor a plant's fuel use and emissions, rather than to construct and maintain a trading system to ensure compliance. On the other hand, carbon emissions come from many different sources, such as households, commercial and industrial facilities, transportation systems, and fossil-fired generating plants. Therefore, the development and operation of a monitoring and trading system for carbon emissions would be complicated.

CARBON PERMITS VS. CARBON TAXES

There has been debate on the relative merits of carbon permits versus carbon taxes to achieve emission reductions. Carbon permit systems fix the overall carbon emission level, while prices vary. On the other hand, carbon taxes fix the price, while the emission level quantity is allowed to vary according to economic activity. Therefore, carbon permits and carbon taxes are called quantity and price instruments, respectively. There are major drawbacks for each system. Carbon permits create uncertainty about the cost of compliance for firms, because the price of a permit is unknown; carbon taxes cannot guarantee the amount of emissions reduction.

Recently, a third option known as a safety valve has been suggested. It is a hybrid of the price and quantity instruments. The system is similar to a carbon permit system, but the maximum permit price is limited. Permits can be either purchased from the carbon market, or government, at a specified price. This system is designed to overcome the fundamental disadvantages of both systems, while providing flexibility.

SEE ALSO: Carbon Cycle; Carbon Emissions; Carbon Footprint; Clean Air Act, U.S.; Economics, Cost of Affecting Climate Change; Emissions, Trading; Kyoto Protocol.

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Carbon Sequestration

MANY COUNTRIES THAT attended the United Nations Framework Convention on Climate Change in Kyoto promised to learn how to mitigate the problem of climate change by managing the global carbon cycle. This resolve shows the significance of carbon sequestration for alleviating the global warming problem. Carbon sequestration refers to the provision of long-term storage of carbon in the terrestrial biosphere, underground, or in the oceans, so that the carbon dioxide (CO_2) buildup in the atmosphere will decrease or slow.

CO_2 makes up approximately 47 percent of greenhouse gases, making it a primary contributor to global warming. The level of CO_2 in the atmosphere has risen from the last century (pre-industrial) level of 280 parts per million (ppm) to the present level of 375 ppm. Carbon sequestration is intended to reduce the atmospheric CO_2 concentration, which is predicted to exponentially rise because of higher global energy use and extensive deforestation in the 21st century. Carbon sequestration can be accomplished by maintaining or enhancing natural processes such as managing forest ecosystems and storing carbon in biomass and soil, or by artificially sequestering carbon in underground geologic repositories, enhancing net oceanic carbon uptakes, and sequencing the genomes of micro-organisms for carbon management.

The Kyoto Protocol recognizes forestry and land-use change activities as carbon sinks and sources. When plants grow, they absorb carbon dioxide from the atmosphere as part of photosynthesis. This is known as carbon sequestration, because carbon is removed from the atmosphere. Therefore, a living plant helps carbon sink. Forest decay does generate carbon into the atmosphere, but sustainable use of forest biomass in biofuel production reduces this amount. Biofuel also reduces the use of fossil fuels, which are major contributors to greenhouse gas production. By the beginning of the 2010s, most of the countries in the world will mandate a minimum of 10 percent biofuel use. Scientists also agree that world forests have the greatest long-term potential to sequester atmospheric carbon by protecting forested lands, slowing deforestation, encouraging reforestation, and agroforestry. Deforestation, harvesting, and forest degradation contribute 1.8 Gt carbon per year.

Soil is a major reservoir of terrestrial carbon. It is about 3.3 times the size of the atmospheric pool. Therefore, if the soil is enriched through sequestration of atmospheric carbon, global warming can be managed significantly. This will also ensure global food security, because enhancement of soil carbon enhances the soil health for sustainable soil production. No-till farming, residue mulching, cover-cropping, and crop rotation are some of the methods that are employed to sequester carbon into soil. Using pyrolysis technique, half of the carbon in biomass can be reduced to charcoal and, thus, decrease the potential to act as a carbon source. The charcoal is later deposited in soil to increase its carbon content.

Atmospheric carbon can be reduced by enhancing the net oceanic uptake from the atmosphere by fertilization of phytoplankton with nutrients and injecting CO_2 to ocean depths greater than 3,281 ft. (1,000 m.), or into deep geologic formations. This reduction can also be achieved by carbon capture and storage (CCS); for example, collecting CO_2 at point sources (such as power plants) and injecting it directly into the deep ocean. If CCS is applied to modern conventional power plants, CO_2 emission into the atmosphere could be reduced by 80–90 percent. However, this injection into the deep sea might influence sea creatures negatively (due to the decrease in pH of sea water). Therefore, carbon storing in deep geologic formations has the greatest potential. Oil fields, gas fields, saline formations, unminable coal seams, and saline-filled basalt formations are suggested storage sites. Mineral storage of CO_2 is another potential means of carbon sequestration. In this process, CO_2 is exothermically reacted with abundantly available metal (Mg and Ca) oxides, which produce stable carbonates.

More advanced CO_2 capture techniques are being developed as part of carbon sequestration. Presently, there are three techniques in use: post-combustion, pre-combustion, and oxyfuel combustion. In post-combustion processes, CO_2 is captured from flue gases (the gas that exits to the atmosphere through a flue or pipe) at power stations. The pre-combustion technique is widely applied in fertilizer, chemical, gaseous fuel (hydrogen and methane), and power production. In these cases, the fossil fuel is gasified and the resulting CO_2 is easily captured from a relatively pure exhaust stream.

In the third type (oxyfuel combustion) the lignite is burned in oxygen instead of air and produces a flue gas consisting only of CO_2 and water vapor. This is cooled and condensed to a pure CO_2 stream that can be transported to the sequestration site and stored. According to scientists, this technique is very promising, but a lot of energy is needed for the initial air separation. Other ambitious techniques under development are the genetic manipulation of plants and trees to enhance CO_2 sequestering potential and sequencing the genomes of microbes that produce fuels such as methane and hydrogen or aid in carbon sequestration.

SEE ALSO: Biomass; Carbon Cycle; Carbon Emissions; Carbon Sinks; Forests; Oceanic Changes.

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Carbon Sinks

A CARBON SINK is defined as a pool or reservoir that absorbs carbon released from another part of the carbon cycle (the net exchange between the biosphere and the atmosphere). If the net exchange is toward the atmosphere, the biosphere is the source, and the atmosphere is the sink. Carbon sources usually release more carbon than they absorb, while sinks soak up more carbon than they emit. Another definition of carbon sink is: any natural or anthropogenic system that absorbs CO_2 from the atmosphere and stores it. Trees, plants, and oceans all absorb CO_2 and, therefore, are carbon sinks. The concept of carbon sinks is based on the natural ability of trees, other plants, and soil to soak up CO_2 and temporarily store the carbon in wood, roots, leaves, and earth.

Fossil fuel deposits are another important carbon store. Buried deep inside the earth, they are naturally separated from carbon cycling in the atmosphere until humans decide to release them into the atmosphere by burning coal, oil, or natural gas. The burning of fossil fuels results in the release of what are known as greenhouse gases (such as water vapors, CO_2, methane, nitrous oxide, sulfur hexafluoride, hydrofluorocarbons, and chlorofluorocarbons).

The downward radiation of long waves from the atmosphere, as opposed to radiation by the sun, is known as the greenhouse effect. A build-up of greenhouse gases in the atmosphere forms a layer that keeps heat from escaping into space and reflects it back to Earth. Because of human burning of fossil fuels, the concentration of greenhouse gases has soared to levels more than 30 percent higher than at the beginning of the Industrial Revolution. Instead of controlling and reducing greenhouse gases, human activities continue to add more than 6 billion tons of carbon per year to the atmospheric carbon cycle, thus exacerbating the situation and increasing the rate of global warming.

While forests act as sinks, deforestation prevents the absorption of CO_2. Therefore, fewer trees mean more CO_2 in the atmosphere. The causes of deforestation include logging for lumber, pulpwood, and fuel wood. The clearing of new land for farming and pastures for livestock, or the building of new housing, are some of the other reasons for deforestation. About 860 acres—the size of New York City's Central Park—are being destroyed every 15 minutes in the tropics.

Oceans are also important carbon sinks. Antarctica's Southern Ocean is a crucial carbon sink into which 15 percent of the world's excess CO_2flows. It is estimated that the world's oceans have absorbed about a quarter of the 500 gigatons of carbon emitted into the atmosphere by humans since the beginning of the Industrial Revolution. Observations have shown that the Southern Ocean's ability to absorb CO_2 has weakened by about 15 percent per decade since 1981. This is attributed to an increase in wind strength over the ocean because of higher levels of greenhouse gases in the atmosphere and long-term ozone depletion in the stratosphere. The strengthened winds influence the processes of mixing and upwelling in the ocean, resulting in an increased release of carbon dioxide into the atmosphere, and, thus, reducing the net absorption of CO_2 into the ocean, showing that climate change, itself, is responsible for the saturation of the Southern Ocean carbon sink.

SEE ALSO: Biomass; Carbon Cycle; Carbon Emissions; Carbon Sequestration; Deforestation; Forests; Global Warming; Oceanic Changes.

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Cenozoic Era

THE CENOZOIC ERA is the most recent of the nine eras in geological time, and extends from 65 million years ago to the present. The Cenozoic Era catalogues extensive climate changes, ranging from hothouse climates with warm-temperate to sub-tropical forests near both the north and south poles, to icehouse climates with ice sheets kilometers thick covering much of the high latitudes in both hemispheres. The first 30 million years of the Cenozoic were the warmest of the era and were characterized by several extreme warmth events.

The first of these climate maxima is the Initial Eocene Thermal Maximum, which occurred approximately 55 million years ago. Geological evidence suggests that at this time, atmospheric CO_2 concentrations soared to nearly 20 times current levels, and temperatures in the Arctic Ocean approached those of a comfortable swimming pool, approximately 68 degrees F (20 degrees C). This climate maximum persisted for 50,000—100,000 years, before the climate cooled and then continued a gradual warming trend through the longest period of sustained hothouse warmth in the Cenozoic, the Early Eocene Climatic Optimum.

THE EARLY EOCENE CLIMATIC OPTIMUM

The Early Eocene Climatic Optimum lasted for over 2 million years, and was characterized by warm and equable (meaning the climate was relatively similar everywhere) conditions. Deciduous, temperate forests covered Antarctica, and palm trees marched north across Wyoming and into Arctic Canada. Summer temperatures in the Arctic Ocean were approximately 59 degrees F (33 degrees C), almost 30 degrees F (17 degrees C) warmer than today, while ocean surface temperatures in the tropics were hardly different (at most, 9 degrees F, or 5 degrees C warmer) from those at present. This low equator to pole temperature gradient, with tropical and subtropical climate zones spanning much of the globe, is a notable characteristic of early Cenozoic hothouse climates, and understanding the mechanisms by which such a low temperature gradient can be maintained is one of the greatest challenges in paleoclimate science.

Long thought to be a time of gradual cooling, scientists have recently discovered additional thermal maxima during the later stages of the Eocene. The occurrence of all Eocene thermal maxima appear to be modulated by the eccentricity of Earth's orbit, (how much the shape of a planet's orbit deviates from a circle), and these new insights into early Cenozoic climate suggest that hothouse climates are as dynamic as the icehouse climates of the later Cenozoic.

FROM HOTHOUSE TO ICEHOUSE

Abrupt cooling at the Eocene/Oligocene transition (35 million years ago) marked the appearance of the first continent-spanning ice sheet on Antarctica, potentially the first Cenozoic Northern Hemisphere ice sheets, and the transition from hothouse to icehouse climate in the Cenozoic. However, much of the planet continued to experience climatic conditions warmer than the present, with cool temperate forests characterizing Arctic highlands, and warm temperate forests covering much of northern North America and Eurasia.

Research on the early Cenozoic era, when tropical forests grew in Wyoming, is revealing new insights about hothouse climates.

Following the abrupt initial cooling, Oligocene climate continued the overall Cenozoic cooling trend as atmospheric CO_2 levels fell to present values by the latest Oligocene. During this time, the driving influence of Earth's orbital parameters became increasingly evident in the waxing and waning of the Antarctic ice sheet, with frequencies that suggest modulation by not only eccentricity, but also the obliquity (variations in the axial tilt) of Earth's orbit.

Atmospheric CO_2 concentrations remain near modern levels throughout the subsequent Miocene epoch and the variability in both ice volume and climate evident in the first half of the Miocene is also attributable to the action of Earth's orbital parameters. Orbital parameters are also believed to be responsible for the last gasp of the warm climates, the approximately 3-million-year-long (14–17 million years ago) Miocene Climate Optimum.

During the Miocene Climate Optimum, ice volume on Antarctica was low, subtropical forests flourished as far north as central Europe, and the Arctic Ocean returned to a seasonally ice-free state. The Miocene Climate Optimum ended with 1.5 million years of rapid cooling, after which global cooling continued more gradually. In the late Miocene, several notable climate events took place, undisputable evidence for Northern Hemisphere glaciation, the establishment of largely modern vegetation zones, the establishment of a near modern latitudinal temperature gradient, and the inception of the Asian and Indian monsoons.

Global cooling continued through the Pliocene epoch (5.3–.8 million years ago), though global average temperatures in the Pliocene were approximately 5.5 degrees F (3 degrees C) warmer than at present. Peak Pliocene warmth occurred in the middle Pliocene from 4–3.5 million years ago, with Northern Hemisphere boreal forest extending to the Arctic Ocean, and deciduous hardwood forests of southern beech covering coastal Antarctica. In spite of this relative warmth, the global climate was cooling, and the late Pliocene, approximately 2.7 million years ago, is marked by the first major Northern Hemisphere cycle of glaciation and deglaciation. This first glacial cycle was modulated by a 41,000-year frequency that is characteristic of climate forcing by the obliquity and precession (the wobble of Earth's spinning axis) of Earth's orbit and a frequency that paced glacial cycles well into the Pleistocene epoch.

The Pleistocene (1.8 million–10,000 years ago) is the epoch commonly known as the Ice Age and was characterized by repeated waxing and waning of Northern Hemisphere ice sheets. For the first 1.2 million years of the Pleistocene, ice ages were paced by variations in solar energy associated with the 41,000-year obliquity cycle. Approximately 900,000 years ago, Northern Hemisphere ice sheets began to grow significantly larger and by 600,000 years ago, those larger ice sheets were waxing and waning with a periodicity of 100,000 years—a frequency that is not easily explained by simple combinations of Earth's orbital parameters. The reasons for this shift and the exact mechanisms driving this frequency in glacial cycles are two of the more challenging questions in ice age climate dynamics; neither is fully explained.

THE HOLOCENE EPOCH

Northern Hemisphere ice sheets have waxed and waned on 100,000 year timescales for at least 600,000 years and the approximately 10,000 years since the waning of the last Pleistocene glacial maximum are known as the Holocene Epoch. The Holocene is the shortest Cenozoic epoch and Holocene climate change is negligible compared to that in longer epochs. However, due to its recent nature, the records of the Holocene climate are better preserved than those of prior epochs and indicate smaller-scale, but significant, climate changes even within this short time span. Potentially the most significant Holocene climate changes are yet to come, as evidence of anthropogenic climate impacts and modern climate change continues to grow. Depending on the ultimate levels of greenhouse gases released by humans, climate change in the end of the Cenozoic Era has the potential to be as significant as the climate changes of the previous 65 million years.

SEE ALSO: Earth's Climate History; Ice Ages; Orbital Parameters, Eccentricity; Orbital Parameters, Obliquity; Orbital Parameters, Precession; Paleoclimates.

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Center for Clean Air Policy

ESTABLISHED IN 1985, the Center for Clean Air Policy (CCAP) is an independent, nonprofit entity headquartered in Washington, D.C. It adopts market-based approaches to environmental problems as the best way to reach common ground. The CCAP's current domestic and international initiatives promote stakeholder dialogues, education and outreach, qualitative and quantitative research, technical analyses of emission mitigation options, and policy recommendation development. The CCAP attempts to combine active, on-the-ground policy and research, and to advance cost-effective and pragmatic policies. CCAP deals with climate policy issues not only in the United States, but also in Europe, Asia, Central America, and South America.

The CCAP's mission statement is "to significantly advance cost-effective and pragmatic air quality and climate policy through analysis, dialogue and education to reach a broad range of policymakers and stakeholders worldwide." The work of the center, both in the United States and abroad, focuses on four major areas related to climate change: greenhouse gas emission mitigation and economics; emerging technologies and technology investment; transportation and land use; and adaptation. Within the United States, CCAP has four programs that try to involve different subjects in a profitable discussion about the environment.

The Climate Policy Initiative collaborates with leading companies; federal, state, and local governments; and environmental organizations to discuss and advance national climate policy solutions. The scheme intends to function as a forum to educate chief industry and government officials on the extent of the climate problem, and develop a set of pragmatic long-term mitigation and adaptation solutions for climate change in the United States. The Urban Leaders Initiative is a partnership with six large counties and cities to prevent climate change impacts through smart land use and infrastructure planning. The Advancing Climate Action in California assists the state in designing climate solutions through analysis and assessing mitigation options. CCAP's independent analysis of greenhouse gas mitigation options for California concluded that Governor Arnold Schwarzenegger's goal of reducing greenhouse gas emissions to 2000 levels by 2010 could be met at no net cost to California consumers.

The successes in California led CCAP to launch a comprehensive program to develop and implement climate change plans in key states, and pave the way for a strong federal approach. Through a combination of technical analysis and facilitation, CCAP is working with key states at different stages of climate change action to further climate change programs. This initiative deals with greenhouse gas emissions from all sectors of the economy, including transportation and land use, electricity generation, industry, buildings, agriculture, and forestry, and examines the full range of measures. The Transportation and Smart Growth Program focuses on transportation and land-use policies to reduce greenhouse gas emissions and improve air quality. This program also stresses the importance of transportation and planning efforts internationally.

CCAP has three major international initiatives in Europe, Asia, Central America, and South America. The Dialogue on Future International Actions to Address Global Climate Change combines in-depth analysis and development of policy options. A parallel program to the domestic Climate Policy Initiative, the European Climate and Energy Dialogue aims at developing medium- to long-term climate change, energy, and finance policy for the European Union. Finally, the Developing Countries Project entails collaboration with research teams in China, India, Brazil, and Mexico to identify technologies and approaches to reduce greenhouse gas emissions.

Through its projects, the CCAP claims to have reached important goals and to have played a major role in shaping climate change policies. In particular, the CCAP lists as its major successes the landmark sulfur dioxide trading program in the Clean Air Act, the original design for the European Union's CO_2 trading system, the development of the NOx reduction and trading program in the eastern United States, and the comprehensive climate policy strategy for New York state, which directly led to the successful creation of Regional Greenhouse Gas Initiative (RGGI). In addition, the CCAP worked with three U.S. utilities to finance the first carbon reduction project, the retrofit of a coal-fired heating plant in the Czech Republic. It has also devised, with stakeholders, the original design rules for the Clean Development Mechanism adopted as the Marrakech Accords.

CCAP has also been actively involved in the development of the Clean Development Mechanism (CDM) under the Kyoto Protocol. The center helped to design the rules for the CDM through work with developing countries. The Canadian Government hired CCAP to facilitate an informal workshop on streamlining the CDM in preparation for the United Nations Convention on Climate Change in Montreal, where CDM strengthening was a key issue. CCAP gathered negotiators from 30 developed and developing countries to discuss technical and legal issues surrounding development and implementation of the CDM. CCAP continues to develop the debate between developed and developing countries on the CDM.

SEE ALSO: California; Carbon Permits; Clean Air Act, U.S.; Clean Development Mechanism; Kyoto Protocol.

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Center for Energy Efficiency

BASED IN MOSCOW, the Center for Energy Efficiency (CENEf) is a nonprofit independent Russian organization founded in 1992 to promote energy efficiency and environmental protection in Russia. The Pacific Northwest National Laboratories of Battelle Memorial Institute, the World Wildlife Fund, the Social and Ecological Union (in Russia), and Mikhail Berner, president of the Russian Energy Manager's Association, founded the center. Initial sponsorship was provided by the World Wildlife Fund, the U.S. Environmental Protection Agency (EPA), the Charles Stewart

Mott Foundation, the U.S. Department of Energy, the U.S. Agency for International Development (USAID), and the John D. and Catherine T. MacArthur Foundation. CENEf has been self-sustaining since 1996. As stated by Pacific Northwest National Laboratories, the center was created to slow the rate of carbon dioxide emission, a key greenhouse gas that causes global warming, and to create new markets for American energy technologies.

CENEf was founded with the intention to develop model legislation and policy proposals to implement energy efficiency measures in Russia during its transition to a market economy, while considering economic, environmental, and social impacts implied in such transition. CENEf identified energy efficiency-related issues and developed policy papers on these issues, initiated energy-efficiency projects, and promoted economic cooperation between Russian and foreign companies to manufacture energy-efficient equipment and provide energy-efficiency services. CENEf has also prepared and disseminated materials for mass media to promote public education and has organized energy-efficiency training programs for nongovernmental organizations.

CENEf also publishes two quarterly newsletters, *Energy Efficiency* and *Energy Manager*, which reach 2,200 Russian city officials, utility managers, and industrial energy managers. It has strong contacts with city and regional governments throughout Russia. CENEf has developed long-term, energy-efficiency investment plans for municipal utilities in Kostroma, Chelyabinsk, Lytkarino, Dzerzhinsk, Zheleznogorsk, and the Orlov region. Participating cities have already invested more than $2 million of their own funds, and will eventually acquire and install roughly $65 million worth of equipment. CENEf also organizes seminars and training programs for industrial energy managers across Russia and holds an annual workshop and trade show each May.

Because of its strong contacts at the municipal level, CENEf is a partner of the Alliance to Save Energy (ASE) and of its Municipal Network for Energy Efficiency (MUNEE) project to promote exchanges of information among municipal leaders and to disseminate practical information on energy efficiency. CENEf traced 19 good examples of energy efficiency in Russia, and developed a municipal energy-efficiency policy through a database of city officials involved in energy issues. The database serves as a line of communication across the country to inform municipal leaders about low- and no-cost methods of reducing energy expenses in their city budget. CENEf's involvement in the MUNEE project is of particular importance because of the trouble that Russian cities have monitoring energy costs. In response to this need, CENEf devised a software package called Energy Attestat that can monitor energy use in up to 100 buildings. It has played a leading role in the creation of energy-monitoring tools and in disseminating them through all the MUNEE countries.

POLICY INVOLVEMENT

CENEf has long stimulated debates on energy efficiency in Russia. In January 1993, it developed a draft federal law, "On Improving Energy Efficiency," which was submitted to the former Supreme Soviet of the Russian Federation and then to the State Duma. The Draft Law was published in 1993. This was an important precedent for public discussion of energy legislation. Since then, CENEf has played an active role in the development of Russia's energy policy. It has contributed to, and commented on, many official energy policy documents for various government agencies. CENEf's first years were marked by suspicion, as it operated in a political climate where centralized administrative control was still strong. In spite of this hostility, from 1992 to 1999, CENEf managed to set up over 40 specialized institutions to develop and implement energy-efficiency policy at the federal and regional levels.

CENEfis committed to improving standards of living in ways that respect the environment. It participated in the Second and Third Assessment Reports of the Intergovernmental Panel on Climate Change (IPCC), identified effective strategies for reducing greenhouse gas emissions, participated in the Joint Implementation Program and the assessment of the environmental characteristics of combustion processes, and developed recommendations to improve combustion efficiency to minimize harmful emissions. CENEf has also produced publications and organized workshops to disseminate international documents on the limitation of greenhouse gas emissions developed in Kyoto Protocol and the United Nations Framework Convention.

SEE ALSO: Carbon Emissions; Nongovernmental Organizations (NGOs); Russia.

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Center for International Climate and Environment Research

THE CENTER FOR International Climate and Environment Research (CICERO) is a nonprofit, independent research institution established in association with the University of Oslo by the Norwegian government in 1990. CICERO conducts experiments and performs research regarding issues, such as climate change and greenhouse gas emissions. Additionally, it offers recommendations to alleviate the detrimental effects of climate change. CICERO has published an array of articles and continues to undertake research projects that serve to deter the process of global warming. CICERO has three objectives: to recommend policies that reduce greenhouse gas emissions, to encourage global participation in adopting climate and environmental policies, and to propose policies that accomplish long- and short-term goals. CICERO's work influences a wide range of audiences, including national and international organizations, government agencies, and academics.

CICERO's research branch has three main programs, focusing on scientific basis and international agreements; mitigation and costs; and the impacts, vulnerability, and adaptation of climate policies. The primary purpose of the scientific basis division is to perform scientific analysis and to incorporate its findings into practical policies and recommendations. In the scientific basis program, the center's researchers explore the effects that greenhouse gases such as carbon dioxide (CO_2), nitrous oxide (N_2O), and perfluorocarbons (PFCs) have on climate. The researchers monitor the effects climate policies have on the global climate system. Many of the published studies discuss how the distribution of greenhouse gases is affecting atmospheric composition. Aside from scientific research, scholars in this division also take part in policy development. Researchers work on creating ways to track the emission of greenhouse pollutants, while others are involved in climate policy negotiations.

The second program looks into the socioeconomic costs and benefits of greenhouse gas emissions and climate policies. This division's objective is to diminish the detrimental effects brought on by climate change. It also applies economic models in order to evaluate the advantages and disadvantages of policies. Scientists examine the impacts greenhouse gases have on energy stability. Besides focusing on how climate fluctuation affects regional populations, climate experts also focus on how it affects the agriculture industry. More specifically, researchers examine the effects pollution and the thinning ozone have on crop growth and yield. The relationship between climate change and the environment is also studied; some of the research topics include acidification, deforestation, and soil erosion. Moreover, scientists examine the connection between climate change and natural disasters such as floods, water shortages, and forest fires.

The third research division identifies the problems caused by climate fluctuations, to discover the attributes that increase regions' susceptibility to climate fluctuations. Additionally, experts take on multidisciplinary research efforts to study how variables such as trade and globalization impact the climate and the environment. Scientists in many different disciplines, such as economics, political science, anthropology, and resource development, work together to construct theoretical and empirical models to assess countries' vulnerabilities to climate change. The team of experts provides solutions to allow a region to accommodate the changes in climate, while minimizing their damaging effects, and measuring the efficacy of these strategies.

CICERO has trained many scholars involved in climate study. It also disseminates research data and policy recommendations. *Cicerone2*, a magazine published by the center, presents recent research findings on climate and environment issues. It also discusses climate policies and regulations. *Cicerone2* also comments on international climate change conferences. CICERO also holds forums to encourage scholars, policymakers, and government officials to discuss the latest developments on climate and its related policies. Its experts attend conferences and international meetings such as the United Nations Framework Convention on Climate Change to present data and commentary.

CICERO is involved in several projects. Some of these include examining what effects energy regulations have on energy sources that are not sensitive to changes in price. Others aim to develop a model to translate the damage caused by environmental pollution into numeric value. The team of scientists at CICERO also collaborate with Chinese experts and policymakers on identifying how different population cohorts are affected by climate policies. The organization also devotes attention and resources to climate issues in Norway. A notable upcoming project focuses on how different communities in Noway cope with global warming.

SEE ALSO: Greenhouse Gases; Nongovernmental Organizations (NGOs); Norway; World Climate Research Program.

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Center for International Environmental Law

ACCORDING TO ITS website, "the Center for International Environmental Law (CIEL) is a nonprofit organization working to use international law and institutions to protect the environment, promote human health, and ensure a just and sustainable society." It aims to: use law to contribute to solve environmental problems and promote sustainable societies, introduce principles of ecology and justice into international law, strengthen national environmental law systems and support public interest movements, and educate and train public interest environmental lawyers.

CIEL advises key participants in the international policy arena on how to work toward a sustainable, enforceable emissions-reduction framework. It is widely recognized as a leading legal research institute, earning respect for objective analysis and strong commitment to the environment. A key part of CIEL's strategy is to provide legal support and advice to other environmental organizations and representatives of indigenous and other local communities, helping build their capacity to advocate for a just and effective climate regime.

ARCTIC AND SUBARCTIC ISSUES

To strengthen the global response, CIEL's Climate Change Program focuses on impacts to people and ecosystems of the Arctic and subarctic. The program works to protect the Earth's climate system through promotion of human rights, forest conservation, and biodiversity protection. According to the Intergovernmental Panel on Climate Change, the destructive effects of climate change will not only affect the environment, but also Arctic peoples. Average annual temperatures in the Arctic have increased by approximately double the increase in global average temperatures.

The direct impacts of global warming include higher temperatures, sea-level rise, the melting of sea ice and glaciers, increased precipitation in some areas, and drought in others. Indirect social, environmental, economic, and health impacts will follow, including increased death and serious illness in poor communities, decreased crop yields, heat stress in livestock and wildlife, and damage to coastal ecosystems, forests, drinking water, fisheries, buildings, and other resources.

During the past several decades, the Arctic has warmed at an alarming rate, and it is projected to continue to warm by as much as 18 degrees F (10 degrees C) by 2100. This warming trend has had a devastating impact on Arctic ecosystems, including sea ice, permafrost, forests, and tundra. Warming has contributed to increases in lake temperatures, permafrost thawing, increased stress on plant and animal populations, and the melting of glaciers and sea ice. Research has revealed decreases in sea ice extent and cover.

In Shishmaref, Alaska, a small Inuit village in the Chukchi Sea, seven houses have had to be relocated, three have fallen into the sea, and engineers predict that the entire village of 600 houses could disappear into the sea within the next few decades. Shishmaref's airport runway has almost been met by rising seawater, and its fuel tank farm, which seven years ago was 300 ft. (92 m.) from the edge of a seaside bluff, is now only 35 ft. (10 m.) from the bluff. The town dump, which has seawater within 8 ft. (2 m.) of it, could pollute the nearby marine environment for years if inundated. Advancing seawater has contaminated Shishmaref's drinking water supply.

If global warming continues unchecked, it threatens to destroy their culture, render their land uninhabitable, and rob them of their means of subsistence. Subsidence due to permafrost melting is destroying homes, roads, and other vital structures in the Arctic. The harm caused by carbon dioxide emissions already violates some fundamental internationally recognized human rights such as those recognized in the American Declaration of the Rights and Duties of Man: the right to life (Art. I), the right to residence and movement (Art. VIII), the right to inviolability of the home (Art. IX), the right to preservation of health and to well-being (Art. XI), the rights to benefits of culture (Art. XIII), and the right to work and to fair remuneration (Art. XIV).

International tribunals have recognized that harm to the environment that affects one's home can violate these rights. For example, in *Lopez Ostra v. Spain*, the European Court of Human Rights held that Spain's failure to prevent a waste treatment plant from polluting nearby homes violated the petitioner's "right to respect for her home and her private and family life," and held the state liable for damages.

CIEL and Earth Justice petitioned the Inter-American Commission of Human Rights on behalf of the Inuits. The commission has in the past recognized the relationship between human rights and the environmental effects of development activities, and its interpretation of this relationship suggests that it would recognize the human rights implications of the effects of global warming. The United States has not ratified the convention, and, as such, is not subject to the jurisdiction of the court. However, a report by the commission examining the connection between global warming and human rights could have a powerful impact on worldwide efforts to address global warming. Recognition by the commission of a link between global warming and human rights may establish a legal basis for holding responsible countries that have profited from inadequate greenhouse gas regulation and could provide a strong incentive to all countries to participate in effective international response efforts.

The Arctic may warm by as much as 18 degrees F by 2100, and research has already found a decrease in sea ice and cover.

CIEL's Climate Change Program works to develop and strengthen the rules within the international climate change legal regime. Its primary goal is to get the rules right so that the Kyoto Protocol can become a genuine tool for environmental protection and sustainable development. During the course of climate negotiations, proposals developed by the center have been included in the negotiating texts and supported by governments and international institutions. The key areas of focus for the center's Climate Change Program include: accounting rules that ensure verifiable emissions reductions, promote sustainable development, conserve biological diversity and respect other ecological values; compliance and monitoring systems for enforcing the Kyoto Protocol; participation of the public, including directly affected local communities and civil society in the Kyoto Protocol; and domestic policy to combat global warming.

SEE ALSO: Arctic Ocean; Sea Ice; Sea Level, Rising.

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Center for Ocean-Atmospheric Prediction Studies

THE CENTER FOR Ocean-Atmospheric Prediction Studies (COAPS) at Florida State University (FSU) carries out research in air-sea interaction, ocean and coupled air-sea modeling, climate prediction, statistical studies, and predictions of social/economic consequences of ocean-atmospheric variations. Students in COAPS come from a wide variety of departments including meteorology, mathematics, computer science, and physical oceanography. COAPS is funded by several federal agencies, producing original published papers that advance our understanding of the ocean and the atmosphere and their role in shaping the Earth's climate. It has over 50 people working on research grants totaling more than $3 per year. COAPS faculty are members of the meteorology and oceanography departments. It has graduate students as well as undergraduate research scholars.

COAPS's areas of research are quite broad. It places a particular emphasis on research to improve hurricane storm surge predictions in the Gulf of Mexico and to develop an understanding of the regional distributions of hurricane activity in the United States. This aspect is of particular importance to Florida and coastal residents. Among other topics, COAPS research includes understanding oceanographic measurements obtained from satellites for sea-surface winds, sea-surface shape, and ocean color. It also encompasses climate forecasting for farmers in Florida, Georgia, and Alabama using coupled atmosphere-ocean global and regional models.

Weather and crop reports are offered to Florida, Georgia, and Alabama farmers through the Florida Climate Center. In addition, COAPS has created AgClimate, an interactive website with climate, agriculture, and forestry information, to assist farmers to manage their crops for maximum outcome. AgClimate uses crop simulation models along with historic and forecast climate data so farmers can compare probable outcomes under different climate conditions. AgClimate tools are aimed at providing farmers with opportunities for adaptating to seasonal climate forecasts so as to limit the production risks caused by climate variability. Tools provide information for specific counties as well as regional overviews.

The research on air/sea interaction focuses on the transfer of energy from the atmosphere to the ocean. Areas of interest cover theoretical modeling, analysis of in situ observations, satellite-based observations, flux coupling for ocean and atmospheric models, and analysis of spatial/temporal variability in surface turbulent fluxes. The In-Situ Fluxes Project at FSU aims to provide better products for marine surface variability. In particular, it addresses the transfer of energy between the ocean and the atmosphere, as well as variables related to this problem (wind speed, wind vectors, sea-surface temperature, air temperature, humidity, surface pressure, and wave characteristics).

FSU In-Situ Fluxes produces monthly averages, based solely on in situ observations (ships and buoys). The FSU Satellite Fluxes largely rely on satellite observations that offer finer resolution in space and time. The project provides a new set of ocean surface forcing fields to understand the global climate system and favor climate prediction. The long-term monthly fields are suitable for seasonal to decadal studies, and the related hybrid satellite and numerical weather prediction (NWP) fields can be employed for daily-to-annual variability and quality assessment.

COAPS is carrying out research on climate change with the National Center for Atmospheric Research (NCAR). Together the two centers are building a new version of the Community Climate System model (CCSM), using the Hybrid Coordinate Ocean Model (HYCOM) as the oceanic model. The CCSM is one of the most respected models in the climate research community. In this project, the CCSM is not employed with the conventional depth vertical coordinate, but with an oceanic model that uses hybrid vertical coordinates. Comparisons will be performed between the new CCSM/HYCOM and the standard (CCSM/POP) version. After the validation of the new coupled model, decadal to centennial time scale experiments will be conducted to study climate change (decades to centuries) and climate variability (seasonal to inter-annual). These experiments will include Intergovernmental Panel on Climate Change (IPCC) integrations as well as investigations of the response and feedback of the ocean to external climate forcing.

COAPS recognizes the Earth's climate as a dynamic system with regional and local variations. It studies climate variability by looking at variations in daily maximum and minimum temperatures across the United States. Researchers examine the trends in temperature at both automated national weather service sites and cooperative observing stations. COAPS also works on the dynamical forecasting/hindcasting of Northern Hemisphere tropical Atlantic basin hurricane activity. To address hurricane prediction, it employs the FSU/COAPS climate global atmospheric model (T126L27) and the FSU/COAPS atmospheric model coupled to the newly-developed Max Planck global ocean model with orthogonal curvilinear coordinates.

In this same area, COAPS examines crop yields as determined by a dynamical downscaled atmospheric model. Climate variability has been shown to be a significant factor in agricultural crops. The seasonal climate shifts due to El Niño–Southern Oscillation (ENSO) phase in the southeastern United States significantly influence corn, wheat, cotton, tomato, rice, and hay production. COAPS uses the FSU/COAPS global and regional models in hindcasting/forecasting crop yields over the southeastern United States. Finally, COAPS compares statistically-downscaled climate data and data generated by dynamical models. The global and regional models used for these studies are all dynamical COAPS is comparing studies using statistical downscaling techniques against dynamical methods. COAPS research has pointed out that the advantage of statistical methods is that they are relatively inexpensive computationally and can be performed at any spatial resolution. Seasonal characteristics and higher moment statistics are some of the comparisons being carried out.

OCEAN MODELING

Ocean-modeling activities at COAPS include model development, research, and graduate instruction. COAPS uses models of various complexity, architecture, and horizontal and vertical coordinate representation as the principal tools. Models employed at COAPS vary from very high-resolution regional models to basin-scale and global models. The models currently used at COAPS are: Navy Coastal Ocean Model (NCOM); Finite Volume Community Ocean Model (FVCOM); Hybrid Coordinate Ocean Model (HYCOM); Regional Ocean Model System (ROMS) (regional/coastal); HYCOM (basin-scale); Hamburg Ocean Primitive Equation (HOPE); HYCOM (global). Model experiments are routinely run on the local COAPS computers as well as at various supercomputer centers (FSU, Naval Oceanographic Office [NAVOCEANO], National Center for Atmospheric Research [NCAR]).

Modeling studies address a wide range of topics from exploring physical processes in the deep and upper ocean to improving ocean forecasting. Coupling of the ocean models with different atmospheric/flux models gives researchers the chance to study air-sea interaction at a wide variety of time scales. For example, regional models coupled to the BVW atmospheric heat flux model are used to simulate more realistic analyses of the air-sea interaction and ocean response during hurricanes. The global models are coupled to either the COAPS/FSU global atmospheric model or to the NCAR Community Atmosphere Model (CAM) within the CCSM. These coupled models are used to investigate climate variability or climate change.

High-resolution numerical models are used at COAPS to study the physical environment of the Gulf of Mexico, which has long been an area of expertise. Researchers have explained why the actual height of the storm surge generated by Hurricane Dennis on the North Florida Coast was 8–10 ft. instead of the predicted 3–5 ft. The result of the project pointed out that, although Dennis had only modest winds off West Florida, these winds drove water on shore which morphed into a barotropic shelf wave that propagated to St. Marks, Florida, nearly doubling the surge caused by local winds. This research had important consequences as it led the National Oceanic and Atmospheric Administration (NOAA) to modify storm surge forecasting methods in the Gulf of Mexico, by including larger model domains to account for remotely-generated sea level anomalies.

For their study on the Gulf of Mexico, researchers at COAPS use two models. NCOM developed at the U.S. Naval Research Laboratory (NRC), is a three-dimensional primitive equation ocean model that has been optimized for running on supercomputers. The NCOM representations serve as a virtual laboratory for studying the physics of the ocean circulation within the Gulf of Mexico. Projects encompass studies of the Loop Current and its eddies within the deep ocean, the circulation on the continental shelves near the coast, the interaction of eddies with the waters of the continental shelves, and the impacts of river discharge on the ocean environment. Additionally, the model is used to advance the understanding of numerical methods, ocean prediction systems, and air-sea interaction.

The second configuration is based the HYCOM, which operates in near real time by the NRL at Stennis Space Center. More specifically, the goal is to further develop this configuration within the framework of the Northern Gulf Institute into a coupled ocean-atmosphere-biogeochemical modeling system. This modeling configuration will include: forcing from a high resolution regional atmospheric model, a wave model to improve the flux computations, real-time river discharge, tidal forcing, and a complex biogeochemical model. COAPS is developing a very high-resolution regional model of the northeastern Gulf and will become part of this Gulf of Mexico HYCOM modeling system.

COAPS works in the field of physical oceanography and ocean prediction within the Global Ocean Data Assimilation Experiment (GODAE), which provides a framework for attempts to combine numerical models and observations via data assimilation to provide ocean prediction products on various spatial and time scales. GODAE supplies a global system of observations, communications, modeling, and assimilation that will deliver regular, comprehensive information on the state of the oceans. COAPS believes that studies in physical oceanography and ocean prediction will result, not only in increased knowledge of the marine environment and ocean climate, but also in improved predictive opportunities that will benefit commercial and industrial sectors of society. The development of this ocean prediction capability will allow a better scientific understanding of ocean physical processes and their influences on marine ecosystems. COAPS works within a large partnership of institutions to develop the performance and application of eddy-resolving, real-time global and basin-scale ocean prediction systems using HYCOM. This partnership is sponsored by the U.S. component of GODAE.

RISK ASSESSMENT

COAPS has a special area of research in risk assessment in the categories of storm surge, freeze forecasting, and fire weather. COAPS is developing new methods to predict the amount of storm surge that will hit the Gulf Coast during a storm that can be very destructive for coastal property. COAPS has played a central role in the research of climate variability related to the ENSO.

The center is involved in the Southeast Climate Consortium and has developed variability and forecast tools applicable to agricultural interests in the southeastern United States. These tools are centered on shifts in the traditional climate variables (monthly averaged temperature and precipitation), but also on extreme events such as droughts, severe weather, hurricanes, and damaging freezes. Through an examination of historical freeze events in central and south Florida, COAPS has revealed a strong connection between ENSO and the occurrence of damaging freezes. Specifically, the severe or damaging freezes tend to occur during the neutral ENSO phase and are much less likely during El Niño or La Niña.

Based on the analysis of more than 50 years of historical weather observations, COAPS makes available a probabilistic freeze forecast for the winter season which is released every fall, based on the state of the tropical Pacific Ocean. The forecast is widely disseminated; it is available online on agclimate.org, is published in agricultural newsletters and publications, and is also presented at winter weather workshops throughout the state. Going to the opposite extreme, COAPS has cooperated with the Florida Division of

Forestry in research projects to identify the connection between ENSO and wildfire burn acreage in Florida. As an extension and continuation of that research, COAPS, funded by the Florida Division of Forestry and the United States Department of Agriculture Forest Service, has developed a prototype wildfire risk forecast system for Florida and the Southeast.

COAPS is also active in satellite studies of the ocean and atmospheric variability. It uses weather radar observations and scatterometers, which estimate near-surface wind speed and direction, as well as surface stress. COAPS also employs a wide variety of instruments to measure wind speed and sea surface temperature.

SEE ALSO: Climate Models; Climatic Data, Atmospheric Observations; Climatic Data, Oceanic Observations; National Oceanic and Atmospheric Administration (NOAA); Ocean Component of Models.

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Center for Science and Environment (India)

THE CENTER FOR Science and Environment (CSE) was established in 1980 by a group of engineers, scientists, journalists, and environmentalists to increase public awareness of science, technology, environment, and development in New Delhi, India. The center became functional with a small group of writers in 1981, and, in its first year, it was involved in producing an information service on science and society-related issues such as energy, environment, health, human settlements, and the impact of science and technology at the grassroots level.

Anil Agarwal, an environmental journalist, advocate, and analyst, was its original founder. His biggest achievement has been to spread the environmental message in India and abroad. Also notable was his invaluable role in arguing for equity in global environmental management in the process that led up to the Rio Earth Summit. He worked to put environment on the global political and civil society agenda from a Southern Hemisphere perspective. Most importantly, through his writings and advocacy, he played a vital role in providing the answers for an environmentally sound development strategy for countries such as India. Sunita Narain, CSE's present director, has carried on with advocacy for the Global South, and has played an important role in climate change negotiations. The center has advocated for the Global South and developing countries. According to its briefing paper, "Equity is a prerequisite for any global agreement, particularly when dealing with the pollution of a global common property resource such as the atmosphere."

CSE helps the public to search for solutions that people and communities can implement, and/or push the government to create a framework for people and communities to act on their own. CSE is considered one of India's leading environmental nongovernmental organizations specializing in sustainable natural resource management. Its strategy of knowledge-based activism has won it wide respect and admiration for its quality of campaigns, research, and publications worldwide. CSE promotes solutions for India's numerous environmental threats, including ecological poverty and extensive land degradation, and rapidly-growing toxic degradation of uncontrolled industrialization and economic growth.

In late 1981, the center embarked upon a major exercise, the *State of India's Environment*, the first citizen's report on the environment. It was a unique document that was prepared in active collaboration with concerned academics, activists, and citizens' groups across the country. The report had a critical impact on the unresolved worldwide debate on environment versus development. The cynics argued that northern India, already affluent, now also wanted clean air and water for their health, and nature parks for recreation. The report detailed how environmental destruction usually targets the poor, who survive on the resources provided by nature. Any development that destroys the environment exacerbates poverty and increases unemployment by destroying the survival base of the poor. This is particularly true of India, which has a large number of biomass-dependent people and a high population density; therefore, a developing country such as India has to take care of its environment even more than an industrialized country. The report generated much debate and was widely read and reviewed nationally and internationally. The United Nations Environment Programme in Nairobi called it a model for all countries to follow.

The second citizens' report was perhaps the first report that showed how environmental degradation has a disproportionate impact on women. Since then, this idea has been widely accepted. The *State of India's Environment* also caught the attention of the Indian Prime Minister Rajiv Gandhi, who invited the center, in 1986, to address the nation's Council of Ministers and the Parliament on the importance of sustainable development.

The third citizens' report, the *State of India's Environment: Floods, Floodplains and Environmental Myths*, was published in 1991. It broke new ground by arguing that the severe floods in the Gangetic Plain and the Brahmaputra River Valley (areas that are more flood-prone than any other region of the world) can be controlled by better management of the floodplains, not the rivers' uplands, as conventional belief dictated.

The fourth citizen's report, *Dying Wisdom: The Rise, Fall and Potential of Traditional Water Harvesting Systems*, was published in 1997, the completion of an eight-year exercise that documented India's millennia-old traditions in water management and rainwater harvesting. This seminal publication on water management started a nationwide interest in community and household-based water harvesting initiatives. It argued that the management of water should be everybody's business. Several Indian states, including Madhya Pradesh, Gujarat, and Andhra Pradesh, and even the central government launched major rainwater harvesting initiatives to combat drought and widespread land degradation.

Incorporating nationwide research efforts, the fifth citizens' report, the *State of India's Environment*, was published in 1998. The fifth report came in two parts. The first part was a comprehensive dossier on environmental issues, events, policies, and practices. The second provided statistical analyses on different aspects of India's environment. CSE's citizens' reports have been the combined product of networking, constituency-building, and intellectual leadership. They have received national and international acclaim and have been translated into several Indian languages.

In early 1992, CSE organized the first South Asian nongovernmental organization summit to discuss the agenda of the forthcoming United Nations Conference on Environment and Development meeting at Rio de Janeiro, and to prepare common positions of South Asian nongovernmental organizations. The summit helped to promote a common understanding in the region on critical global environmental issues. Four staff members represented CSE at the Rio conference. The director, Anil Agarwal, was a member of the official Indian delegation. The team intervened in the forest convention debate and mobilized public opinion in favor of the view that the world's forests are best managed by the local communities. The industrialized countries, on the other hand, had proposed a system in which economic interests in the developed nations and professional foresters could control the levers of forest management.

While Rio established environment firmly in the political agenda, implementation of the agreement has been hesitant and slow. CSE has identified its key function as an agency monitoring international developments, research, and analysis of issues, and initiating an informed public debate in India, in particular, and the developing world, in general. CSE's researchers have tried to develop a policy framework for participatory and environmentally-sound development. Some of the significant concepts that have emerged from CSE's past research programs are: the need for ecosystem-specific and culture-specific approaches to economic development; participatory, legal, and institutional mechanisms for rural development; the importance of traditional knowledge systems; and just and equitable governance for global environmental problems.

SEE ALSO: Developing Countries; Drought; Floods; India; Nongovernmental Organizations (NGOs).

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Central African Republic

A FORMER FRENCH colony in central Africa, the Central African Republic is entirely landlocked and has an area of 240,534 sq. mi. (622,984 sq. km.), with a population of 4,216,666 (2007 est.), and a population density of 17.5 people per sq. mi. (6.8 people per sq. km.). The country is poor, with 3 percent of the land arable, and a further 5 percent used for meadows and pasture. In spite of this, many of the desperately poor people in the country survive through subsistence farming.

Some 64 percent of the country is forested, which helps reduce its already extremely low carbon dioxide (CO_2) emissions from the country. CO_2 emissions per capita from the Central African Republic have never exceeded 0.1 metric tons per person, reaching 0.06 metric tons per person by 2003. These come entirely from the use of liquid fuels, and the country has a poor public transport network. It has also faced problems with water shortages, not only due to global warming and climate change, but also from the growing of cotton that has been used to manufacture velvet.

The government of André Kolingba took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, and it ratified the Vienna Convention in the following year. The government has so far not expressed an opinion on the Kyoto Protocol to the UN Framework Convention on Climate Change.

SEE ALSO: Agriculture; Developing Countries; Forests.

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Chad

A FORMER FRENCH colony, Chad has a land area of 495,753 sq. mi. (1,284,000 sq. km.), with a population of 10,146,000 (2005 est.), and a population density of 20.4 people per sq. mi. (7.9 people per sq. km.). Although 85 percent of the people work in agriculture, only three percent of the land is arable; a further 36 percent of land is used for pasture, much of it with extremely poor soil. Some 26 percent of the country is forested, and this has lessened the already extremely low carbon dioxide (CO_2) emissions. Its per capita emission rate is 0.01 metric tons per person, the second lowest rate in the world, only slightly more than Somalia.

All of Chad's CO_2 emissions come from liquid fuels. The country has a very small public transportation system, with most people traveling long distances by hitching rides with trucks. The railway line planned in 1958 to link Bangui in the Central African Republic with N'Djamena, Chad's capital, was never completed. As a result, many of the elite and middle-class use cars, adding to air pollution. The government of Hissène Habré ratified the Vienna Convention in 1989. His successor, Idriss Déby, took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992.

Although the Déby government has not expressed its stance on the Kyoto Protocol to the UN Framework Convention on Climate Change, Chad is likely to be one of the countries most affected by climate change and global warming. This is particularly apparent through the marginalization of agricultural land, the reduction of rainfall, the increased demand for water for agricultural irrigation, and temperature change. These environmental factors have led to a dramatic reduction in the size of Lake Chad, which has decreased in size from 9,650 sq. mi. (25,000 sq. km.) in 1963, to 521 sq. mi. (1,350 sq. km.) in 2007.

SEE ALSO: Developing Countries; Drought; Land Use; Transportation.

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Chamberlin, Thomas C. (1843–1928)

THOMAS C. CHAMBERLIN was an American glacial geologist and educator who, at the turn of the 20th century, challenged the generally accepted Laplacian theory that the Earth was formed by hot gases and was gradually becoming cooler. He suggested the planetesimal hypothesis, arguing that the planets were formed after a star passed near the Sun, pulling away material from both bodies that later condensed into the planets. Chamberlin was one of the first scientists to emphasize the role of carbon dioxide in regulating the Earth's temperature, thus anticipating the current debates on global warming. Chamberlin also founded the *Journal of Geology*, acted as its editor for many years, and was the first director of the U.S. Geological Survey's Pleistocene Division (1881–1904).

Chamberlin was the first geologist to demonstrate that there had been multiple Pleistocene glaciations in North America. He offered early analyses of moraines, drumlins, eskers, and boulder trains. Starting from these features, he worked out regional glacial flow patterns and calculated the outermost limits of the two last glacial advances.

Chamberlin was born on September 23, 1843. At the time of Chamberlin's birth, his family was living in Mattoon, southern Illinois, but they soon moved north to Beloit in Wisconsin. The future scientist grew up in a religious family (his father was a Methodist minister), where education was held in high esteem. With his four brothers, Chamberlin attended a preparatory academy, and then Beloit College, where he developed a strong interest in natural science. The young Chamberlin was immediately attracted to geology, in spite of the apparent conflicts with his strong Methodist background. While studying at Beloit College, where he was an outstanding student, Chamberlin directed the church choir.

To finance his education, Chamberlin worked in country schools and, upon his graduation in 1866, he became a teacher, and later, principal in a high school near Beloit. He became a particularly popular speaker within the community, giving lectures on science and organizing field trips. In 1867, he married Alma Wilson. The couple had one son, Rollin, who also became a distinguished geologist. Chamberlin went to the University of Michigan for the academic year 1868–69 to strengthen his overall science background and thereafter became very critical of the classical curriculum in colleges. He then went on to teach natural science at the Whitewater, Wisconsin, Normal School, and joined the Beloit faculty in 1873, where he was professor of geology, zoology, and botany.

In 1873, Chamberlin was recruited to work part time with other geologists on a comprehensive geological survey of Wisconsin, the task that marked the beginning of his career in glacial geology. In 1876, due to the reorganization of the survey, Chamberlin was appointed chief geologist and, over the next six years, he supervised the completion of the project. The resulting publication, consisting of four large volumes of the highest academic standards, brought Chamberlin to national attention and led to his appointment as head of the glacial division of the national survey in 1881.

Six years later, the board of regents of the University of Wisconsin in Madison invited Chamberlin to be president. During his tenure, Chamberlin introduced many reforms aimed at strengthening the science curriculum and recruiting outstanding faculty members. He also established the extension program, offering farmers new knowledge that could be helpful to them. He introduced seminars as a core element of teaching and started formal postgraduate study with a Ph.D. program. In 1892, Chamberlin accepted the chair of the geology department at the University of Chicago, a position that he kept for the next 26 years. As a chair, he made the department one of the world's leading institutions in the field and established the Walker Museum.

While at Chicago, Chamberlin worked with astronomer Forest R. Moulton to define the planetesimal hypothesis. Their research was published in *Two Solar Families* (1928). With Rollin Salisbury, he coauthored *Geology* (1904–06), probably the most influential American textbook of geology before World War II. At a time when single, comprehensive introductory textbooks were not common, *Geology* had a profound impact. In 1909 Chamberlin worked for the Rockefeller Foundation, spending five months in China to organize an aid program for the country.

Chamberlin retired in 1918. Although he is best remembered for the planetesimal theory, Chamberlin's interest in glaciation led him to question prevailing notions of a gradually cooling earth, making him an important forerunner of global warming debates. The cycles of glacial formation, growth, and retraction that he identified suggested that the Earth was warming up, rather than cooling down. To find an explanation, Chamberlin investigated climatic change, focusing on changing levels of carbon dioxide in the atmosphere.

As far as methodology was concerned, Chamberlin argued that evidence should never be accepted uncritically. Researchers should always maintain an open mind, testing several hypotheses at once. This is known as the method of multiple working hypotheses, which he pioneered in spite of a certain dogmatism that his conclusions tended to acquire later in his career. Chamberlin was awarded countless honors and prizes during. He was president of the Geological Society of America (1894–95), president of the Wisconsin (1885–86), Chicago (1897–1915), and Illinois (1907) academies of science, president of the American Association for the Advancement of Science (1908–09), member of the National Academy of Sciences (1903), and the first Penrose Medalist of both the Society of Economic Geologists (1924) and Geological Society of America (1927). He was also a member of the American Philosophical Society and the American Academy of Arts and Sciences and received six honorary degrees. Chamberlin died on November 15, 1928, in Chicago.

SEE ALSO: Glaciers, Retreating; Glaciology; Global Warming.

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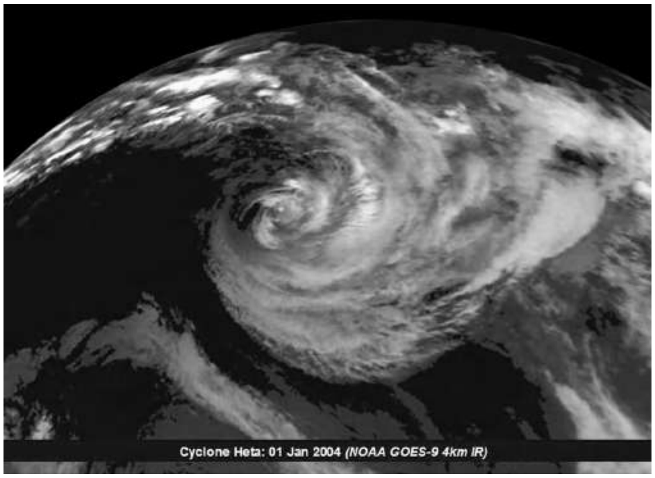
Chaos Theory

NONLINEAR DYNAMICAL SYSTEMS that have sensitive dependence on initial conditions may exhibit chaotic behavior. In other words, if initial conditions are available only with some finite precision, two solutions starting from undistinguishable initial conditions (i.e., whose difference is smaller than the precision) can exhibit completely different future evolutions after time. Thus, the system behavior is unpredictable. Sensitive dependence on initial conditions can occur even in deterministic systems whose solutions are not influenced by any stochastic effects. Chaos theory attempts to find an underlying order in such chaotic behavior

In the early 1900s, H. Poincare noticed that simple nonlinear deterministic systems can behave in a chaotic fashion. While studying the three-body problem in celestial mechanics, he found that the evolution of three planets could be complex and sensitive to their relative initial positions. Other early pioneers in chaotic dynamics from a mathematical viewpoint include G. Birkhoff, M.L. Cartright, J.E. Littlewood, S. Smale, and A.N. Kolmogorov, for a wider range of physical systems. Experimentalists also observed chaotic behaviors in turbulent fluid motion and radio circuits.

Weather is, without a doubt, one of the best examples of chaotic behaviors in nature. Future weather can never be predicted correctly beyond a certain period of time. The first identification of chaotic behavior in atmospheric sciences was made accidentally by E. Lorenz in 1960s. To study the problem of predicting atmospheric convection, he developed a simple deterministic model with 12 variables. Simplified models such as these are quite useful in shedding light on the corresponding complex system. He followed a numerical approach by solving the model on a digital computer. On one occasion, he repeated a numerical experiment using an initial condition that was rounded-off to the first three digits (e.g., 0.506) from the original six digits (e.g., 0.506127), expecting that the difference between the two solutions would remain very small. To his surprise, the new solution stayed close to the original one for about a month of the model simulation, and then suddenly transitioned to a completely different behavior. This discovery has come to be known as the "butterfly effect."

By repeating similar experiments, Lorenz also noticed that transitions happened randomly, irrespective of the size of the perturbations in the initial conditions. To conduct further investigations, Lorenz developed a simpler model, with three variables, able to mimic the chaotic behavior of the 12-variable model, in terms of sensitivity to the dependence on



NASA hurricane animation may help predict storms more accurately. Weather is the best example of a chaotic behavior.

initial conditions. By plotting the solutions, he discovered another astonishing aspect of chaotic behavior: all solutions were attracted to a densely nested curve with a shape of double spirals. Starting from an arbitrary initial condition, a solution eventually reached the double spirals and never left them. It looped around one spiral, occasionally made a transition to the other spiral, then looped around, returning to the first spiral, and so on. The curve clearly moderates the chaotic behaviors of this model and is called the *strange attractor*. Qualitative and quantitative description of chaotic behavior can be made by understanding the properties of the strange attractor.

Since then, advances in scientific computation brought full appreciation to the significant implications of chaotic behaviors in a variety of fields. Many mathematical concepts and techniques have been developed to study such behaviors and make quantitative statements about them. Collectively, they form the chaos theory. Naturally, much of the chaos theory was developed to study and demonstrate the predictability limit.

Fundamental questions in today's atmospheric sciences include the extent of the predictability of weather and climate, as well as the reliability of forecasts made by numerical models. Not only simple but also many realistic models are known to exhibit chaotic behaviors. Chaos theory implies that a single definitive forecast made by such a model will fail because future evolution is unpredictable. This unpredictability is due to the impossibility of obtaining the exact initial condition with arbitrarily high precision, even if the model truthfully describes the evolution of the complex system. Instead, chaos theory suggests the need for "probabilistic forecasts" that express the uncertainty associated with a forecast. For example, the probabilistic forecast of tomorrow's precipitation may be expressed as "95 percent to exceed 0.1 inch," while a definitive forecast may be "0.1 inch."

To represent the uncertainty, and establish a probability distribution associated with a forecast, most leading weather forecast centers use the ensemble forecast approach, in which an ensemble of forecasts is made starting from the initial conditions slightly different from the best possible estimate of the current state of the atmosphere. If all forecasts in the ensemble stay close together, then real future evolution is likely to be close to the mean of the forecasts. In contrast, if the forecasts show a wide spread, then the forecast is considered to have high uncertainty. Uncertainties can be quantified if the ensemble consists of a large number of forecasts. Probabilistic forecasts can be used to study and quantify impact of human activities on future climate change by running the ensemble forecasts of multiple climate models under certain forcing scenarios as described in the Intergovernmental Panel on Climate Change (IPCC) reports.

SEE ALSO: Climate Models; Computer Models; Measurement and Assessment; Simulation and Predictability of Seasonal and Interannual Variations.

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Charney, Jule Gregory (1917–81)

JULE GREGORY CHARNEY was an American meteorologist who contributed to the advance of numerical weather prediction and to increased understanding of the general circulation of the atmosphere by devising a series of increasingly sophisticated mathematical models of the atmosphere. Charney was one of the dominant figures in the field of atmospheric science in the decades following World War II. Jule Gregory Charney was born in San Francisco, California, on January 1, 1917, to Ely Charney and Stella Littman. His parents were Yiddish-speaking Russian Jews who worked in the garment industry and were left-wing militants. The family moved to Los Angeles in 1922.

Charney earned several degrees from the University of California at Los Angeles (UCLA): an A.B. in mathematics in 1938, an M.A. in mathematics in 1940, and a Ph.D. in meteorology in 1946. In that same year, Charney married Elinor Kesting Frye, a student of logic and semantics at UCLA. The couple had two children, Nora and Peter. In 1967, Charney married a second time, to Lois Swirnoff, a painter and color theorist who was a professor at UCLA and Harvard.

While completing his Ph.D., 1942–46, Charney was an instructor in physics and meteorology at UCLA. The entire October 1947 issue of the *Journal of Meteorology* was devoted to the publication of his dissertation, entitled "Dynamics of Long Waves in a Baroclinic Westerly Current." This paper emphasized the influence of long waves in the upper atmosphere on the behavior of the entire atmosphere and provided a simplified method of analyzing perturbations along these waves.

After graduation, Charney worked for a year as a research associate at the University of Chicago. During the academic year 1947–48, he held a National Research Council postgraduate fellowship at the University of Oslo, Norway. While in Oslo, he developed a set of equations for calculating the large-scale motions of planetary-scale waves known as the quasi-geostrophic approximation. Charney's method replaced the horizontal wind by the geostrophic wind as the term representing the vorticity. He did not make this replacement in the term representing the divergence. Thanks to this change, Charney was able to come up with a manageable set of filtered equations calculating large-scale atmospheric and oceanic flows.

Two years after his graduation, Charney joined the Institute for Advanced Study in Princeton, New Jersey. Charney served as director of theoretical meteorology in a project to develop a computer program. With his team, he constructed a successful mathematical model of the atmosphere and showed that numerical weather prediction could be done using the Electronic Numerical Integrator And Computer (ENIAC), which took 24 hours to generate a forecast, and von Neumann's stored-program computer to create a forecast in five minutes. In 1954, Charney contributed to establishing a numerical weather prediction unit within the U.S. Weather Bureau. He is considered to have pioneered the use of computers in forecasting.

In 1956, the Massachusetts Institute of Technology (MIT) hired Charney as professor of meteorology and 10 years later he was made Alfred P. Sloan professor there. His research dealt with the dynamics of atmospheres and oceans. From 1963 to 1966, he chaired the National Research Council's Panel on International Meteorological Cooperation.

From 1968 to 1971, he coordinated the U.S. Committee for the Global Atmospheric Research Program (GARP). This international project, which lasted for an entire decade, aimed to measure the global circulation of the atmosphere, to represent its behavior, and to develop better predictions of its future state.

Charney's role was fundamental in setting the global agenda and vision of GARP. The scientist repeatedly stressed that researchers should view the atmosphere as a single, global system. Charney was always a convinced supporter of international cooperation in meteorology and constantly pointed out that the lack of global observations prevented examination of the global side of the discipline.

During his long career, Charney received many awards and honors. He was a fellow of the American Academy of Arts and Sciences, the American Geophysical Union, and the American Meteorological Society. He was a member of the U.S. National Academy of Sciences and a foreign member of the Norwegian and Royal Swedish Academies of Science.

The most important awards that Charney garnered were the Meisinger Award (1949), the Rossby Medal (1964) (both by the American Meteorological Society), the Losey Award of the Institute of Aeronautical Sciences (1957), the Symons Medal of the Royal Meteorological Society (1961), the Hodgkins Medal of the Smithsonian Institution (1968), and the International Meteorological Organization prize (1971). He was extremely popular as a visiting professor and guest lecturer. The University of Chicago awarded him an honorary D.Sc. in 1970.

Charney's career was complemented by his political commitment. After the invasion of Cambodia and the Kent State shootings in May 1970, he conceived his most ambitious political project, setting up the Universities National Antiwar Fund, raising money from academics to support anti-war candidates in the upcoming elections. Charney died from cancer in Boston, Massachusetts, on June 16, 1981. The American Meteorological Society honors Charney's memory by presenting an award named after him to reward individuals for "highly significant research or development achievement in the atmospheric or hydrologic sciences."

SEE ALSO: Climate Models; Climatic Data, Atmospheric Observations; Massachusetts Institute of Technology.

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Chemistry

CHEMISTRY IS THE academic discipline concerned with the study of the composition, structure, properties, and speed of change of matter. The main building blocks of matter of interest to the chemist are elements, atoms, and molecules. A chemical element is a pure substance comprised only of one type of atom. The atom is the smallest unit of an element and is comprised of subatomic particles called protons (positively charged), neutrons (no charge), and electrons (negatively charged). The neutrons and protons reside in the central core of the atoms called the nucleus, whereas the electrons are smaller and free moving. The number of electrons in a given atom balances the protons, and this number is characteristic of any atom of a given element.

Dmitri Mendeleev, a Russian chemist, produced the first periodic table in 1869. In this table, elements are arranged in increasing order of the number of protons and are placed in columns based on common properties. The first element in the periodic table is hydrogen, which is comprised of only one proton and one electron. Other elements of interest include carbon, which has atoms containing 6 protons, oxygen with 8, and iron with 26. Although the number of protons and electrons is characteristic of an atom of a given element, the number of neutrons may vary. Two atoms of the same element, with different numbers of neutrons, are called isotopes. Carbon, for example, has three naturally occurring isotopes with 6, 7 or 8 neutrons; these are named carbon-12 (^{12}C), carbon-13 (^{13}C) and carbon-14 (^{14}C), as both the number of neutrons and protons is taken into account in the nomenclature. Of the three isotopes, only ^{12}C is stable.

Atoms are described as physically stable if the atom itself does not decay into its constituent parts or to smaller atoms. The vast majority of the elements toward the top of the periodic table are stable, whereas those with a greater number of protons (more than 85) toward the bottom of the table are not. The most stable element is iron. In contrast to their physical stability, the vast majority of elements are chemically reactive. The term *chemical reactivity* describes the reaction between atoms that combine to form molecules and compounds. An atom is unreactive to other atoms/molecules (inert) if it has a closed outer shell of electrons. The number of electrons required to do this varies as a function of the size of the atom (as predicted by quantum theory). The periodic table reflects this by placing the stable elements on the right-hand side, referred to as the inert or nobel gases. All other elements will undergo chemical reaction in which electrons from each atom are shared in order to achieve the same number of electrons as a nobel gas.

Chemistry is conventionally divided into three subdisciplines: organic, inorganic, and physical. Organic chemistry studies the reactions of molecules that have a carbon and hydrogen skeleton, with additional atoms of oxygen, nitrogen, phosphorous, and sulfur. Organic chemistry is so named, as these are the elements that make up life; most of its applications are the pharmaceutical and petrochemical industries. Inorganic chemistry deals with the reactions of molecules without a carbon and hydrogen-based skeleton, and has a wide range of applications, from catalysts to nuclear reactors. Physical chemistry is the study of the underlying structure of matter and the mechanisms and speed of chemical changes that underpin the other subdisciplines. Physical chemistry is also concerned with the interaction of radiation and matter. Other important subdivisions include biochemistry (study of organic molecules in cells), analytical chemistry (study of techniques to separate and quantify chemicals), atmospheric chemistry, ocean chemistry, and biogeochemistry.

GLOBAL WARMING AND CLIMATE CHANGE

Chemistry is relevant to global warming and climate change in three important ways. Climate change is governed by chemical phenomena; the underlying chemistry of global warming centers on the phenomena commonly described as the greenhouse effect. In short, this term refers to the theory that the temperature at the surface of the Earth is maintained higher than would be calculated from a simple radiative budget due to the adsorption of longer-wave radiation in the atmosphere.

The main focus of climate change is on the rising atmospheric concentration of CO_2. This gas was first isolated by the burning of charcoal in an enclosed vessel and the observation that the resulting ashes were less dense than the original charcoal, whereas the resulting air was denser. Starting in 1958, Charles David Keeling was the first to begin measuring CO_2 in the baseline (non-polluted) air at the top of Mauna Loa, Hawaii. The basis of all techniques used to measure CO_2 is infrared (IR) spectroscopy.

IR spectroscopy is the technique used to probe the IR absorption of molecules from which information about their concentration and vibrational/rotational energy levels can be obtained. In a general IR spectroscopy experiment, a beam of IR light is split into two. One half of the beam passes directly through to a detector; the other half passes through a gas sample (such as CO_2). Scanning or Fourier transform techniques can be used to obtain information at a range of wavelengths. The concentration of the analyte is related to the absorption of light by the Beer-Lambert law:

$$A = \alpha \cdot c \cdot l,$$
$$\text{Where } A = \log (I/I_0),$$
$$\alpha = (4 \cdot \pi \cdot k) / \lambda,$$

and c is the concentration of the compound, l is equal to the path length of light through the sample, I is the intensity of radiation having passed through the sample, I_0 is the intensity of radiation in the reference beam, k is a constant for a given substance called the extinction coefficient, and λ is the wavelength. Ultraviolet spectroscopy works on the same principle as IR spectroscopy, but with UV light, which excites electronic, not vibrational energy levels. UV spectroscopy is useful for quantification of compounds that do not have an IR signal, such as ozone.

Many of the elements utilized by life have more than one stable isotope. Because isotopes decay at a fixed rate and some physical, chemical, or biological processes favor one isotope over the other, this often offers the ability to use these isotopes to give paleontological information. Two of the most important techniques from a climate change perspective are ^{14}C dating and ^{18}O temperature records.

The ratio of $^{12}CO_2$ to $^{14}CO_2$ in the air is maintained at a constant ratio, with $^{14}CO_2$ making up less than one part per million of the total. However, when the carbon from the CO_2 is trapped away from the atmosphere, either physically in ice or chemically in biology, the ^{14}C decays at a fixed rate (the half-life at around 6,000 years). Thus, for any sample of carbon that has been locked away from the atmosphere, the time it has been locked away can be calculated based on the amount of remaining ^{14}C. The ratio of ^{18}O to ^{16}O in the atmosphere varies as a function of temperature. When the O_2 is fixed into ice or biological systems, the ratio is determined only by the decay of ^{18}O. Thus, if the time since the oxygen was fixed is known, then the temperature at the time the oxygen was fixed can be calculated.

When air is trapped in ice cores, these two techniques can be combined to determine how long ago the air was trapped, and what the local temperature was when the air was trapped. When the amount of CO_2 in the air is quantified by IR and the dust in the air is collected a record of temperature, CO_2, and dust going back hundreds of thousands of years can be constructed. This record has been central to the global warming debate.

When faced with the task of measuring atmospheric components such as chlorofluorocarbons (CFCs), which have very low atmospheric mixing ratios, one approach is to first attempt to separate the air into its constituent components. Russian scientist Mikhail Tswett invented this technique in the early 20th century. Tswett ground up plant leaves in petroleum ether, and passed the resulting liquid though a glass tube filled with powdered chalk. Tswett observed that as the liquid passed down the tube, a range of colored bands were formed; thus demonstrating that leaves contain a range of different pigments. More important, however, he had invented a new separation technique, this technique he named *chromatography* (meaning literally "color writing").

In a general chromatography experiment, analytes in a mobile phase are passed though a stationary phase and are separated depending on their affinity for the stationary phase. A century after its discovery, there are now a great number of different chromatographic techniques allowing the separation of a wide variety of analytes. The technique of most relevance is gas chromatography, which separates a mixture of gases by passing them through a long column. The column is packed or lined with material that traps different components with a greater or lesser affinity; this ensures that each component arrives to the end of the column at a different time. Once separated, the analytes are detected by a number of techniques. The most popular one for CFCs is called Energy Citations Database (ECD), which measures the dip in current across a small gap that occurs when the CFC molecules pass.

Svante Arrhenius, considered the father of climate change science, was also a founder of the field of physical chemistry.

THE GREENHOUSE EFFECT AND GLOBAL WARMING

The greenhouse effect was discovered by Joseph Fourier in 1824, and was first investigated quantitatively by Svante Arrhenius in 1896. Radiation from the Sun, when measured at the top of the Earth's atmosphere, can be seen to cover a wide spectrum. This spectrum is consistent with the blackbody radiation associated with the temperature of the Sun's surface (5250 K). The spectrum observed from the Earth's surface is consistent with this once the adsorption of atmospheric species has been accounted for. The peak intensity of the solar radiation is around 500 nm., or in the UV-Visible region.

The Earth absorbs this radiation and reradiates at a lower wavelength, again consistent with a blackbody radiation at its temperature. The peak radiation emitted by the Earth is around 1,000 nm., which corresponds to infrared. Different atmospheric gases absorb infrared radiation, and are collectively referred to as greenhouse gases. This absorption traps the outgoing radiation, maintaining the planet at habitable temperatures.

Greenhouse gases absorb IR radiation at characteristic frequencies that correspond to the normal modes of vibration of the molecule. Greenhouse gases of notable importance include water (H_2O), which causes about 36–70 percent of the greenhouse effect (not including clouds); CO_2, which causes 9–26 percent; methane (CH_4), which causes 4–9 percent; and ozone, which causes 3–7 percent, according to Kiehl et al. These gases all absorb radiation, as they have a vibrational mode that results in a change in dipole of the molecule. These vibrational modes are normally investigated using IR spectroscopy. The IR spectrum of CO_2 reveals that it absorbs at two characteristic frequencies; the Bending mode at 14 μm, and the Asymmetric Stretch at four μm.

Greenhouse gases are rated with a greenhouse potential, which ranks their ability to absorb the Earth's radiation relative to CO_2 and gives some idea of the relative contributions of each component. Although water is a powerful greenhouse gas, the contribution of additional water is hard to quantify, as its concentration varies greatly throughout the atmosphere. In many areas of the globe, the water vapor concentration is such that all IR radiation of the relevant wavelength is absorbed. This highlights the importance of CO_2 as a greenhouse gas, which absorbs wavelengths that water does not.

The amount of time a chemical persists in the atmosphere clearly has great importance for many compounds such as CO_2, whereas the fastest loss of CO_2 is to the oceans, the main chemical sink in the atmosphere is oxidation. Oxidants are present in the atmosphere as a result of the evolution of photosynthetic organisms around 2–3 billion years ago. The primary oxidants present include oxygen (O_2), ozone (O_3), and the hydoxy radical (OH).

Global warming is proposed to occur because of growing atmospheric concentration of the greenhouse gases; these can be increased by a variety of human processes. The concentration of CO_2 in the atmosphere has risen from less than 250 ppm (parts per million) to over 380 ppm since pre-industrial times. This is as a consequence of the burning of fossil fuels such as coal, oil, and gas. Thus carbon that was stored in the ground is released in the form of CO_2.

An aerosol is a colloidal suspension of either liquid or solid particles in the gas phase. Aerosols are created in the atmosphere by the action of the winds suspending dust, sea salt, and organic matter, and from biogenic sources such as plant pollen, as well as from anthropogenic sources such as fossil fuel burning. Aerosols are of interest, as one of the key areas of uncertainty in climate change predictions involves the role of aerosols.

GREEN CHEMISTRY

There are many ways in which chemistry has helped to reduce CO_2 emissions and helped adaptation to a changing climate. Iron fertilization experiments aim to reduce the concentration of atmospheric CO_2 by promoting the growth of phytoplankton in oligotrophic regions of the ocean, where primary production is supposedly limited by the iron supply, such as in the Southern Ocean. Some paleontology researchers have shown a link between large quantities of iron in the air and the onset of ice ages. On first discovering of this, according to J.H. Martin and S.E. Fitzwater, the lead oceanographer in the project commented on the strong link between iron and planetary temperature saying, "Give me a half a tanker of iron and I'll give you the next ice age."

Paul Crutzen, a British atmospheric chemist and head of the group who initially discovered the stratospheric ozone hole, has suggested a radical proposal to mitigate global warming. Crutzen proposes to control the climate with the use of sulphate aerosol injected directly into the stratosphere. These aerosols would reflect sunlight, thereby cooling the planet significantly, but he predicts the effect will be short-lived (about one week). Crutzen suggests that regular planeloads of sulphate dispersed in the stratosphere would be a safe and cost effective way regulate the Earth's climate.

Photovoltaic describes the use of semiconductors to convert the sun's radiation into electrical energy. The cost of producing photovoltaic energy is high, as the chemicals need to be extremely pure. However, the technology has the potential to provide large amounts of energy with low CO_2 emissions. Green chemistry is an emerging discipline that looks at ways to produce chemical products with reduced impact on the environment. Its importance was recognized in 2005, when the Nobel Prize for chemistry was awarded to Yves Chauvin, Robert H. Grubbs, and Richard R. Schrock for their work in this field.

SEE ALSO: Aerosols; Arrhenius, Svante August; Biogeochemical Feedbacks; Biology; Carbon Cycle.

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Chile

LOCATED ALONG THE Pacific seaboard of South America, the Republic of Chile has a land area of 292,183 sq. mi. (756,950 sq. km.), with a population of 16,598,074 (2007 est.), and a population density of 57 people per sq. mi. (22 people per sq. km.). With 5 percent of the land arable, 21 percent of Chile is forested, with 1.15 million hectares of plantation forests, most of which is pine. In spite of a heavy reliance on mining, Chile has a relatively low level of carbon dioxide emissions—2.7 metric tons per person in 1990, rising to 4.1 metric tons in 1999, and then falling to 3.7 metric tons in 2003. Most of the carbon dioxide emissions come from liquid fuels (56 percent). Twenty-eight percent of emissions come from transportation, largely through heavy use of cars. The public transport system is very good in some parts of the country, such as in the capital, Santiago, and the area around it including Valparaiso, but many people rely on the use of cars, leading to considerable urban congestion in Santiago.

Some 30 percent of Chile's carbon dioxide emissions come from the use of solid fuels, largely made up from heavy use of coal for electricity generation, with 51.2 percent of electricity coming from fossil fuels, and 46.6 percent from hydropower. Chile has operated hydroelectric power plants since 1897, when the Chivilingo Hydroelectric Plant was built, only the second to operate in South America. Since then, the Chilean energy company Empresa Nacional de Electricidad S.A. (ENDESA) has built a number of other hydroelectric plants such as the Colbún Hydroelectric Plant, located in the Maule region; the Pangue and Penuenche Hydroelectric Plants, situated on the upper Bío-Bío River; the Pullinque Hydroelectric Plant using water from the Pullinque Lake; and the Ralco Hydroelectric Plant.

Chile faces serious problems resulting from climate change and global warming. The El Niño effect has caused some damage to the Chilean wine industry, with less rainfall likely to lead to a decline in grape yields. There has been a steady increase in the annual average temperature since 1939, with the rate of warming doubling in the last 40 years, and more than tripling in the last 25 years; this has also been noticed in the Andes Mountains and in other parts of the country. This has had a major effect on the southern parts of Chile, where there has been glacial melting; the rising water levels in Chilean Patagonia are expected to flood some of the small islands off the country's southern coast.

The ozone hole also is expected to lead to a rise in the prevalence of skin cancer over the next decades. Global warming and climate change has caused much damage to Chilean Antarctica, which the Chilean government, unlike the other nations that have territory in Antarctica, regards as an integral part of the country.

The Chilean government of Patricio Aylwin Azócar ratified the Vienna Convention soon after he became president in 1992, and Chile took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May of the same year. The government of Azócar's successor, Eduardo Frei, signed the Kyoto Protocol to the UN Framework Convention on Climate Change on June 17, 1998; it was ratified on August 26, 2002, and took effect on February 16, 2005.

SEE ALSO: El Niño and La Niña; Floods; Glaciers, Retreating; Global Warming.

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China

THE RISE OF the Tibetan Plateau in western China caused a major worldwide climate shift. As the highest region on Earth, this area became the world's third major weather-maker, after the polar regions, and gave rise to the South Asia Monsoon about 8 million years ago. The growth of the plateau also set the stage for the ice ages that began approximately 2.5 million years ago. Glacial deposits, lake strand-lines, paleo-biologic studies, and ice core records now available from the Tibetan Plateau are filling a critical gap in comparing the Asian mid-latitude climate record with the more extensive records from other continents and the polar regions.

During historic times, China has undergone significant climate shifts, some natural, others most likely anthropogenic. Although desertification has been ongoing in China for perhaps 3,000 years, at least some of this has been attributed to human activities. The recent rapid retreat of China's glaciers appears to be linked to global warming. Although the Chinese government places its highest priority on economic growth, it also appears to be taking anthropogenic climate change very seriously.

IMPACT OF THE TIBETAN PLATEAU

Rapid uplift during the late Cenozoic has shaped the landscape of the Tibetan Plateau and has drastically changed China's climate. Regional differences in geomorphology and local precipitation can result in different timing of glacial advances around the world. Currently, the Pacific Ocean monsoon dominates east China, while both the South Asia Monsoon and the mid-latitude Westerlies control the weather of the Himalaya and western China. The South Asia Monsoon dominates the southern part of Tibet, while the mid-latitude Westerlies dominate the northern part. These different climatic regimes have had important influences on the Quaternary glaciations.

The rise of the Himalayan Mountains and plateaus significantly increased worldwide erosion rates. Silicate weathering provides one of the major natural processes that remove CO_2 from the atmosphere, in the process forming carbonates. Hence, the rise of the Himalaya and Tibetan Plateau could have contributed to the onset of Pleistocene glaciation by depleting atmospheric CO_2, the most abundant greenhouse gas.

The Tibetan Plateau contains the largest ice mass on the Earth outside the polar regions. The Tibetan Plateau holds almost 37,000 catalogued glaciers, with a combined area of nearly 50,000 km^2. These glaciers owe their existence to the rise of the Tibetan Plateau. They extend north into the arid and desert regions, feeding the Yellow and Yangtze rivers, which provide the main water resource for arid central Asia, and northeastern China. They also extend south into the warmer, wetter forests and concentrate around the Brahmaputra, Mekong, and Salween rivers, which provide needed water to both local residents and much of southeast Asia.

Coastal areas of China could suffer from sea-level rise due to melting of polar ice caps. On the Tibetan Plateau, however, the immediate response to the accelerating glacial retreat could be villages displaced as a consequence of lake expansion and disasters related to glacial lake outbursts and other floods. Severe water shortages may follow once the reservoir of glacial ice is depleted.

PALEOCLIMATE RECORDS

Until recently, researchers have found it difficult to compare the relative ages of China's Quaternary glaciations with each other, let alone with global ice ages. However, absolute numerical dating now allows China's glaciations to be placed into the pre-existing worldwide framework. Based on these new dating results, Yi Chaolu and others have determined that most Asian Quaternary glaciations in the last 100,000 years were synchronous with global glacial events. One glacial advance between 44,000 and 54,000 years ago in southeastern Tibet was not synchronous with global cooling, and might have been caused by greater precipitation during a locally colder period. Chinese researchers have identified more Quaternary glacial periods before the Wisconsin Glaciation than have been identified in other regions of the world. The uplift of Tibet during the Cenozoic could be responsible for these differences.

As one of the thickest ice caps in central Asia, the Guliya Ice Cap, on the crest of the Kun Lun Mountains, provides valuable information for this critical region about the past climatic and environmental changes. Yang Meixue and others report that the Guliya ice core demonstrates periodic oscillations of the temperature and precipitation over the past 1,700 years. The results show various oscillations in the ice core records, with multiple timescales (200, 150, 70, 40, and 20 years). Their amplitude, phase, and frequency vary with time. Temperatures recorded since 1700 C.E. show that precipitation correlates well with temperature in this region.

Yao Tandong and others used data from an ice core from the Puruogangri Icefield on the central Tibetan Plateau to construct a temperature history for the region based on the temperature proxy, $\delta^{18}O$. Reconstructing temperatures back to 1000 C.E. shows changes on the plateau generally similar to those in other parts of the Northern Hemisphere on a multidecadal timescale. These data indicate that the 20th century warming in China was abrupt and exceptional, and that the 20th century was warmer than any time during the past 1,000 years.

Unlike much of the Northern Hemisphere, temperatures throughout the Tibetan Plateau showed no widespread cooling trend from 1000 C.E. to the late 19th century. They show, instead, slightly increasing temperatures. For the northern portion of the plateau, however, temperatures exhibited a very slight cooling trend from 1000 C.E. to the late 19th century. This reconstruction confirms the existence of the Medieval Warm Period and the Little Ice Age in China. However, the Little Ice Age was not as relatively cold as in other regions of the Northern Hemisphere.

The impressive Tibetan Plateau contains the largest ice mass on Earth outside the polar regions, with almost 37,000 catalogued glaciers that have a combined area of nearly 50,000 km^2.

RECENT CLIMATE CHANGE

China is experiencing a well-documented, widespread warming. The glaciers on the Tibetan Plateau are retreating rapidly, and permafrost is melting. This rate has accelerated in the early 21st century under the impact of an intensified South Asia Monsoon, which is likely a consequence of global warming.

Yao Tandong and others trace the glacial retreat in China to the termination of the Little Ice Age, around the beginning of the 20th century. Since then, the glacial retreat can be divided into several stages. The first half of the 20th century was characterized by shifting from glacial advances to retreats. Between the 1950s and the 1960s, the glaciers began extensive retreat, with over half of the studied glaciers retreating, about 30 percent advancing, and the others stable. In a short period from the late 1960s to the late 1970s, advancing glaciers increased again and the percentage of retreating glaciers decreased to less than half. Starting in the 1980s, glacier retreat intensified again, with 90 percent of the studied glaciers retreating. Since the 1990s, glacial retreat has been accelerating, with 95 percent of the studied glaciers now retreating.

The magnitude of glacial retreat is less on the northern Tibetan Plateau, and more at the margins; the greatest retreats are on the southeast plateau. The rate of glacial retreat reached 213 ft. (65 m.) per year on the southeast plateau, where the South Asia Monsoon prevails. The smallest glacial retreat appears on the central plateau, where a continental climate dominates.

Monsoons and the Westerlies affect the dominant patterns of glacial retreat on the Tibetan Plateau. The monsoon water vapor flows through the lower reaches of the Brahmaputra River valley toward the interior of the plateau, which results in the development of the largest glaciers. With global warming, the Southeast Asia Monsoon is intensifying, which causes more precipitation on the southeastern plateau. The increased precipitation there comes mostly as rainfall, as opposed to the situation in the mountains influenced by the Westerlies, where increased precipitation on high elevation glaciers falls mostly as snow. Trends showed strong increases for spring and winter precipitation from 1961 to 2001.

Over the last decade, many lakes in highly glaciated regions have expanded. Yao Tandong and others assessed size changes of lakes greater than 3.7 sq. mi. (10 sq. km.) and discovered that over 70 percent of the lakes evaluated expanded by at least 12 percent, since the 1990s. Glaciological observations in the region suggest that intensified glacial melting in response to the current warming is the principal driver, not precipitation patterns over the plateau.

Lake expansion will most likely modify the hydrologic cycle over the Tibetan Plateau. Grassland destruction and resultant reduction of livestock grazing is now occurring near Lhasa. (Higher CO_2 concentrations also favor woody plants over grasslands.) Furthermore, the potential for glacial lake outburst flooding is also increasing, which could cause serious damage in south Asian countries such as India, Nepal, and Bhutan.

The southern limits of China's permafrost appear to be moving northward at over .93 mi. (1.5 km.) per year. The area of permafrost is expected to decline by 30–50 percent during this century. Permafrost collapse tends to cause slumping of the soil surface and flooding, followed by a complete change in vegetation, soil structure, and many other important aspects of these ecosystems. Melting permafrost causes concern, because frozen ground stores huge quantities of carbon as methane and CO_2.

Recent studies show that initial flooding caused by melting boosts plant productivity, sequestering more carbon from the atmosphere in plant biomass. Hence, permafrost degradation may initially increase soil carbon sequestration, rather than release large amounts of carbon into the atmosphere, as originally predicted. But over time, the greenhouse effect of high methane emissions will outweigh the reduction of carbon in the atmosphere.

Chinese scientists conclude that human activities have accelerated the desertification process and have driven the north China deserts southward by approximately 186 mi. (300 km.) over the past 3,000 years. A growing population, intensive agricultural activities, excessive tree-cutting, and frequent warfare have damaged the natural vegetation, caused soil erosion, and intensified desertification. Reforestation projects and greater rainfall from changes in the East Asia Monsoon patterns currently affecting the semi-arid to arid areas in this region are likely to help prevent and reverse desertification. However, water shortages will persist, due to lack of glacier storage and the current heavy mining of ground water.

Most recently, both the International Energy Agency and the Netherlands Assessment Agency say that China became the world's leading source of greenhouse gas emissions in 2007. According to the World Bank, Chinese industry uses 4–10 times more water per unit of production than the average in industrialized nations. China ratified the Kyoto Protocol in 2002, but as a developing nation was not held to specific emissions targets. China's emissions of sulfur dioxide and particulates that act contrary to greenhouse gases (decreasing radiative heating in the lower atmosphere) are increasing even faster than China's economic growth. Their control may exacerbate the warming.

The *China Daily* recently reported that over 400 sq. mi. (644 sq. km.) of land in southern China would be flooded by 2050 as sea levels rise due to global warming. The Pearl River Delta area, a leading manufacturing hub, will be hard hit by climate change in the coming decades. The cities of Guangzhou, Zhuhai, and Foshan are expected to be the worst hit as sea levels rise by at least 11.8 in. (30 cm.) by 2050. Climate change will thus likely depress economic development of this province, which is currently one of the biggest consumers of energy and producers of greenhouse gases.

CLIMATE CHANGE POLICY

Although China's leaders recognize that they must deal with emissions of climate and health-related pollutants, economic growth remains the country's highest priority. The state is a partner in most energy, and many industrial, enterprises, as well as the regulator of environmental issues. As a result, environmental controls are weak, and enforcement of standards and laws lacks uniformity. China's central Energy Bureau has only 100 full-time staff (compared to the U.S. Department of Energy's 110,000). Another result of the economic system has been to allow low-efficiency energy use with little, if any, economic penalty.

China depends heavily (about 70 percent) on coal for its energy. With energy demands rising, more coal production is planned at least until 2020. China produces about 35 percent of the world's steel, 50 percent of the world's cement and flat glass, and about 33 percent of the world's aluminum—all very energy-intensive industries. In 2007, China was the second largest producer of cars (passing Japan), next to the United States. On average, China uses 20 percent more energy per ton of steel and 45 percent more per unit of cement than the international averages. Because of the international nature of their market, China's leaders argue that pollution originating from these global industries should not be attributed strictly to China, but that end users are partners in degrading the environment.

The Chinese leadership has issued numerous statements recognizing the need for a change in course. Recent actions include the passage of the Renewable Energy Law (endorsing expanded use of renewables), the phasing out of export subsides for polluting industries, and the closing of illegal coal mines and some heavily polluting factories. Targets for energy efficiency have been established, but have so far gone unmet. The government has been unwilling to use significant financial tools to implement climate-related goals. The government controls the rates for commodities such as electricity, fuel oil, gasoline, and water, which all remain relatively inexpensive. Officials have rejected proposals to introduce surcharges on electricity and coal to reflect the true cost to the environment. China has also declined to institute other tax policies or market-based incentives or to accept mandatory limits on its CO_2 emissions.

The per capita use of energy in China still falls far below that of most of the industrialized world; only about 15 percent of that in the United States. As citizens of China achieve the level of affluence of the industrialized world, they will invariably desire more amenities. Private cars, for instance, are increasingly common. To achieve parity in standard of living without greatly increasing their energy use and greenhouse gas emissions will be a daunting challenge.

SEE ALSO: Coal; Developing Countries; Glaciers, Retreating; Monsoons; Sea Level, Rising.

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Clean Air Act, U.S.

THE U.S. CLEAN Air Act (CAA) was passed by the U.S. Congress in 1963 and strengthened with amendments passed in 1970, 1977, and 1990. The U.S. Environmental Protection Agency (EPA) is responsible for implementation and regulation of the CAA, although much of the work falls to state and local governments. EPA regulates many pollutants (such as particulate matter) that play an important role in the Earth's radiation balance, but CAA has not been used to regulate greenhouse gases (GHGs), the pollutants most responsible for global warming. A 2007 U.S. Supreme Court decision ruled that GHGs fall within the jurisdiction of the EPA and the CAA, forcing the EPA to re-examine its ruling on this matter.

The first U.S. federal legislation dealing with air pollution was the Air Pollution Control Act of 1955, which recognized air pollution as a national hazard and encouraged research on the issue. In 1963, the original version of the CAA was passed, which called for the study of air quality issues and set emissions standards for stationary sources. The 1970 CAA was a major overhaul of the original version, making it a comprehensive federal law regulating stationary and mobile sources of air pollution.

The 1970 amendments further established a federal regulatory roll that had previously been lacking. Along with these amendments, Congress created the EPA in 1970 and charged it with carrying out the CAA. The EPA set National Ambient Air Quality Standards for six "criteria" pollutants, and set the target year at 1975 for locations across the United States to meet these standards. Many parts of the country did not meet this deadline, however, and the CAA amendments of 1977 were passed mainly to set new goals and deadlines.

A larger revision occurred with the CAA amendments of 1990. Most significantly, a new market-based cap-and-trade system was implemented as an approach for meeting air quality goals. The 1990 amendments included new standards for hazardous air pollutants and new requirements for EPA regulation and reporting. The 1990 amendments also included provisions to deal with the pressing air quality issues of the time, such as stronger regulation of ground-level ozone, particulate matter, and carbon monoxide; provisions to protect the stratospheric ozone layer; and measures to reduce the pollutants contributing to acid rain. Despite existing knowledge of global warming, however, the amendments did not include any measures to deal with GHGs or climate change.

GHGs, such as carbon dioxide (CO_2), have not been included in either of the groups that the EPA regulates, which are comprised of the six "criteria" pollutants and a group of hazardous air pollutants. In 1999, a group of private organizations petitioned the EPA to begin regulating four GHGs, including CO_2. The EPA denied the petition by responding that CO_2 is not a pollutant under the CAA, that the EPA did not have the authority to regulate against climate change, and that even if it did, it would choose not to regulate due to uncertainty in establishing a causal link between global warming and GHGs. Led by Massachusetts, 12 states, four local governments, and 13 private organizations then filed suit against the EPA (joined by 10 states and six trade associations), challenging that decision.

In the case's Supreme Court hearing, the judges did not rule directly on the issue of global warming. Rather, they had to decide if the states had legal standing to sue; that is, if they had demonstrated there was imminent harm and that regulation would have a significant impact on reducing that harm. The majority of the court agreed that there was a well-recognized threat of harm from climate change, particularly the threat of sea-level rise to Massachusetts's coasts, and that the EPA's refusal to regulate was contributing to the threat of injury. In addition, the court rejected the EPA's argument that CO_2 was not an air pollutant under the definitions of the CAA. Although the EPA now has the authority to regulate CO_2, the agency must still decide if and how GHGs will actually be regulated.

SEE ALSO: Environmental Protection Agency (EPA); Greenhouse Gases; Policy, U.S.; Pollution, Air; Regulation.

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Clean Development Mechanism

THE KYOTO PROTOCOL establishes three innovative mechanisms known as joint implementation, the clean development mechanism (CDM), and emissions trading to reduce greenhouse gas emissions. These are designed to help Annex I Parties cut the cost of meeting their emissions targets by taking advantage of opportunities to reduce emissions (or increase greenhouse gas removals) that cost less in other countries.

The CDM was established under Article 12 of the Kyoto Protocol to achieve two goals: to promote sustainable development in the developing nations, and to allow developed (industrialized) nations to earn emission credits by investing in emission-reducing projects in developing nations. To get credits under this mechanism, the project proponent has to prove that the greenhouse gas emission reductions are real, measurable, and that these reductions are in addition to what would have occurred in the absence of the project. These credits can then be used by the nations to meet their targets under the Kyoto Protocol. However, there is a limit on how many an Annex I party can use toward their target (it is restricted up to one percent of the party's emissions in its base year, for each of the five years of the commitment period).

Current modalities of the CDM include activities that focus on greenhouse gas reductions through several activities, such as afforestation and reforestation (often known as sinks), solar electrification, recovery of energy (biogas) from waste, installation of more energy-efficient boilers, and introduction of cleaner transportation methods. The countries are expected to refrain from building nuclear facilities to generate credits for CDM. It is generally believed that the CDM will generate investment in developing nations and promote the transfer of environmentally friendly or cleaner technologies to developing nations. This would be in addition to the financial and technology transfer commitments under the convention and Kyoto Protocol.

A number of domestic and international governance structures have been set up to oversee the CDM projects. Three key institutions validate the CDM projects: Designated National Authorities (DNAs are usually housed in some government agency or ministry, but in some cases can be outsourced to a private agency), Designated Operational Entities (usually private sector entities, so far about 12 such companies have been accredited), and the CDM Executive Board (EB) that operates under a Member of the Party (MOP) and consists of 10 members and 10 alternates of the EB drawn from all the constituencies of the parties. As of January 2006, about 68 projects were registered with the CDM EB, and, if implemented, could reduce up to 30 million tons of greenhouse gas emissions on an annual basis.

The project cycle of the CDM as described by the United Nations Framework Convention on Climate Change consists of six phases: project activity design, proposal of a new baseline and/or monitoring methodology, use of an approved methodology, validation of the CDM project activity, registration of the CDM project activity, and certification/verification of the CDM project activity. Under the project activity design phase, project participants (or the parties) submit the proposed CDM project activity information using the project design document developed by the EB.

The DNA is the first institution to review a project design document. Assuming everything is in order, the DNA will write a letter of approval saying that all participants are voluntary and that the sustainable development criteria have been met. The next phase in the cycle involves submission of the new baseline methodology (in addition to the description of the project with a list of participants) to the EB for review before the project activity can be registered.

If the project is not using a pre-approved methodology in the project activity, the next phase involves submitting the details of the methodology to the EB for review and approval of the methodology/technology. If the project is using the already approved methodology, the next phase involves validation of the CDM project activity. Under the validation phase, an independent evaluation of the project activity is carried out by a designated operational entity against the requirements of the CDM as defined under the protocol.

To validate a project, the designated operational entity will review the project design document (PDD) to determine if the project's methodology is in line with approved methodologies, that the claimed emissions reductions and baseline scenarios are accurate, and that the project is "additional." In making its determination, the designated operational entity will also post the PDD on the internet for a 30-day public comment period. After validation, the project is registered, which means that EB has formally accepted the project, a prerequisite for the verification, certification, and issuance of credits related to the project activity.

There is also a final 30-day public comment period while the project is at the EB/CDM. Verification involves periodic review by the designated operational entity of the monitored reductions in anthropogenic emissions of greenhouse gases by sources that have occurred due to the registered CDM project activity. Certification is the written assurance provided by the designated operational entity that the registered CDM project activity has achieved the reductions in anthropogenic emissions of greenhouse gases by sources as verified. After the full cycle has been completed, the credits are granted to the parties involved. Because this is a long process, many parties/nations are discouraged. Emphasis by the EB on the additional reductions due to the CDM project activity, high costs associated with the approval process, and administrative delays hinder the development of many small-scale, community-based CDM projects.

Although this mechanism provides for the transfer of cleaner technologies to developing countries and gives credits to developed countries, there are a few problems. One of the most controversial aspects of Article 12 is that it requires projects to show "reductions in emissions that are additional to any that would occur in the absence of the certified project activity." This requirement has become known as "additionality" and is intended to ensure there is a net emissions reduction. This is an important clause, but it is not always easy to establish.

Another controversial aspect of the CDM is the requirement that projects must also help developing countries in "achieving sustainable development." However, under this mechanism, a universal definition of sustainable development was not developed (which could have ensured accountability of the authorities overseeing project approval); instead, individual countries have been allowed to set their own definition of sustainable development and judge whether a project meets these criteria.

Although it was perceived that the CDM projects would help developing countries by transfer of technology and finances, it has been observed that the CDM projects are not that global in scope. This market is heavily concentrated in large, middle-income countries led by India, China, and Brazil, which is consistent with the current direction of Foreign Direct Investment. On the other hand, some of the poorest countries, especially in Africa, have almost entirely been left behind, with only two countries—South Africa and Morocco—to have validated a CDM project (as of September 2006). According to the Prototype Carbon Fund's report "Carbon Market Trends 2005," published by the World Bank Group, "This under-representation of Africa raises deep concerns about the overall equity of the distribution of the CDM market, as the vast majority of African countries have not, for the moment, been able to pick up even one first deal."

These facts do not support the notion that the CDM would help remove poverty and move the poorest countries to a cleaner path of development.

SEE ALSO: Carbon Permits; Developing Countries; Emissions, Trading; Kyoto Protocol.

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CLIMAP Project

THE CLIMAP PROJECT (Climate: Long range Investigation, Mapping, and Prediction), run by the World Data Center for Paleoclimatology, first published its oceanic map in 1981. Although nominally meant to map ocean conditions, the project gave insight into global warming, due to the fact that oceanic conditions in a region distant from the ice sheets were largely dependent on greenhouse gases. Therefore, a model of the conditions thousands of years ago compared to current conditions could provide evidence for human-caused global warming.

Although CLIMAP is frequently cited as a useful resource for mapping oceanic conditions during the last glacial maximum, several of its claims are controversial and, perhaps, misestimates. Unfortunately, collecting sediment core samples from the Pacific Ocean is quite expensive; therefore, re-collecting the data or obtaining more samples is difficult and unlikely.

The World Data Center for Paleoclimatology is based in Boulder, Colorado, and operated by the National Climatic Data Center (NCDC) in Asheville, North Carolina, along with the National Data Center for Meteorology. The NCDC is part of the National Environmental Satellite, Data, and Information Service (NESDIS), a part of the National Oceanic and Atmospheric Administration within the U.S. Department of Commerce. Its mission is to: "provide access and stewardship to the nation's resource of global climate and weather related data and information, and assess and monitor climate variation and change," and is self-proclaimed the "world's largest archive of climate data."

Within the NCDC, there are six branches for data: Land-Based; Marine; Paleoclimatology; Satellite; Upper Air; and Weather/Climate, Events, Information & Assessments. The Paleoclimatology branch manages the World Data Center for Climatology and the Applied Research Center for Climatology; it also deals with CLIMAP. Paleoclimatology is the study of climates before the current era, when accurate, high technology instrumentation was not available. Therefore, paleoclimatologists reconstruct models of climates from such data sources as corals, ice cores, ocean and lake sediments, and tree rings; these data sources are called natural proxy sources.

CLIMAP was based on research during the 1970s (the International Decade of Ocean Exploration) and 1980s, focusing on mapping the Earth's climate during the period of the last glacial maximum (approximately 18,000 years ago). Researchers for the CLIMAP Project collected numerous sediment core samples, and generated detailed maps of the climate 18,000 years ago, with information such as glacial patterns and vegetation zones. The core samples were from anywhere between 24,000 and 14,000 years ago; during this period, the climate was assumed to be relatively constant and stable.

After thorough analysis, the CLIMAP scientists predicted that the sea surface temperatures (SST) in the tropics were only three or fewer degrees C cooler than they are today; this estimate is considered by most Earth scientists to be inaccurate. Many scientists instead support the theory that the tropical SSTs have since dropped closer to 5–6 degrees C. How this discrepancy arose is unknown.

SEE ALSO: Modeling of Ocean Circulation; National Oceanic and Atmospheric Administration (NOAA); Ocean Component of Models; Oceanic Changes; Oceanography; Paleoclimates.

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Climate

CLIMATE AND WEATHER are not synonymous. Weather is the condition that prevails at a given moment and may change within days or even hours. At moments of meteorological fluidity, weather can change in minutes. Weather is variable, whereas climate is constant under ordinary circumstances. This is so because climate is the average of weather over long durations. Climate may change rapidly, as it did at the end of the Cretaceous era, but the circumstances that change climate rapidly are unusual. When climate changes rapidly Earth is in crisis. At the end of the Cretaceous, for example, a gigantic meteor impacted Earth, ejecting a huge cloud of debris and dust and touching off widespread forest fires. The debris, dust, and ash from this catastrophe blocked out sunlight, cooling Earth. These are not ordinary circumstances and most of the time, climate holds steady.

Climate arises from the interaction of several factors: latitude, proximity to oceans or mountains, altitude, radiation from the Sun, ocean currents, wind, continental drift, the greenhouse effect, volcanic activity, radioactivity of Earth's core, photosynthesis, transpiration, eccentricity of Earth's orbit around the sun, the tilt of Earth's axis, rainfall, and the reflection of sunlight from clouds, snow, and ice. Earth has many climates, ranging from desert to lush rainforest. Temperature and rainfall vary widely by locale. Near the equator, the range of temperatures is small and rainfall abundant. Away from the equator, temperatures and rainfall vary considerably. Humans have adapted to many climates. In contrast, many other animals are adapted to a single climate, and change threatens them.

The factors that shape climate begin with the Sun, for without it, Earth would be a dark, frozen, lifeless rock. The Sun's radiation, which Earth absorbs as heat, is 2.5 times greater at the equator than at the poles. Equatorial waters play a crucial role as a vast reservoir of heat. Near the equator, the ocean absorbs as much as 98 percent of the sun's rays, reflecting only 2 percent back into space. Warm equatorial waters flow toward the poles. The Gulf Stream, for example, carries equatorial water and warm air into the North Atlantic Ocean before cooling near the North Pole. In the past, equatorial currents have been warm enough to melt the ice caps, heating the climate.

Earth's tilt on its axis magnifies the effect of the sun's radiation. An Earth that did not tilt on its axis would not have seasons, because each latitude would receive a constant amount of sunlight and therefore a constant amount of heat year round. Earth is, however, tilted 23.5 degrees on its axis, causing it to receive varying amounts of sunlight and imparting seasons to the planet. When the Northern Hemisphere is tilted toward the Sun, this portion of Earth experiences summer, and the Southern Hemisphere, receiving less Sun that the north, experiences winter. When the Southern Hemisphere is tilted toward the Sun, the reverse is true.

THE GREENHOUSE EFFECT

The greenhouse effect likewise amplifies the effect of the Sun's radiation. Greenhouse gases—carbon dioxide (CO_2), methane, and water vapor are examples—trap sunlight in the atmosphere. Without any greenhouse gases, sunlight would pass through the atmosphere and strike Earth, which would absorb a portion of the sunlight. (Land absorbs less sunlight than water.) The rest would rebound from Earth as infrared radiation, passing out of the atmosphere and into space. Greenhouse gases do not, however, permit infrared radiation to pass into space, but rather absorb it as heat, in turn heating the atmosphere. Of the greenhouse gases, methane breaks down in the atmosphere after a few decades. CO_2, however, may linger centuries in the atmosphere.

Earth produces CO_2 through volcanic eruptions, spewing large quantities of it into the atmosphere. Since the Industrial Revolution, humans have increased the concentration of CO_2 by burning fossil fuels. Humans are adding CO_2 to the atmosphere faster than natural processes can reduce its concentration. As the concentration of CO_2 in the atmosphere increases, so does temperature.

Counterbalancing the effect of volcanoes in increasing CO_2 in the atmosphere, three factors reduce CO_2 and so cool Earth. First, CO_2 dissolves in rainwater to form carbonic acid, taking a portion of the gas out of the atmosphere. Second, the ocean absorbs CO_2. Microorganisms in the ocean convert CO_2 into carbonates, taking the gas out of circulation. Third, photosynthetic algae and plants consume CO_2 during photosynthesis, converting it into sugars. Plants also affect the climate through transpiration, a process that adds water vapor to the atmosphere.

Water vapor traps more heat than either methane or CO_2. Like methane, water vapor does not persist in the atmosphere, but rather falls to the ground as rain. The clouds that carry water vapor reflect sunlight back into space without letting it penetrate to Earth. Water vapor, therefore, has a complex effect on the climate. Water vapor is a greenhouse gas that warms Earth, but the clouds that carry water vapor cool the planet by blocking out sunlight. Clouds cover half the planet, reflecting 30 percent of sunlight, thereby cooling Earth.

Rain affects climate in several ways. It is abundant at the equator and at 30 degrees latitude, where it drenches Earth in monsoons. Rain is also plentiful at the windward side of mountains. As they rise to cross a mountain, clouds cool and release water vapor as rain. On the leeward side of mountains, clouds have little water vapor left to discharge as rain, and so the climate is arid. The climate is likewise arid between 15 and 30 degrees latitude, where air at low pressure prevents clouds from rising, cooling, and releasing their water vapor as rain. Rain sustains the growth of plants. Rapidly growing rainforests consume large amounts of CO_2, though humans are chopping them down at an unsustainable rate.

Heat from Earth's core augments the heat supplied by the sun. Radioactive elements in the core decay over time, converting mass into energy, just as the sun and nuclear reactors do. This energy is in the form of heat and pressure. Pressure forces heat, in the form of molten rock, toward Earth's surface. Volcanic eruptions, in addition to spewing huge amounts of CO_2 into the atmosphere, transfer molten rock from inside Earth to the surface, where molten rock liberates its heat.

A cold climate reinforces itself with the accumulation of snow and ice, which reflect sunlight back into space.

Despite the fact that volcanoes liberate heat and release CO_2, their effect on the climate is not always in the direction of higher temperatures. Volcanoes also spew debris, dust, and ash into the atmosphere. These particles block out the Sun and so may cool Earth. The eruption of Mount Tambora, in 1815, ejected huge clouds of debris into the atmosphere. Feeling the full effects of the eruption, 1816 was so cold that it is remembered as the year that had no summer.

Wind affects climate by carrying warm or cool air across the land. Warm air originates at the equator and follows ocean currents to higher latitudes. Cool air, originating at the poles, blows to lower latitudes. When warm and cool air meet, warm air rises and cool air sinks. As warm air rises, it cools, and sheds its water vapor as rain. The areas along contrasting weather fronts are, therefore, places of abundant rainfall.

In their restlessness, the continents affect climate. Earth is not a static entity as was once believed. Rather, the continents wander across Earth, changing their position and their orientation toward one another. When continents have moved toward the poles, their climates have cooled. Only when Antarctica, for example, moved to the South Pole did it acquire glaciers. In contrast, when continents gather near the equator, as Pangea did, the climate becomes balmy. Plants grew in abundance and herbivores became large, setting the conditions for the evolution of the dinosaurs.

Nor is Earth's orbit constant. In the 17th century, German astronomer Johannes Kepler demonstrated that Earth's orbit, as is true of the orbits of all the planets, is an ellipse. At one extreme, the ellipse is pronounced, and Earth is nearest the Sun at the closest approach of the ellipse and furthest from the sun at the greatest distance of the ellipse. The climate in these instances alternates between warmth when Earth is near the sun, and cold when Earth is far from the Sun. At the other extreme, Earth's orbit, though still an ellipse, is nearly circular. Earth, being roughly the same distance from the Sun at every point in its orbit, receives roughly the same amount of sunlight year round, and so has a uniformly warm climate.

A cold climate reinforces itself through the accumulation of snow and ice, both of which reflect sunlight back into space. By this mechanism, Earth, covered with snow and ice, cools because it reflects, rather than absorbs, heat in the form of sunlight. At the culmination of this feedback loop is an ice age, with Earth covered in glaciers. However, a warm climate can also reinforce itself through the accumulation of CO_2 in the atmosphere. At the culmination of this feedback loop CO_2 accumulates until all snow and ice have melted. The succession of climates, with varying temperatures, makes clear that climate is not static, but changes over time. The current climate is a warm interlude at the end of the Pleistocene ice age. Whether the climate will stay warm or descend into another ice age remains open to question.

THE CLIMATES OF AFRICA

The climate is not uniform, but rather varies by locale. From this, it follows that the continents have a multiplicity of climates. Africa, the cradle of humanity, has a Mediterranean climate in its coastland along the Mediterranean Sea. The sea imparts its heat to North Africa. But, the sea breeze does not penetrate far into Africa, making only a thin strip of coastline Mediterranean in climate. The sea absorbs heat in summer and retains this heat into autumn, radiating it to Mediterranean Africa and making it hotter in summer and autumn than in spring and winter.

The coast of Algeria and Tunisia records temperatures above 80 degrees F (26 degrees C) in August, and around 50 degrees F (10 degrees C) in January. January in North Africa is warmer than January in many other regions of the world. The Atlantic coast of Morocco is cooler, with July temperatures recorded below 70 degrees F (21 degrees C). The Canaries Current, which bathes the Atlantic coast of North Africa, is cooler than the Mediterranean Sea, and accounts for the lower temperatures along the west coast of Morocco.

Most of North Africa has temperatures above 70 degrees F (21 degrees C) during at least nine months of the year. Between May and September, the air is clear, sunshine is abundant, and rainfall is scant. Temperatures rise going east along the Mediterranean coast. Mediterranean Libya and Egypt record summer temperatures as high as 105 degrees F (41 degrees C). In the interior of Egypt, away from the moderating effect of the sea, temperatures rise still higher. Merowe, Egypt has recorded 111 degrees F (44 degrees C) in June, and Wadi Halfa, 127 degrees F (53 degrees C) in April.

In Mediterranean Africa, rain falls in winter rather than in summer. October marks the onset of the winter rains. The coast of Algeria and Tunisia average more than 20 in. (51 cm.) of rain per year. Geryville, Algeria averages a bit less, between 10–20 in. (25–51 cm.) of rain per year. Tripoli, Libya receives 16 in. (41 cm.) of rain per year, Alexandria, Egypt 7 in. (18 cm.), but Cairo only 1 in. (2.5 cm.). Inland and away from the influence of the sea, Cairo and its surrounding lands resemble the Sahara more than the Mediterranean. Winters are mild in Mediterranean Africa. Libya and Egypt average 57 degrees F (14 degrees C) in January, although Algeria has recorded temperatures below freezing.

South of Mediterranean Africa is the Sahara desert, an arid region that receives less than 2 in. (5 cm.) of rain per year. Rainfall is variable. Some years, the Sahara receives no rain, whereas in other years it has between 2–5 in. (5–13 cm.). Temperatures are torrid, sometimes exceeding 170 degrees F (77 degrees C). Between May and September, temperatures regularly surpass 110 degrees F (43 degrees C). Yet January is mild, with record temperatures around 50 degrees F (10 degrees C) on the northern fringe of the desert, and 70 degrees F (21 degrees C) on the southern fringe.

West of the Sahara lie the countries of West Africa. The climate is moderate along the Atlantic coast, but varies inland. West Africa has extremes of temperature. In April and May, temperatures exceed 100 degrees F (38 degrees C), though August has recorded temperatures as low as 71 degrees F (22 degrees C). At the wettest locales, rainfall exceeds 175 in. (444 cm.) of rain per year. The rainy season stretches from April to November and peaks in June. Less rain falls between December and March, though no part of West Africa has a period without rain. The volume of rain diminishes moving east to Niger and Nigeria. Niger averages 40 in. (102 cm.) of rain a year, and Nigeria 60 in. (152 cm.). Most rain falls between June and September. Temperatures peak between April and June, exceeding 90 degrees F(32 degrees C) in Niger and Nigeria. Temperatures cool to 70 degrees F (31 degrees C)between December and February.

South of Egypt lies Sudan, an arid region and further south are Ethiopia and Somalia, both of them wetter than Sudan. Somalia receives between 10–20 in. (25–51 cm.) of rain per year; the upper bound holds for northern Ethiopia, though the southwest has more than 75 in. (190 cm.) of rain a year. Rainfall peaks in February and March and, again, between June and September. The Indian Ocean cools Somalia, whose temperature hovers around 60 degrees F (16 degrees C) in January and 75 degrees F (24 degrees C) in July. The heights of Ethiopia are, likewise, cool. Addis Ababa, Ethiopia has recorded 60 degrees F (16 degrees C) in April. In winter, temperatures fall to freezing.

Cameroon is one of the wettest countries in Africa. In one year, Debundja recorded 374 in. (950 cm.) of rain. The heaviest rains fall between July and September. Year-round, the air is hot and humid. To the east lie Congo and the Democratic Republic of Congo. Their location on the equator holds the temperature nearly constant. The mean is 78 degrees F (25 degrees C), with a variance of only 3 degrees. March and April are the hottest months and July and August the coolest. As is true of other equatorial regions, rainfall is heavy, totaling 100 in. (254 cm.) per year. These countries have two rainy seasons, one between March and June, and the other between September and November.

East of the Democratic Republic of Congo lie Kenya, Tanzania, and Uganda, whose hottest months, January and February, are dry. Daytime heat gives way to nighttime temperatures as cool as 55 degrees F (13 degrees C). Rains fall between March and May, with northern Kenya subsisting on less than than 10 in. (25 cm.) per year. The highlands of Kenya and the whole of Uganda get 40–50 in. (102–127 cm.) of rain per year. South of the Democratic Republic of Congo, the Indian Ocean moderates the climate. Whereas temperatures in January hover in the 80s degrees F (high 50s degrees C), they fall in July into the 50s and 60s degrees F (10–15 degrees C). In contrast to Mediterranean Africa, spring is warmer than autumn in southern Africa. Most of this region receives less than 25 in. (64 cm.) of rain per year, with the most arid lands getting only 5 in (13 cm.). Despite the dearth of rain in these lands, other regions, visited by clouds from the Indian Ocean, receive 100 in. (254 cm.) of rain per year.

THE CLIMATES OF ASIA

Northeast of Africa stretches Asia, a continent of contrasts. The deserts of Central Asia give way to rainforest in Southeast Asia. India and Sri Lanka host rainforests that are fed by the monsoons. Monsoons originate in the South Indian Ocean and dump their rain over large tracts of land between June and September. India and Sri Lanka derive 85 percent of their rainfall from monsoons. The west coast of India and Malaysia receive more than 75 in. (191 cm.) of rain per year. The coast of Burma and Thailand and most of Sri Lanka are drenched by 350 in. (889 cm.) of rain per year. In the north, however, small regions of India and Pakistan receive as little as 3 in. (8 cm.) of rain per year.

The Indian Ocean moderates the climate of Sri Lanka, whose temperatures seldom fall below 70 degrees F (21 degrees C) or exceed 85 degrees F (29 degrees C). In southern India, temperatures in April and May hover between 82–85 degrees F (28–29 degrees C). In central India, temperatures in April exceed 85 degrees F (29 degrees C), and in May, 95 degrees F (35 degrees C). At their warmest, temperatures exceed 105 degrees F (41 degrees C).

Large and distanced from the equator, China has a variable climate. Heaviest in the south, rainfall decreases moving north. Hong Kong gets 85 in. (216 cm.) of rain per year, the lands between Hangchow Bay and the Gulf of Tonkin receive 40 in. (102 cm.), and northern China makes do with 20–25 in. (51–64 cm.). Mongolia subsists on fewer than 10 in. (26 cm.) of rain per year. In the middle of the Yangtze River valley, the heaviest rains fall in May and June. South of the river, the rains begin in June. Temperatures are warm in southern, central, and parts of northern China. Hankow, a town along the Yangtze River, averages 40 degrees F (4 degrees C) in January and 86 degrees F (30 degrees C) in July. The middle and lower Yangtze valley averages above freezing in January and above 80 degrees F (26 degrees C) in July and August. Further north, Beijing has recorded 110 degrees F (43 degrees C) in July. The region north of the Russian port of Vladivostock is cold in winter. Temperatures have fallen to minus 30 degrees F (minus 34 degrees C). Temperatures in Mongolia have fallen below zero degrees F (minus 18 degrees C) in January.

Off the coast of China lies Japan. The Pacific Ocean warms Tokyo, whose temperature in January exceeds 40 degrees F (4 degrees C). July temperatures peak at 87 degrees F (31 degrees C). January is the coldest month and July and August the warmest. In winter, precipitation falls as snow. Between November and April, temperatures are cold enough for snow to linger on the ground in drifts as high as 10 ft. (3 m.). The heaviest rains fall in June and July. Southernmost Japan and the mountains of the northeast receive 80 in. (203 cm.) of rain per year. The island of Honshu receives between 40–60 in. (102–152 cm.) of rain per year. Hokkaido in the north receives only 20–30 in. (51–76 cm.) of rain per year.

South of China is Southeast Asia and the islands of Indonesia, the Philippines, and New Guinea. Indonesia has an equatorial climate with little variation in temperature. With a range of only a few degrees, the monthly mean varies between 78–81 degrees F (25–27 degrees C). Jakarta, Indonesia, with temperatures of 78–79 degrees F (25–26 degrees C), has a range of only 1 degree. The air is hot and moist and rainfall heavy. Indonesia and New Guinea total more than 100 in. (254 cm.) of rain per year. The heaviest rains fall between September and December. The Philippines can exceed 120 in. (305 cm.) of rain per year, and the mountains of Indonesia and New Guinea tally 150 in. (381 cm.). Cambodia receives more than 200 in. (508 cm.) of rain per year with the heaviest rains in autumn.

West of China stretches the vast tract of Central Asia. Much of the land is arid, receiving fewer than 2 in. (5 cm.) of rain per year. Some areas total as little as .5 in. (1 cm.) of rain per year. Parts of southwest Asia are likewise dry. The deserts of Syria and Arabia tally less than 2 in. (5 cm.) of rain per year. Jerusalem, Israel fares better with 16 in. (41 cm.) of rain per year. Haifa, Israel totals 24 in. (61 cm.) and Beirut, Lebanon receives 35 in. (89 cm.). The interior of Turkey receives only around 15 in. (38 cm.) of rain per year, but the Mediterranean coast totals between 25–45 in. (64–114 cm.). The heaviest rains fall in April and May. In the Levant, the rains fall between October and April, with the heaviest rains in January. Little rain falls between May and September. Away from the coast, temperatures vary widely. Ankara, Turkey has recorded temperatures as low as minus 13 degrees F (minus 25 degrees C) in January, and as high as 100 degrees F (38 degrees C) in July. In Sivas, Turkey temperatures have fallen to minus 30 degrees F (minus 34 degrees C) in January, and in Beirut and Jerusalem temperatures have soared to 107 degrees F (42 degrees C) in July.

Arabia, Mesopotamia, and Persia lie southeast of Turkey. Saudi Arabia, inland from the Indian Ocean, totals less than 2 in. (5 cm.) of rain per year, whereas Oman and Yemen, benefiting from the moist air of the Indian Ocean, receive 15–20 in. (38–51 cm.) and 20–30 in. (51-75 cm.) of rain per year, respectively. Iraq and Iran tally fewer than 10 in. (25 cm.) of rain per year. The rains fall between November and April, though they are not steady. Little rain falls between May and October. These lands have only a brief spring. In April, temperatures rise rapidly to their summer highs. Baghdad, Iraq, reaches 110 degrees F (43 degrees C) in July; Tehran, Iran, 109 (42 degrees C) ; and Basra, Iraq, 105 (40 degrees C) .

North of Mongolia stretches the vast expanse of Russia, whose winters are among the coldest on Earth. In Siberia, temperatures stay below 0 degrees F (minus 18 degrees C) in January. Verkhoyansk, Russia averages minus 58 degrees F (minus 50 degrees C) in January and has recorded minus 94 (minus 70 degrees C) . January temperatures have fallen to minus 90 degrees F (degrees C) in Oymyakon, to minus 44 (minus 68 degrees C) in Moscow and to minus 35 (minus 37 degrees C) in St. Petersburg. Ice and snow cover the ground in Siberia more than 200 days per year. The port of Vladivostock remains frozen between December and April. Blanketed by snow, the ground is warmer than the air. The Crimea, benefiting from the warm waters of the Baltic Sea, averages nearly 40 degrees F (4 degrees C) in January. In summer, rain totals more than 20 in. (38 cm.) throughout Russia. As is true of the Mediterranean basin, autumn is warmer than spring in Russia.

THE CLIMATES OF EUROPE

West of Russia is Europe, a peninsula of Asia. The Gulf Stream originates near the Equator and, as it flows north, it warms the Atlantic coast of Europe, including Great Britain. Western Europe is warmer than comparable latitudes. Most of Western Europe has winter temperatures above freezing. As far north as Norway, the ocean is above 40 degrees F (4 degrees C) in winter, warmer than the ocean at comparable latitudes elsewhere. In January, Britain and France post temperatures above 40 degrees F (4 degrees C) , and Spain averages 50 (10 degrees C) .

Clouds and rain characterize the climate of northwestern Europe in winter. The region is among the cloudiest on Earth. As in Mediterranean lands, autumn is warmer than spring in Europe. Along the Atlantic coast, summer is cooler than it is in the interior of the continent. Portugal averages only 70 degrees F (21 degrees C) in July, and Norway only 50 (10 degrees C) . As rain falls in the winter, January is the wettest month in Western Europe and Britain and June the driest.

Central Europe, bereft of the warm Gulf Stream, is colder than Western Europe. Sveg, Sweden is as cold as minus 56 degrees F (13 degrees C) in winter. Rainfall is moderate, averaging 20 to 25 in. in much of Central Europe. The Po valley, having a continental rather than a Mediterranean climate, averages 30 in., and the wettest regions receive 40 to 50 in. Clouds hover in the sky much of the year. In winter, clouds drift into the valleys of the Alps. The mountain summits are clear and sunny.

In summer, the pattern reverses, with clouds above the summits and the valleys bathed in sunlight. South of the Alps stretches Mediterranean Europe. Its climate mirrors that of Mediterranean Africa. In some parts of the Mediterranean, temperatures average 50 degrees F (10 degrees C) in the coldest months. Temperatures year round are warmer in the south and east than near the Atlantic. Clear and sunny, summer is dry. Rainfall peaks in April and May and again in October. Rainfall tends to be heavy, with drizzle infrequent.

THE CLIMATE OF THE AMERICAS

Like Western Europe, the Atlantic coast of North America benefits from the warmth of the Gulf Stream. The American southeast has hot and humid summers and warm winters. South Florida records temperatures above 80 degrees F (27 degrees C) even in winter. The temperature never falls below freezing in Key West, Florida. Key West, Galveston, and San Antonio, Texas, and Vicksburg, Mississippi average more than 80 degrees F (27 degrees C) in July. The Gulf Stream brings rain to the American southeast. The Gulf Coast between New Orleans, Louisiana and Mobile, Alabama averages more than 60 in. (162 cm.) of rain per year.

At the other end of North America, the California Current cools the Pacific Coast. San Diego averages 67 degrees F (19 degrees C) in July, whereas Savannah, Georgia, at comparable latitude, averages 80 (27 degrees C) in July. The Pacific coast receives the most rain in North America. Wynoochee Oxbow, Washington averages 146 in. (371 cm.) of rain per year. Away from the moist Pacific air, the interior of North America receives less rain. The Colorado basin averages fewer than 3 in. (8 cm.) of rain per year. The Great Plains are prone to drought, with disastrous results in the 1870s and 1930s.

The Pacific Ocean warms British Columbia, Canada. Victoria and Vancouver, British Columbia average 39 degrees F (4 degrees C) in January. Away from the warmth of the Pacific and the Gulf Stream, northern latitudes are cold. The coldest winters occur between the Hudson Bay and Alaska. Fort Good Hope, near the Arctic Circle, has recorded minus 79 degrees F (minus 62 degrees C). Fort Vermillon, Canada has recorded minus 78 (minus 61 degrees C) and Churchill, Manitoba minus 57 (minus 49 degrees C) in January.

Storing the heat from the summer sun, the Great Lakes warm adjoining lands year round. The effect of the Great Lakes is mild, but measurable in winter. Toledo, Ohio, near Lake Erie, has recorded minus 16 degrees F (minus 9 degrees C) , whereas Columbus, Ohio, 100 mi. (161 km.) south and thus outside the moderating effect of Lake Erie, has recorded minus 20. Snowfall is heavy in the Great Lakes; clouds absorb moisture from the lakes, returning it to the region as snow. As in the Mediterranean, autumn is warmer than spring in North America. In autumn, temperatures reminiscent of summer often follow a cold spell. Americans know this time as Indian summer.

South of the United States stretch Mexico, Central America, South America, and the Caribbean islands. Moving south through Mexico, rainfall increases. The warmth of the Pacific Ocean makes the western coast of Mexico among the hottest lands in the Americas. The coasts of Central America are hot and rainy. The mountains of the interior are comparatively cool, though rainfall is abundant. Most of Central America receives more than 100 in. (254 cm.) of rain per year. Warmed by tropical waters on both coasts, Central America displays a uniform temperature. Panama averages roughly 80 degrees F (27 degrees C) year round.

South America narrows moving south. The decreasing width of the continent amplifies the effect of ocean currents on the southernmost lands. The east coast of South America, warmed by the Atlantic Ocean, is 10

Climate is so important that it has shaped human affairs—drought may have extinguished the Mayan civilization.

degrees F (6 degrees C) warmer than the western coast at comparable latitudes. Tropical South America is cooler than tropical Africa because the former has thicker clouds, heavier rains, and denser forests than the latter. As far south as the Tropic of Capricorn, South America averages more than 70 degrees F (21 degrees C) year round. South America is warmer in winter and cooler in summer than comparable latitudes in North America.

The heaviest rains fall east of the Andes Mountains, summer being the rainy season. Moist equatorial air, flows east to west across South America. The Amazon River valley receives more than 80 in. (203 cm.) of rain per year, with some locales tallying 100 in (254 cm.). The continent receives rain at least 250 days per year.

The Caribbean Sea and the Gulf of Mexico, with temperatures above 80 degrees F (27 degrees C) year round, warm the Caribbean islands. The climate is hot and humid. Rain is heaviest in June and again in October, with less rain falling in July and August. Moore Town, Jamaica averages 222 in. (564 cm.) of rain per year, and Port Antonio, Jamaica averages 137 in. (348 cm.). Kingston, Jamaica, on the leeward side of the mountains, averages only 31 in. (79 cm.) of rain per year. The moderating effect of the Caribbean Sea and the Gulf of Mexico holds temperatures constant. Only four degrees separate January and July mean temperatures in Barbados. The Caribbean, Florida, and the Gulf Coast are vulnerable to hurricanes.

THE CLIMATES OF AUSTRALIA, NEW ZEALAND, AND ANTARCTICA

In the South Pacific lies Australia, among the driest continents on Earth. Nearly half of the continent receives fewer than 10 in. (25 cm.) of rain per year. Less than 10 percent of Australia receives more than 40 in. (108 cm.). The South Equatorial Current warms the north and west coasts of Australia. Because of this ocean current, northwestern Australia is hottest. Marble Bar, Australia has recorded 121 degrees F (49 degrees C) and 161 consecutive days of at least 100 degrees F (38 degrees C). Roebourne, Australia has reached 117 degrees F (47 degrees C) in January and 220 days of at least 90 degrees F (32 degrees C) . The north of Australia receives its rain in summer, whereas the south receives its rain in winter. Paradoxically, the rainy season is less humid than the dry season.

Off the southeast coast of Australia lies New Zealand. At about the latitude of Italy in the Northern Hemisphere, New Zealand, bereft of the warmth of the Mediterranean Sea, is 10 degrees F (6 degrees C) cooler than Italy in summer. In winter, New Zealand, benefiting from warm Pacific currents, is warmer than Italy. New Zealand summers are sunny. Much of New Zealand receives fewer than 40 in. (102 cm.) of rain per year. The rains fall between October and January, with the heaviest rain in October.

South of the habitable continents is Antarctica, a land of unremitting snow and ice. The climate is too cold for the continent to host permanent settlements of humans. December averages minus 8 degrees F (minus 22 degrees C) and in January, minus 18 (minus 28 degrees C) . Precipitation, in the form of snow, falls in winter. Summer has clear skies and sunshine, but the sun is not warm enough at this latitude to melt the snow and ice. Instead, snow falls upon already existing piles of snow, compacting it into ice.

So important is climate that it shapes human affairs. The drying of the climate about five million years ago changed East Africa from forest to grassland and forced human ancestors out of the trees and onto the grasslands as bipeds. Drought may have extinguished the Akkadian and Mayan civilizations. The Little Ice Age nearly froze George Washington's Continental Army at Valley Forge. Humans are very much creatures of their climate.

SEE ALSO: Climate Change, Effects; Climate Cycles; Climate Models; Climate Zones; Climatic Data, Historical Records; Ice Ages; Greenhouse Effect; Volcanism.

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Climate Action Network

THE CLIMATE ACTION NETWORK (CAN) is an international network of over 365 nongovernmental organizations working toward the building of collaborative and individual actions and programs designed to combat and minimize human-induced impacts leading to climate change. Established in March 1989, the network has seven regional offices located in Africa, Europe, Latin America, North America, South Asia, and Southeast Asia.

The vision of the network is to "protect the atmosphere while allowing for sustainable and equitable development worldwide." Based on the Intergovernmental Panel for Climate Change (IPCC) reports, the network has developed a comprehensive agenda for achieving change. The network is trying to keep global average temperatures as far below a two-degree rise as possible. The network calls on governments to commit to a global objective to maintain global temperatures at this level. While advocating this action, the network is also researching how to achieve this goal without compromising development needs. The network has developed a three-track approach to addressing the issue of climate change. The Kyoto track targets developed countries, the greening track targets developing countries, while the adaptation track targets the countries most vulnerable to climate change.

The Kyoto track uses the legally binding instruments of the United Nations Framework Convention on Climate Change and the Kyoto Protocol to drive greenhouse gas emissions reductions. The Kyoto Protocol contains mandatory provisions for the reduction of greenhouse gases by Annex I (industrialized) countries. Obligatory, dated targets, emissions-trading programs, and compliance mechanisms are vital components of the protocol.

In accordance with principles of historical responsibility and equity, only industrialized countries will be subject to these commitments. However, as developing countries industrialize, they will come under the purview of the protocol's mandatory provisions. The Kyoto track will spur the rapid development of sustainable technologies by industrialized countries, which will then be transferred to developing countries in the greening track.

The greening (decarbonization) track involves the rapid introduction of clean, sustainable technologies to developing countries in order that they may reduce their current emissions and follow a low-carbon path to development. The ability of these countries to develop in a sustainable way is largely dependent on the provision of technical and other assistance from industrialized countries. The greening track applies to all developing countries, except the least-developed countries, whose emissions are negligible, though they are provided incentives to participate, if they so desire. The emissions reduction and clean development goals vary according to the capacity of individual developing countries.

The adaptation track is designed to assist the most vulnerable counties (for example, small island states) in anticipating and limiting the effects of climate change. Industrialized countries bear the responsibility of providing assistance to these countries and, in the case that some consequences of climate change cannot be mitigated, the responsibility for compensation. Countries that receive assistance in the adaptation track may also participate in the other tracks, if circumstances permit.

The network has adopted this three-track system because it is committed to the principle of historical responsibility. This system calls on governments and countries that have historically contributed the most greenhouse gases to take responsibility for their actions.

While all countries have equal access to the atmospheric commons, different countries suffer disproportionately from the effects of global warming and climate change. This is particularly the case for developing countries. This three-track system is also based on the intergenerational principle, calling on nations to think about future generations and their right to have equal access to, and to live within, the atmospheric commons.

SEE ALSO: Alliance of Small Island States; Developing Countries; Kyoto Protocol; Nongovernmental Organizations (NGOs).

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Climate Change, Effects

CLIMATE CHANGE IS commonly used to describe any systematic alteration or statistically significant variation in either the average state of the climate elements such as precipitation, temperature, winds, or pressure; or in its variability, sustained over a finite time period (decades or longer). It can be referred to as the long-term change in global weather patterns, associated especially with increases in temperature, precipitation, and storm activity.

These inconsistencies in climate systems are a potential consequence of the greenhouse effect by greenhouse gases (GHGs). Examples of greenhouse gases include: carbon dioxide (CO_2), methane (CH_4), dinitrogen monoxide or nitrous oxide (N_2O), halocarbon gases such as trichlorofluorocarbon ($CFCl_3$) and dichloroflurocarbon (CF_2Cl_2), water (H_2O), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). The atmospheric concentrations of these gases have been increasing, due to anthropogenic activities.

Climate change is attributed directly or indirectly to anthropogenic activities that impact the natural composition of the global climate elements. It may also be a result of natural external forcing, such as changes in Earth's orbital variables, or solar emission, and other natural internal processes of the Earth's climate system. The relative influences of external anthropogenic and natural factors on climate can be broadly compared, using the concept of radiative forcing. Radiative forcing simply refers to the process that disrupts the infrared radiation balance between incoming solar radiation from the Sun and the outgoing radiation from the Earth. A positive radiative forcing primarily results in the relative warming of the Earth's surface and is due to increasing levels of GHGs. A negative radiative forcing, which can arise from an increase in some types of aerosols, tends to bring about the cooling of the Earth's surface.

Changes in orbital variables, solar output, or explosive volcanic activity, are natural external factors that can also cause radiative forcing. The systematic account of these climate-forcing agents and their differences over a timescale is required to understand past climate changes in the context of natural variations, and to predict the nature of future climate changes.

The effects of climate change include variations in biospheric ambient temperature, which could lead to heat stress, change in rainfall patterns, sea-level rise, saltwater intrusion, loss of biodiversity, drought, habitat loss, and freshwater depletion and pollution. In most cases, climate change has been used interchangeably with global warming, and the greenhouse effect. However, in recent accepted usage, climate change only connotes any change or changes in modern climate systems, whether due to natural variability or as a result of human-caused activity, including an increase over a period of time of the average temperature of the Earth's atmosphere and oceans, known as global warming.

The United Nations Framework Convention on Climate Change (UNFCCC) has adopted the phrase *climate variability* for non-human mediated changes in climate elements. Climate variability is usually natural in origin, resulting primarily from slight variations in the complex processes that drive the movement of heat and mass between the atmosphere, the marine aquatic ecosystems, and the land surfaces. For example, the El Niño–Southern Oscillation (ENSO) is caused by weakening trade winds in the southern part of the Pacific Ocean, and has consistently affected regional variations of precipitation and temperature over much of the tropics, subtropics, and some mid-latitude areas, leading to warmer episodes in these areas. Trade winds carry warmer air west, which leads to rising sea temperatures and increased precipitation.

According to reports by the Intergovernmental Panel on Climate Change (IPCC), human beings are altering the Earth's natural climate system. Evidence indicates that human-induced climate change, if allowed to continue unabated, could have profound consequences for the economy and the quality of life of future generations. Fossil fuel consumption, which has been steadily increasing since the pre-industrial period, is causing an overall increase in concentrations of atmospheric GHGs, especially CO_2.

Current research indicates that radiative forcing driven by greenhouse gases is the primary cause of global warming. According to these studies, GHGs traps the Sun's heat energy and compels a redistribution of the trapped radiation available near the Earth's surface, thus regulating the Earth's temperature. GHGs, especially CO_2, are the major non-climate factors driving climate change. The continuous build-up of these gases is expected to cause significant changes in climatic conditions over the next century.

WATER RESOURCES AND TEMPERATURE RISE

Researchers around the globe have found that climate change is likely to impact water resources depletion and pollution significantly. There have been observed changes in surface temperature, rainfall, evaporation, and extreme events since the beginning of the 20th century. The atmospheric concentration of CO_2 has increased from about 280 parts per million by volume (ppmv) to about 369 ppmv, and the global temperature of the Earth has increased by about 0.6 degrees C. The present CO_2 concentration has not been exceeded during the past 420,000 years and likely not during the past 20 million years. The current rate of atmospheric CO_2 level increase is unprecedented during at least the past 20,000 years. About 75 percent of the anthropogenic emissions of CO_2 to the atmosphere during the past 20 years is attributed to fossil fuel burning. The rest is predominantly due to land-use change, especially deforestation.

The globally averaged surface temperature is projected to increase by 1.4 to 5.8 degrees C 1990–2100. The global mean sea level has risen by 4–8 in. (10–20 cm.). The average global surface temperature is projected to increase by 1.4–3.0 degrees C 1990–2100 for low-emission scenarios, and 2.5–5.8 degrees C for higher emission scenarios of greenhouse gases in the atmosphere. Over the same period, associated rise in global mean sea level is projected between 1.3–13.6 sq. in. (9–88 sq. cm.).

A number of researchers have reported the impact of climate-change scenarios on hydrology of various basins and regions; they project that increasing temperature and decline in rainfall may reduce net recharge and affect freshwater resources. Human-caused influences are expected to follow a steady growth trend in the future; climate modifications caused by anthropogenic radiative forcing are considered to be more permanent than those caused by natural variability factors.

According to the Intergovernmental Panel on Climate Change (IPCC), since the Industrial Revolution began in the mid-16th century, CO_2 levels in the atmosphere have increased by 35 percent and the atmospheric concentration of CH_4 has increased by 1060 parts per billion (151 percent) and will continue to increase. The present CH_4 concentration has not been exceeded during the past 420,000 years. The inter-annual growth in CH_4 level slowed and became significantly variable in the 1990s, compared with the 1980s. It has been suggested that a significant ratio of the current CH_4 emissions are anthropogenic rather than natural. The anthropogenic sources of methane include the consumption of fossil fuels, cattle, paddy rice fields, and landfills. Recent studies have indicted carbon monoxide (CO) emissions as a cause of increasing atmospheric CH_4 concentration.

In addition, the emissions of persistent GHGs such as CO_2, N_2O, PFCs, and SF_6 could continue to have long-term impacts on atmospheric composition, radiative forcing, and climate elements. This could imply that anthropogenic climate change may persist for a long time to come. The enhanced atmospheric concentrations of GHGs are implicated as the primary cause of global warming.

Recent findings by the IPCC indicate that the atmospheric concentration of CO_2 in 2005 was 375 ppm compared to the pre-industrial levels of 280 ppm. This has contributed to the increase in the Earth's surface temperature by 0.6 degrees C (one degree F). Worldwide measurements of sea level have demonstrated a rise of about 0.56 ft. (0.17 m.) during the 20th century. The world's glaciers have, over time, receded steadily and Arctic sea ice extent has steadily shrunk by 2.7 percent per decade since 1978.

Glaciers are an intriguing part of the Earth's natural environment and have been identified as one of the significant and sensitive indicators of climate change. Their size, lifespan, and timescale information of accumulation and ablation, or growth and collapse (glacier retreat) are primarily attributed to change in climate elements such as temperature, precipitation, wind speed, humidity, and solar radiation.

Increased surface temperatures of the Earth are causing glaciers to melt faster than winter snows can replenish them. Melting sea ice may eventually lead to global changes in water resources and circulation, and melting ice could speed up warming of the Arctic because water absorbs much more heat than ice. Extreme and ongoing declines in the thickness and extent of Arctic sea ice will pose enormous consequences for the Arctic population, their ecosystems, and coastal evolution. As the glaciers shrink, a greater portion of the Earth's water will enter the liquid phase and becomes available to the oceans and the atmosphere. This will ultimately result in a increased volume of water in the oceans, which could lead to a significant rise in sea level.

IMPACTS OF SEA-LEVEL RISE

During the 20th century, the sea level rose by 4–8 in. (10–20 cm.) primarily as a result of melting glacier ice and thermal expansion of warmer ocean water. It has been predicted that sea level rise will be even greater as the oceans warm along with the rest of the Earth. This is due to the fact that water expands as its temperature increases. Climate change models have predicted that a global mean sea level rise as much as 33 in. (85 cm.) is expected during the 21st century. Accelerated global sea-level rise is expected to have far-reaching and dramatic impacts in vulnerable regions of the Earth where subsidence and erosion challenges already exist. Rising seawaters are already submerging, for example, coastal wetlands and mangroves in southern Florida, and approximately one million acres of Louisiana wetlands have become open water since the mid 20th century.

Sea-level rise has the potential of causing increases in the intrusion of saltwater into coastal aquifers. Shallow islands, and coastal aquifers supporting human use (such as those in Long Island, New York, and central California) could be at greatest risk. Rising sea level has also contributed to increased mortality of trees in coastal areas of Louisiana and southern Florida, where saltwater has already intruded into the groundwater on which trees depend.

Other impacts associated with sea-level rise include changes in salinity distribution in estuaries, altered coastal circulation patterns, destruction of transportation infrastructure in low-lying areas, and increased pressure on coastal levee systems. Atlantic and Gulf Coast shorelines will be especially vulnerable to long-term sea-level rise, as well as any increase in the frequency of storm surges or hurricanes. Most erosion events on these coasts are the results of storms, and the slope of these areas is so vulnerable and gentle that a small rise in sea level may produce a large inland shift of the shoreline. This increases the threats to coastal development, transportation, freshwater aquifers, infrastructure, and fisheries. These impacts can adversely affect the quality of water resources. Moreover, the potential negative implications of climate change for water quality include reductions in stream flows, increased storm surges, and higher water temperatures. An increase in the number of intense precipitation days could lead to increases in the variety of agricultural and municipal polluting substances being washed into rivers, estuaries, streams, and lakes, and sea-level rise would contribute to saltwater intrusion into rivers, estuaries, and coastal aquifers.

FRESHWATER SUPPLY ISSUES

Global climate change will have major impacts on freshwater ecosystems. This will affect availability, as well as quality, distribution, and form. In certain regions, where stream flow and precipitation increase, flooding could threaten the structure and functions of aquatic systems, leading to increased pollution of freshwater ecosystems, especially in areas where human-mediated activities might have altered the landscape. The impacts of climate change on the Earth's freshwater resources have the potential of affecting international relations, especially at continental or country borders, where shared wetlands can generate local and international political and geographical disputes.

Impacts of climate change on water resources will have a wide range of consequences for coastal ecosystems. The health of the Earth's ecosystems will be affected by changes in the quality and quantity of freshwater runoff into coastal wetlands, higher water temperatures, extreme runoff rates or altered timing, and the ability of watersheds to assimilate pollutants and wastes.

Global climatic changes could pose a serious demand on the water supply. In most regions of the world where there are observed and projected declines in per capita average of annual freshwater availability, coupled with attendant population growth, the possibility of increased demand for water will likely lead to increased withdrawal of water, which will invariably reduce the recharging time of the water tables. These changes may influence a wide range of water-system components, including reservoir operations, water quality, hydroelectric generation, and navigation. In some regions, where large volumes of water are channeled for non-consumptive purposes such as agriculture demand, particularly for irrigation, water supply will be particularly sensitive to climate conditions;

Predicted mean sea-level rise of as much as 33 in. in the 21st century threatens fragile shorelines such as this one in Florida.

demand for irrigation water tends to increase as conditions become hotter and drier. A possible change in field-level climate may result in altering the timing of, and need for, irrigation.

In-stream water uses such as hydroelectric power generation, navigation, recreation, and ecosystem maintenance are also sensitive to changes in the quantity, quality, and timing of runoff stemming from greenhouse warming. Potential negative implications of climate change include reductions in dilution flows, increased storm surges, and higher water temperatures. Low flows in many rivers will lead to increases in salinity levels to downstream water users.

On the other hand, higher flows could help reduce some water quality concerns. Warmer water could threaten aquatic life directly, as cool-water habitats disappear, and indirectly, as dissolved oxygen levels decline with higher temperatures. An increase in days with more intense precipitation could increase the agricultural and urban pollutants washed into streams and lakes, further reducing oxygen levels. Heavy rainfall is primarily responsible for soil erosion, leaching of agricultural chemicals, and runoff of urban and livestock wastes and nutrients into water bodies.

CHANGING ECOSYSTEMS AND WEATHER

Another possible effect associated with climate change is the potential danger it holds for marine ecosystems. As the sea-level rises, coupled with increased warming of the ocean waters, marine biodiversity will be further threatened by the myriad impacts on all marine ecosystems, from tropical coral reefs (especially in the Maldives), to polar ecosystems. Coral reefs are already under severe stress from human activities, and have experienced unprecedented increases in the extent of coral bleaching, emergent coral diseases, and widespread die-offs. Damages to coral reefs lead to depletion of important habitat for fish food.

Changes in ocean temperatures, currents, and net productivity will affect the distribution, abundance, assemblages, and productivity of marine populations, with unpredictable consequences to marine ecosystems and fisheries. As the Earth's surface temperature warms, species may either migrate to a cooler, more suitable habitat, or die. Species that are particularly vulnerable to climate change effects include polar animals, such as seals, penguins, and polar bears, coral reefs, and many other endangered animal and plant species.

Climate change has the potential to alter the hydrologic cycle. In many regions of the world, global climate change will have significant effects on precipitation and evapotranspiration. Heavier rainfall could lead to flooding in many regions as warmer temperatures speed up the hydrologic cycle. Flood frequencies in some areas are likely to change. In northern latitudes and snowmelt-driven basins, floods may become more frequent, although the increase in flooding for any given climate scenario is uncertain and impacts will vary among basins.

Over the past century, it is estimated that there has been a 5–10 percent increase in precipitation. Climate-induced changes in hydrology will affect the magnitude, frequency, and cost of extreme events, which have the greatest economic and social impact on humans. Flooding, the most costly and destructive natural disaster, is becoming a common and extreme event as a result of climate-induced variations. Severe weather events are becoming more common and extreme, as well.

Climate change researchers have indicated that the number and strength of anthropogenic-induced climate extreme events such as storms, hurricanes, typhoons, floods, and tornadoes have increased over the past 10–20 years. For example, a record breaking 28 tropical storms hit the United States in 2005, alone. All these phenomena are traceable to variations in radiative forcing brought about by anthropogenic GHGs in the atmosphere. Increases in precipitation and runoff are likely to intensify the stresses on streams, lakes, bays, estuaries, and rivers in some regions of the world by strengthening the transport of nutrients and contaminants loading to coastal ecosystems. Higher latitudes are more likely to receive increased precipitation and runoff, while lower latitudes are more likely to experience decreased runoff.

Regions with snowfall, such as the Rocky Mountains and Sierra Nevada, California, will experience seasonal shifts in runoff, with increases in winter and early spring runoff, decreases in late spring and summer runoff, and possible increased flood intensities. The frequency and severity of droughts could increase in some areas as a result of a decrease in total rainfall, more frequent dry spells, and greater evapotranspiration.

HEALTH ISSUES

Several health challenges can be linked to global climate change. According to IPCC scientists, a climate-induced warmer world could lead to a number of health problems. These health challenges include increased global distribution of tropical diseases, such as malaria and dengue, heat stress, hunger-related ailments, and injuries and drowning associated with increased storm frequency and intensity.

Africa, for example, is expected to be at risk from increased incidence of vectorborne diseases. A warmer Africa has the potential of opening up new areas for malaria, and altered temperature and rainfall patterns in the continent could lead to increased incidence of yellow fever, dengue fever, onchocerciasis, and trypanosomiasis. In the Middle East and Asia, heat stress, which will affect human comfort levels, and the possible spread of vectorborne diseases will likely result from climate-induced changes. In general, decreases in freshwater availability would lead to indirect impacts on human health.

SEE ALSO: Climate; Climate Models; Diseases; Floods; Health; Hurricanes and Typhoons; Salinity; Sea Level, Rising; Weather.

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Climate Change Knowledge Network

THE CLIMATE CHANGE Knowledge Network (CCKN) was established in 1998, to enhance cooperation between developed and developing countries on research related to climate change. The network aims to make knowledge about climate change available to all countries of the world. The collaborative efforts encouraged by the network strive to disseminate knowledge on climate change and to make such knowledge relevant for the international policy process. The network includes 12 core member institutions in Senegal, Zimbabwe, the United States, Canada, Brazil, Argentina, China, India, Norway, the Netherlands, and Sweden. The governments of Canada, the United States, and Norway support its activities.

The aims of the network are to promote more sustainable and equitable climate change management through research and communication on issues such as the Kyoto Protocol, to develop a dialogue between developed and developing countries for a better understanding of the global effects of climate change, and to help each member institution to increase its capacity to propose regional policies about climate change. The network promotes international negotiations that make explicit connections between development and climate change. The network also enables members to take part in various projects, to share their results with other members, and to bridge the gap between development and climate change. The CCKN is pledged to equity among its members and is based on mutual learning. Members take part in activities that involve the whole network and also in partnerships with other members.

The CCKN has its headquarters at the International Institute for Sustainable Development, in Canada, which also helps the members to disseminate their work and projects via the internet. The network's core members are institutions selected from developing and developed countries. They participate in decision-making processes, research projects, and fundraising activities. The network also has associate members, who are either former core members, or organizations with interests in climate change that share the same aims as those of the network. Network members usually meet in person, once a year, at the annual meeting the Conference of the Parties to the United Nations Framework Convention on Climate Change.

Through individual and joint projects, member organizations identify relevant research areas and work collaboratively to shape the international climate change process, as well as regional and local processes. An ongoing interest of the knowledge network is the assessment of the socioeconomic and environmental impacts to implement the UN Framework Convention on Climate Change and the Kyoto Protocol.

The CCKN is committed to the training of negotiators from developing countries so that they can effectively take part in international negotiating processes. As part of its activities, the network has devised an online resource to provide an overview of the key topics and actors in climate negotiations. This is an important tool for developing countries that are the most affected by climate change, but whose negotiating capabilities are often challenged. The network recognizes that developing and least-developed countries are the most vulnerable to the impacts of climate change, so it has undertaken research on the long-term policy measures to be adopted. The CCKN was able to bring together the International Institute for Sustainable Development, the Center for International Climate and Environmental Research, and the Tata Energy Research Institute to explore the impacts of economic changes and climate change for India's agricultural sector.

The most significant project of the CCKN is the Clean Development Mechanism (CDM), a multiphase assessment of the role of decentralized renewable energy in sustainable development, poverty relief, and greenhouse gas mitigation through the Kyoto Protocol. As the first stage of the CDM, the network commissioned a series of short scoping studies completed by its partners in developing countries. These studies assessed the national state of decentralized renewable energy in China, India, Senegal, Zimbabwe, and Chile and were completed in early 2002. The second stage of the project involves ways to encourage the use of decentralized renewable energy systems.

SEE ALSO: Center for International Climate and Environmental Research; Clean Development Mechanism; Kyoto Protocol; Nongovernmental Organizations (NGOs).

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Climate Cycles

THERE ARE IDENTIFIABLE cycles in the weather patterns of the Earth. There are four seasons every year in the temperate zones. In the polar regions, there are seasons of light and dark, and in the tropical regions, there are seasons of wet monsoons and dry periods. These identifiable annual cycles are like the cycles of the climate of the Earth over vast eons of the geologic eras.

Geologists estimate the age of the Earth at about 4 billion years old. For much of that time, it was a ball of gas, then the scene of enormous volcanic activity, and then weather activity dominated the whole of the Archaic or Pre-Cambrian eras of Earth's history. During that time, repetitions of climate patterns may have occurred, but there were also dramatic changes. There was a time when oxygen came to be a major part of the atmosphere, when it was not as abundant as now. These point to cycles in the climate, or the long-term average of the weather on Earth.

The last ice age ended around 12,000 years ago. However, it was not the first ice age on Earth, nor the last. It was only the end of the most recent ice age. There were at least three others in the recent history of the Earth. These ice ages, between interglacial periods, are identifiable cycles of climate in the history of the Earth.

One possible cause of cyclical changes in Earth's climate is its orbiting of the Sun (the Milankovich cycle). The solar calendar is keyed to the annual journey of the Earth around the Sun. It is a journey that occurs every year and causes seasonal change. Although there are the same seasons every year, they are never exactly alike. Astronomers and others have observed that there is a cycle that some set at roughly 24,000, or 48,000, or even 72,000 years. The cycle is believed to be responsible for climate changes because the Earth wobbles a bit as it orbits the Sun due to the variations in the gravitational pull of other planets and of the Sun itself. The slight changes in orbit and the tilt of the Earth in relationship to the Sun's rays means more or less sunlight hitting the Earth, increasing or reducing the amount of energy available to warm the Earth and its atmosphere.

Some scientists believe that ice ages may be caused by the variations in sunlight hitting the Earth during its solar journeys. However, the amount of sunlight during the solar journey has to be combined with solar variations. The sun goes through cycles of activity in which varying levels of energy are emitted. The solar energy variations are related to the presence and absence of sunspots. Increases in these are likely to also bring about an increase in aurora lights, in both the Northern and Southern Hemispheres. The aurora lights are connected to the magnetic field of the Earth. Researchers studying the sun's magnetic activity over 100,000-year cycles have proposed the theory that the climate of the Earth is affected by this solar activity cycle. Waldo S. Glock attempted to show a relationship between the weather as a part of a climate pattern and variations in periodic solar activity.

The pattern that paleoclimatologists have discovered is one that describes significant climatic changes with relatively small changes in the Earth's solar orbit. The variations in sunlight have been compared to variations in weather on Earth. Instruments have been developed to measure the amount of solar energy striking the Earth. Cycles have been detected using data from weather records. Weather records have also been compared statistically with wheat prices. The higher the price of wheat in historically available data, the poorer the weather likely was. Other plant information that has been available to study climate cycles is found in the rings of trees. Dendrochronology is the study of tree rings over time. Trees grow faster in wet warm years than in dry years or in cooler times.

The discovery of climate cycles that has been verified by a variety of sources points to the current phenomenon of global warming. However, it was preceded by an ice age in which there was global cooling. Consequently, the Earth has experienced both global cooling and global warming in its 4-billion-year-old history. Opposed to theories of climatic cycles is the fact that the climate of the Earth also changes in non-cyclical ways when charted on a variety of timescales.

There are shorter cycles, such as the El Niño Southern Oscillation, the Pacific decadal Oscillation, the Arctic Oscillation, and the North Atlantic Oscillation, the 1,500-year cycle from ice core samples, and the sunspot cycle (the Hale cycle). All of these cycles can be hypothesized from climate records. They are being used in debates over global warming to argue that either the cause is anthropogenic, or that global warming is part of a natural cycle that is only apparently anthropogenic.

SEE ALSO: Aurora; Climatic Data, Historical Records; Climatic Data, Tree Ring Records; Ice Ages; Sunlight.

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Climate Feedback

CLIMATE FEEDBACK (CF) is a direct or indirect partial response (sensitivity) of any component of the climate system (for example, clouds, atmospheric chemical composition, or atmospheric water vapor) back on the Earth's near-surface temperature (NST) that was initially offset by an external to the climate system forcing. An initial disturbance of the NST comes from a change in the physical properties of the surface (for example, due to human agricultural activities) or atmosphere (for example, an industrial increase of greenhouse gases), or occurs due to the presence of an external to the system's heat source (such as urban heat islands). When the NST is initially forced, a feedback either amplifies (positive feedback) or damps/controls/scales (negative feedback) the effect of the disturbance back on the NST.

CF should be differentiated from radiative feedbacks (RF), which represent a response of the NST back to the radiative balance at the top of the atmosphere (TOA), which was initially offset by an external forcing. The radiative balance (RB) at the TOA is the difference between the incoming into the Earth's solar radiation, and the outgoing terrestrial radiation. Both CF and RF are components of a climate feedback loop's network. The system's net feedback loops effect (netFLE) accounts for all possible influences of the climate variables on each other and is compounded with direct and indirect feedback loops.

There are many CFs that are recognized in the Earth's climate system of interactions. Among them are water vapor feedback, lapse-rate feedback, ice/snow albedo feedback, carbon cycle feedback, biogeochemical cycles feedback, dynamical feedback, ocean circulation and marine life feedbacks, and cloud feedbacks. In most cases, feedbacks can be expanded further to a set of other feedbacks in accordance with the physical properties of a climate variable in relation to the NST. Thus, a cloud feedback is expandable to changes in cloud cover, cloud top temperature and/or height, cloud optical thickness, or cloud droplet size. It is recognized that, for the climate system, the most important CF is water vapor feedback, which is closely coupled to lapse-rate and cloud feedbacks.

There are direct (one-to-one relationships between temperature and a climate variable) and induced (via other variables) CFs. Another term for induced feedback is *indirect feedback*. Due to the atmospheric, oceanic, and land processes interactions, most of which depend on temperature, the direct CFs compete with, and are enriched by, the induced ones. Sometimes, it is possible to find a scale in time (such as annual or decadal) and space (such as regional or global) where a separation of the climate variables into fast and slow varying ones is possible, and the climate system can be simplified to understand and predict its evolutionary paths. Slow varying variables define slow feedbacks. Fast feedbacks, acting along a chain of interactions, cancel each other, affecting the tendencies of the climate system evolution. An example of a fast negative CF is a lapse-rate feedback (sometimes termed *atmospheric temperature profile feedback*), which establishes the atmospheric temperature profile and the magnitude of the near-surface temperature in response to surface heating in a matter of hours. An example of a slow positive CF is a global ice-albedo feedback, which is active over many centuries and brought the Earth to the ice ages and back.

Strength of the feedbacks is defined by climate system composition (for example, how many elements of the climate system are under consideration), an initial state (for example, the recent climate, or an ice age), and the nature of the relationship among climate variables spanned over spatial and time domains. For example, an atmospheric feedback initiated by surface warming due to an increase in carbon dioxide is different in dry and moist atmospheres: the presence of water vapor in the atmosphere increases the strength of the dry atmosphere positive feedback on the surface temperature. Feedbacks initiated in a cloudy and/or polluted atmosphere are different from ones initiated in a clear (no clouds) and clean (no aerosols) atmosphere. Feedbacks resulting from a volcano confined to the polar vortex region (or just to one hemisphere) will be different from the feedbacks resulting from a tropical volcano eruption.

A general measure of CFs is the climate sensitivity (CS), or its reciprocal, a climate feedback parameter (CFP). The CS depends on a netFLE and where climate forcing is in place. The CS and CFP are easily estimated from the numerical models as they represent a closed description of the model climate state's evolution and they allow for executing "sensitivity" experiments with a model. Differences in the model

CS estimations are explained by implementation of a slightly different set of feedbacks (such as that related to clouds) that amplify or dampen the initial perturbation. It is difficult to infer CS from the observations, as they do not supply a complete and continuous mirror of the real world, and each observational climate state carries footprints of numerous non-attributed forcings from the present and past. Without a model, it is difficult to recognize a single feedback or a single feedback loop, or to validate an estimated model feedback with observations. However, observations are the only source to validate model parameterizations, which are approximations of the climate system feedbacks.

SEE ALSO: Biogeochemical Feedbacks; Climate Forcing; Climate Models; Dynamical Feedbacks; Evaporation Feedbacks; Ice Albedo Feedback.

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Climate Forcing

CLIMATE FORCING OCCURS when the global energy balance of the Earth is changed. There are a number of mechanisms that can force climate change. The Earth's global climate is a dynamic system that is in equilibrium. On a planetary scale, it is steered by the amount of energy available in the system for use by its various ecosystems. If the amount of energy stored or received in the climate system changes, then climate changes occur as well. The global climate is affected by the Sun, which provides much of the energy in the global energy balance. If the energy from the Sun increases or decreases, climatic changes will likely occur. On the other hand, if the amount of energy kept by the Earth from sunlight increases, then climate changes will also occur.

The flows of energy occurring in the planetary climate system are important to the global climate system. The global climate system includes the heated core of the Earth and the parts of the Earth that receive the Sun's energy. The parts of the Earth's climate system include the atmosphere, the oceans, the cryosphere (ice caps at the poles and the alpine glaciers), the geosphere (for example, the reflective desert sands), the dense foliage of the tropics, the vast forests of the temperate and boreal zones, and other parts of the biosphere. All of these play a role in the convection system on the planet that transfers heat around the globe.

The atmosphere is central to the Earth's climate, which is a mixture of gases and aerosols (suspended liquids and solid articles). Commonly known as the air, the atmosphere is mostly nitrogen and oxygen. These two gases are available in amounts of about 78 percent nitrogen, 21 percent oxygen. They total about 99 percent of the air that surrounds the planet. The remaining gases and aerosols are present in only trace amounts; however, the greenhouse gases (such as carbon dioxide, methane, and nitrous oxide) play an extremely important part in the energy dynamics of the planet's global climate.

Greenhouse gases regulate the amount of heat that is present in the lower atmosphere. The gases capture radiant infrared energy and bounce it back to Earth. The gases act as a thin thermal blanket and have a natural greenhouse effect. As a result of greenhouse gases, the temperature of the Earth is 33 degrees C warmer than it would be otherwise. However, since the Industrial Revolution began about 200 years ago, the volume of human-made greenhouse gas emissions has increased enough to affect the greenhouse gas effect and to cause global warming.

Convection is the mechanism through which many energy transfers in the system are exchanged. The oceans are heated by the energy of sunlight. The sunlight is a system input that dynamically affects the global climate on a planetary scale. The output in the system is that most of the Earth's sunlight warming occurs in the tropics on either side of the equator. The warm seawater evaporates and rises, forming a lower pressure over the oceans and seas of the tropics and the land, as well. The rising warmer air is replaced by cooler, denser air flowing in from the polar regions. Movements in the atmosphere are also heat transfers. The atmosphere also stores energy. About 70 percent of the Earth's surface is covered by water. The oceans are energy storage centers that contain, in their top 656 ft. (200 m.) of ocean water, 30 times the amount of energy that is stored by the atmosphere.

The continental and alpine glaciers of the high mountains contain most of the Earth's cryosphere. Filled with ice and snow, and frozen by subzero temperatures for much of the year, the white surfaces reflect vast quantities of energy that would otherwise be absorbed by the Earth. The global climate system would then have a major energy source that would affect the dynamics of the interrelated parts of the system, and thereby invoke major changes in its output.

The plant portion of the Earth's biosphere (all living organisms, including humans) uses carbon dioxide and sunlight to photosynthesize food for growth. The oceans play an important role in this process because plankton, while microscopic, consume vast quantities of carbon dioxide. The gas is locked away in carbonate shells, which sink to the ocean depths. In the planetary climate system, this portion of the biological part of the system reduces the amount of carbon dioxide in the atmosphere and thereby weakens the greenhouse gas effect. Both the sunlight reflection of the cryosphere and the biosphere reduce the energy in the global climate system, thereby cooling the Earth. Clouds and the upper levels of the atmosphere also play a role in the global climate system. Clouds reflect vast volumes of sunlight into outer space. Energy in the form of x-rays, gamma rays, or ultraviolet energy is also reflected back into outer space.

The global energy balance can be affected by changes on Earth, such as an increase in volcanism. Active volcanoes send huge clouds of gases and ash into the atmosphere. If the volume is sufficiently large, the input of gases and ash to the system can affect the planetary climate system by blocking the amount of the available energy and temporarily forcing cooling of the planet. The major question is whether rising levels of anthropogenic carbon dioxide are forcing global warming.

SEE ALSO: Anthropogenic Forcing; Carbon Sinks; Cloud Feedback; Greenhouse Effect; Ocean Component of Models; Sunlight; Volcanism.

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Climate Impacts LINK Project

THE CLIMATE IMPACTS LINK Project (LINK) provides climate model data harvested at the Met Office Hadley Centre (MOHC) for use by researchers, institutions, companies, and political organizations. These users are located both in the United Kingdom and abroad; the data from LINK impact many fields such as marine biology, aviation, civil engineering, public policy, economics, and atmospheric sciences.

LINK is supported financially by the United Kingdom's Department of the Environment, Food, and Rural Affairs (DEFRA), based in London, England. DEFRA, in fact, established LINK in 1991, and assigned the Climate Research Unit (CRU) at the University of East Anglia (UAE) to handle the data. The task became too large for the computer systems at the UAE Climate Research Unit and the contract was sublet to the United Kingdom's British Atmospheric Data Centre (BADC). The CRU maintained the ancillary data responsibilities until the year 2006 when those, too, were taken over by the BADC. Subsequently, the duties were subcontracted to the MOHC by the BADC, though still overseen by the BADC.

The BADC, overseen by the United Kingdom National Environment Research Council (NERC), acts as the chief data center for Atmospheric Sciences and reports to the NERC. It was established in 1994 to take over the responsibilities of the former Geophysical Data Facility. At the time, it was funded by NERC's predecessor, the Science and Engineering Research Council (SERC) and generally supported research concerned with the atmosphere within approximately 6–249 m. (10–400 km.) above the Earth's surface. Today, the broader NERC supports all atmospheric science.

DEFRA works to reduce greenhouse gas emissions both domestically and internationally. Its other chief goal of the Department is to foster a clean, healthy environment for people to live and work in. To achieve this second goal, DEFRA is a strong proponent for sustainable development. It works to achieve this in rural settings, urban communities, within the European Union, and beyond.

LINK uses several models to analyze the data at the MOHC. These models include the HadCM2 (Hadley Centre Coupled Model versions 2) and HadCM2 (for global datasets), HadRM2 and HadRM3 (high resolution regional atmospheric models), and HadGEM1 (an integrated model for both types of data). The HadCM2 and HadCM3 (Hadley Centre Coupled Model versions 3) models were used for the International Panel on Climate Change (IPCC) Second and Third Assessment Reports to the United Nations, respectively. The newer HadGEM1 along with the HadCM3 models were both used for the Fourth Assessment Report. The regional HadRM2 and HadRM3 models cover European climates and the latter contributed data to the United Kingdom Climate Impacts Programme 2002 Scientific Report on Climate Change Scenarios for the United Kingdom (UKCIP02). The 2008 report (UKCIP08) will also use data from the HadRM3 model.

SEE ALSO: CLIMAP Project; Climate Action Network; Climate Change Knowledge Network; Climate Models; European Union; Greenhouse Gases; Hadley, George; United Kingdom; United Nations.

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Climate Models

CLIMATE MODELS ARE quantitative representations of the earth, its atmosphere, and the ways in which they interact to influence the climate. Models range from the comparatively simple to the extremely complex and their range, complexity, and predictive power have increased significantly in the 21st century as computational power has increased. The ability of scientists to create sophisticated climate models is of several magnitudes of order beyond what was possible even a few years ago.

Scientists use mathematical formulae, combined with the modeling ability of computers and available data sources, to create an understanding of how climate and weather effects work in different parts of the atmosphere. The purpose of the models is not just to understand atmospheric interactions, however, but to predict how they will work in the future. Predicting the weather will be of great benefit in helping people prepare for adverse phenomena such as hurricanes and typhoons, as well as the longer-term effects of drought or floods.

Further, as evidence has begun to accumulate that increased release of carbon dioxide and other gases is having a significant effect on the warming of the atmosphere, climate models have acquired the additional role of predicting the future of the world's climate and the effect of constant warming of the atmosphere.

This has led to some controversy because there are powerful economic and political incentives for some to try to demonstrate that atmospheric warming, and hence, global climate change, is not a long-term, persistent phenomenon or, if it is, that it is the result of human actions. Climate scientists have found themselves, their motives, and their methodologies questioned, much more fiercely than before and not every scientist has been comfortable with this development.

Academic discourse and the scientific method require knowledge to be accumulated in a systematic method subject to peer review, which means that most scientists are, quite properly, hesitant about giving simple, unequivocal answers to questions that require 'yes' or 'no' answers. The entire academic process is not transparent to outsiders and it is difficult to refute criticism.

THE SCIENTIFIC BASIS

The fundamental climate change equation concerns the exchange of heat in the atmosphere. Heat is transmitted to the atmosphere from radiation from the Sun. Some of the heat energy is absorbed and some reflected. The amount of energy reflected depends on the albedo of the surface and can be affected by variables such as color, elevation, and shape. If more energy is retained than reflected, then the atmosphere will increase in temperature, but temperatures will decrease if the opposite is true. This equation is affected by the composition of the atmosphere, among many other factors. While the equation appears navigable, in fact the complexity of the atmosphere is such that it is extremely difficult to write accurately.

Scientists in the 19th century attempted to create the equation using the mathematical and analytical tools available. At that time, the number of atmospheric observations and the extent of their coverage were very limited. As observations improved in quality and quantity, the ability to model the equation improved. Scientists realized that the wind system was not consistent acround the world and, consequently, what happened in one part of the world was different from another part of the world, even with similar initial conditions. Consequently, it became a logical step to divide the surface of the world into smaller subsections on a grid basis and attempt to solve the equations and, hence, predict the weather, for each grid square.

However, these efforts failed as it became clear that solutions required contemporaneous computational power. It was practically impossible to predict the weather by solving equations for grid squares more quickly than weather elapsed in real time. Consequently, new forms of modeling were considered.

Serendipitously, World War II provided a significant boost to climate modeling because, for military purposes, the extent and range of atmospheric observations increased enormously. As the war gave way to the Cold War, that level of observation continued and, in some ways, intensified. The launching of satellites and attendant technology was also beneficial in this respect. These observations helped to reveal the global patterns of wind and wave circulation and helped to identify variations across the globe and the reasons for them.

Scientists had abandoned the idea of using a single equation (no matter how complex) to represent the whole atmosphere on practical grounds; now there was further proof that such an approach was flawed on scientific grounds. In the years since then, scientists have approached the problem by treating the relevant individual variables with increasing sophistication. For example, the first generation of models included as a variable the Earth's surface, which was posited to have properties that were an amalgam of both land and water. While this approach would give an approximate result at the global level, at lower levels the results would vary from real life conditions.

Subsequent iterations of models have increased the sophistication of the treatment of the surface by dividing land and sea areas, with different types of elevation and of albedo, as these clearly have an impact on the circulation of the atmosphere. In the third generation of models, land is now treated as having up to three levels: the base level of the ground itself, a possible layer of snow or ice overlaying the ground, and a possible third layer of vegetation. Because these conditions can change quite rapidly, it is clear that constant surveillance of both the atmosphere and the Earth's land cover are required. Areas such as the Amazon rainforest, for example, are being rapidly deforested; this can have a significant impact on how models should be constructed, since it has an impact upon the circulation of the atmosphere. For example, stubble burning in Indonesia annually produces a heavy pall of smoke over much of island Southeast Asia, affecting the atmosphere to the extent that it should be considered in climate models. Volcanic activity is less predictable, but can also have a strong impact upon the atmosphere.

COMPUTATIONAL POWER

Clearly, the need to deal with these variations requires an enormous amount of computational power. This power has not been available until recent years. In 1965, the computer scientist Gordon E. Moore predicted that, because of the increasing sophistication with which transistors could be placed upon a circuit board, computational power was doubling approximately every two years. Moore's Law has continued to hold true until the first decade of the 21st century, although it is through different technologies that the improvements are made. The result is that modeling of the atmosphere with multiple, rapidly changing variables has become possible for the first time.

When a single computer is insufficient for computations required or the amount of data and observations collected, it is also now possible to use distributed networks of computers that use spare computing power to contribute to analyses over a comparatively lengthy period of time. Owing to the very high level of penetration of personal computers in Western societies, as well as cheap and reliable internet access, it is possible to use spare capacity on machines belonging to members of the public who are willing to subscribe to the scheme. This shows, among a number of other changes, that personal computers are now hugely more powerful devices than were available to even the most advanced scientific researchers just a few years ago.

ADVANCED CLIMATE MODELS

Climate models have now reached a third generation of variants. They have, in the more than one century of iterations that have taken place, added a considerable level of sophistication to the original approaches. Models now attempt customarily to explain the entire global system instead of regional or partial attempts, owing to the greater level of understanding of the heterogeneity of interactions around the world.

Nevertheless, the basic approach remains the same, in that the atmosphere is divided both vertically and horizontally into sections. This entails dividing the surface of the earth into a series of two-dimensional squares that are then provided with a three-dimensional element of height. Early models posited a homogeneous surface cover that was a composite of land and water. Subsequently, grid squares have been accurately divided into those areas which are land and which are sea, together with possible layers of ice with an additional variable concerning land cover. Degrees of salinity and the exchange of salt between land and sea ice have also been integrated, as have up to several dozen vertical layers of the atmosphere. The models themselves are divided into three principal component areas; the land, the sea (and the ice), and the atmosphere. To make improvements more feasible, researchers will tend to work on one of these component areas individually, although this is not required.

Climate modelers create their own individual models, which are similar in basic approach but vary in the forcings, or weighting given to specific variables within the model. The different weightings, like variations within the initial conditions ascribed to the model, will produce often significant changes in predictions, especially over the long-term if variations become magnified with regular, perhaps annual, increases in the relevant variables concerned. Consequently, it is prudent to run a series of simulations with marginally different initial conditions and forcings to consider possible outlying results.

DATA

The ability of climate modelers to integrate the increasing number of variables into their models and add more sophisticated techniques for modeling the interactions between them relies to a considerable extent on the greatly enhanced number of data observations and their accuracy. Generations of weather balloons and their successors, for example, have been instrumental in the enormous increase in volume and scope of observations that are now available. Expansion of satellite coverage of the world, often driven by military objectives, has also increased the amount of data.

However, few data observations are of the depth required for sophisticated new models. To supplement actual observations, therefore, it has been necessary (and very helpful) to consider the evidence from past records, such as ice cores and tree-ring growth, which provide a considerable amount of useful information dating, in some cases, back many thousands of years. In other cases, proxy variables are used, especially for those variables which it is not possible or practical to measure directly, no matter how advanced the measuring technology may be.

The use of proxy variables and the comparatively narrow temporal range of some crucial observations means there is some equivocation in results and this, again, means it is prudent to take a broad view of results and simulations from models used around the world, which use a variety of initial conditions and weightings. Many scientific institutions make their data freely available for just this purpose.

SEE ALSO: Atmospheric Component of Models; Atmospheric General Circulation Models; Climatic Data, Atmospheric Observations; Climatic Data, Proxy Records; Computer Models; Historical Development of Climate Models; Ocean Component of Models.

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Climate Sensitivity and Feedbacks

CLIMATE SENSITIVITY IS generally defined as the global mean surface temperature change that is followed by the doubling of carbon dioxide (CO_2) in the atmosphere. Put simply, climate sensitivity is the amount that temperatures rise or fall in response to alterations in climate.

Since 1990, official estimates of climate sensitivity have ranged between 2.7–8.1 degrees F (1.5–4.5 degrees C). In the summer of 2004, at the Workshop on Climate Sensitivity, researchers generally agreed that temperatures have warmed by 0.6 degrees C over the last 100 years. Feedbacks are mechanisms that amplify or diminish climate change. Examples include water vapor, land ice-cover, vegetation cover, and ocean heat transport. Feedbacks may be affected by physical processes such as wind, snow, and seasonal variations.

Climatologists have identified three major ways in which climate sensitivity and feedbacks may be studied using computer models. The first method uses a three-dimensional global climate model according to a specified formula based on CO_2 doubling. The second uses CLIMAP climate boundary conditions to produce an analysis based on the cooling of the last ice age, which occurred approximately 18,000 years ago. Finally, climatologists analyze climate sensitivity by estimating the changes in global temperature, in conjunction with the presence of greenhouse gases, to estimate empirical climate sensitivity. In computer models designed to estimate climate change, feedbacks are used to determine the magnitude of predicted climate changes, as well as the time span in which the changes are likely to occur. Results vary among climate sensitivity models, because of the differences in the ways in which climate feedbacks are handled in the particular model used.

As early as 1984, a study of climate sensitivity and feedbacks conducted by James Hensen, et al., determined that increased levels of greenhouse gases in the atmosphere were indicative of eventual global mean warming of approximately 1 degree C, a reading that was comparable to the Altithermal, a dry postglacial interval that is believed to be the warmest period on earth over the last 100,000 years. Beginning in the late 20th century, the Intergovernmental Panel on Climate Change (IPCC), established by the United Nations Environment Programme (UNEP) and the United Nations World Meteorological Organization (WMO), began issuing assessments of the scientific and socioeconomic data that were available on climate change. These assessment reports have greatly contributed to the understanding of global warming and climate change, although they have continued to generate considerable controversy.

STEADY TEMPERATURE RISE

The Third Assessment Report (TAR) was released in 2001, predicting that average surface temperatures of the Earth would increase steadily between 1990 and 2100, with estimates ranging from 2.5–10 degrees F (1.4–5.8 degrees C). At the same time, IPCC researchers predicted that sea levels would continue to rise steadily. Despite these pessimistic predictions, IPCC scientists generally believe that human behaviors, which are considered contributory factors in global warming and climate change, may alter predictions if humans begin to engage in more environmentally responsible behavior. Examples of possible responsible actions include making drastic reductions in CO_2

emissions and eliminating use of aerosols and some pesticides.

TAR findings have consistently been used to support the notion that a consensus exists among scientists concerning global warming. The Third Report acknowledges that considerable confidence exists in the ability of climate sensitivity and feedback models to predict future climate changes, but notes that many such models fail to account for all elements of climate change. A fourth IPCC report, released on April 27, 2007, employed tens of thousands of data series on climate sensitivity and feedbacks to more fully assess current conditions and make more accurate predictions on the future of global warming and climate change.

CONTROVERSY AND IMPROVEMENTS

A number of scientists continue to take issue with the position taken by IPCC scientists. Some find fault with the entire concept of climate sensitivity. The debate about climate sensitivity modeling is so great that it is sometimes called SWAG (a "scientific wild-ass guess").

Some researchers find fault with measurement techniques, while others insist that global warming and climate change are responses to geophysical occurrences rather than irresponsible human behaviors. A good deal of the controversy about climate sensitivity modeling results from disagreements on the best ways to characterize feedbacks, because variations in the ways that feedbacks are employed in various models produces vastly different results.

The uncertainty of climate change predictions based on cloud feedback are arguably the most frequently-cited evidence that climate sensitivity models are inaccurate predictors of future climate patterns. In most models, cloud feedback is perceived as a positive indicator of global warming. In others, cloud feedback is viewed as a neutral mechanism. Many researchers insist that some uncertainty in predicting global warming through climate sensitivity modeling is inevitable.

Reasons given for this inherent uncertainty include gaps in the understanding of the physical processes that contribute to feedbacks, the fact that interactions among the various processes are likely to be complex, and the dynamic nature of climate. Ongoing attempts to make the use of feedbacks in climate sensitivity predictions more accurate have led to the use of supplementary observational studies, such as those that include data gathered from satellites. Another way in which scientists are trying to make climate modeling more accurate is through the use of Climate Process Teams (CPT), in which groups of scientists work together to improve the prediction process. The National Center for Atmospheric Research (NCAR) and the Geophysical Fluid Dynamics Laboratory (GFDL) have developed two models that are widely used by American researchers in predicting global warming and climate change.

Using low-latitude cloud feedbacks, team members have arrived at vastly different predictions. The NCAR team first used the Community Climate Model (CCM), which they developed in 1983 for use by the global research community. In 1994, NCAR introduced an improved model, the Climate System Model (CSM), which uses atmosphere, land surface, global ocean, and sea ice feedbacks. Research at GFDL combines computer modeling with specialized observations based on the atmosphere and oceans, and on chemistry and biology, to make predictions on climate change.

SEE ALSO: Attribution of Global Warming; Carbon Dioxide; Climate Feedback; Climate Models; Cloud Feedback; Computer Models; Intergovernmental Panel on Climate Change (IPCC).

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Climate Thresholds

CLIMATE CHANGE IS not always a gradual process. Just as the weather includes both the ordinary passage of seasons and unpredictable, extraordinary events, such as devastating hurricanes and droughts, so, too, does climate change entail both gradual processes and the sudden, sharp changes called climate thresholds. These thresholds are hypothetical—that is, they have not been observed directly, though it is believed that they have happened in the past.

Methane is often implicated in climate threshold theories. A powerful greenhouse gas, methane is contained on the Earth in a number of forms that could be unlocked all at once by sufficiently warm temperatures. For instance, in western Siberia, permafrost peat bogs that have remained frozen since the end of the last ice age are beginning to thaw; if they continue to do so, they will release large amounts of dissolved methane in a sharp spike rather than the gradual increase seen in the past. The clathrate gun hypothesis focuses on an even larger supply of methane: the methane clathrate (ice containing methane) found in enormous amounts on the cold ocean floor. Sufficient warming would melt the ice, releasing enough methane over a short period of time to severely accelerate global warming.

The most severe mass extinction, much greater than the extinction of the dinosaurs, is the Permian-Triassic Extinction. The event caused the extinction of over 90 percent of sea life and two-thirds of terrestrial vertebrates, about 250 million years ago (before the birth of the dinosaurs). This was also the only known mass extinction of insects, at a time when they enjoyed their greatest diversity and largest size. The sudden emptying of so many niches in the ecosystem likely accounts for the success of fungi, and of bivalves such as oysters, both of which were rare before the extinction but which survived and thrived after it.

There is evidence of an extraordinary release of methane at about this time. The only known possible cause of such a release would be the melting of oceanic methane clathrate, which could explain why the Permian sea life was affected much more than land-dwelling life forms. Seen in this light, catastrophic scenarios for global warming no longer seem unprecedented.

Any positive feedback to the greenhouse effect can force a climate threshold. Such an occurrence is called a runaway greenhouse effect. Most positive feedbacks, even strong ones, are obviously not runaway effects; it must be a self-perpetuating feedback, such that the effects are stronger every time it "loops" back around. Runaway greenhouse effects not only cause a rapid rise in temperature, they are fed by rising temperatures until something changes the system sufficiently to reduce the effect or achieve equilibrium. The planet Venus certainly resembles the aftermath of a runaway greenhouse effect, whether or not that is how it developed.

SEE ALSO: Abrupt Climate Changes; Earth's Climate History; Greenhouse Effect; Greenhouse Gases; Species Extinction; Triassic Era.

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Climate Zones

FROM THE POLAR regions to the temperate zones to the tropics, there are different climate zones that create different habitats. Within the tropics, the temperate regions, and the polar areas, there are varying amounts of sunlight, water, temperatures, and soil conditions that are the product of proximity to large bodies of water, to lack of rainfall, and to the elevations in specific areas. Like the Alpine region of Europe, each of these regions is found in different climate zones.

Climate is the long-term weather pattern (for at least 30 years) in an area. The climate includes general patterns and extremes of drought, rains, storms, and freezing temperatures. Air temperature and precipitation are two of the most important factors affecting the climate of a region. The world's biomes are regulated by their respectively localized climates. It is climate that determines what plants grow in a locality and the animals that can inhabit it.

THE KÖPPEN CLIMATE CLASSIFICATION SYSTEM

In 1900, the Russian-German climatologist Vladimir Köppen presented the scientific community with a system for classifying the world's climates. Today, it is called the Köppen Climate Classification System. It divides the Earth's surface into climatic regions that generally coincide with world patterns of vegetation and soils. The system has five major climate types. These are based on averages of annual rainfall and temperatures. The annual averages are combined with the monthly rain and temperature statistics. The Köppen System gives each zone a letter name. A is for Moist Tropical Climates, where the temperature is warm all year long, but usually within a narrow range. In addition, there dry seasons followed by wet seasons, which are often the result of monsoon winds.

Zone B is for Dry Climates, which have little rain and a wide daily temperature range, hot in the day and cold at night as radiant heat is returned to outer space. This zone has two subgroups: the semi-arid or steppe regions (S) and arid or desert (W) areas. The C zone is the Humid Middle Latitude Climate, where the land and water differences are the determining factors. These are zones that have warm dry summers and wet, cool winters. D zones have Continental Climates. These climates are in the interior of large landmasses such as central Asia or central North America. The total precipitation can range from low to above moderate. The seasonal temperatures range widely. Zone E climates are the Cold Climates. These are the regions of permanent ice and tundra. Summer temperatures are above freezing, but not enough to melt most of the accumulated ice and snow, or the permafrost.

The Köppen Climate Classification System divides the major five zones into sub-zones. These are assigned a lowercase letter to distinguish specific seasonal characteristics of temperature and precipitation. A lowercase "f" designates zones that are moist year-round. In these zones there is no dry season, with precipitation usually every week or so. The lowercase "f" is usually assigned to zone A, C, and D climates. Lowercase "m" is used to designate rainforest climates. This sub-zone has a short dry season that is monsoon in character, but the rain is enough to create a forest that feeds on a nearly constant rainfall. The lower case "m" sub-zone is assigned to A zone climates. The lowercase "s" stands for the places that have dry season in the summer. This letter applies to summer in both the Northern and Southern Hemispheres. In contrast, lower case "w" is used for localities that have a dry season in the winter. The letter is applied to winter in both the Northern and Southern Hemispheres.

The Köppen Climate Classification System has been refined to account for subtler variations in climates. A third letter is applied to denote these sub-zones. The lowercase letter "a" is used to indicate hot summers where the summertime temperatures are above 72 degrees F (22 degrees C) in the warmest month. Zones C and D are climates where these conditions prevail. The lowercase letter "b" is used to indicate areas where there are warm summers with the warmest month below 72 degrees F (22 degrees C). Again, these conditions are found in Zone C and D climates. Lowercase "c" is used to indicate areas with cool, short summers. In these areas, the summertime lasts less than four months. The temperatures reach over 50 degrees F (10 degrees C). Zone C and D climates have areas with these conditions. Areas with a "d" designation have very cold winters, with the coldest month having temperatures that reach below minus 36 degrees F (minus 38 degrees C). Areas with these conditions are found in the D climate only.

An "h" designation means the area is dry-hot with an average temperature that reaches to above 64 degrees F (18 degrees C). These conditions are found in B climates only. Areas with a lowercase "k" designation have dry-cold climates. These are areas with annual weather conditions where the average temperature does not get above 64 degrees F (18 degrees C). These conditions are found in B climates only.

The climate zones can also be described as Low-Latitude, Tropical Rainforests, Tropical Savanna, Middle-Latitude, Marine West Coast, Humid Continental, Humid Subtropical, Mediterranean, Continental Steppe, High-Latitude, Sub-arctic, Tundra, Polar Ice, Dry Climate, Desert and Highland Climates. All of these zones are related to their location relative to the poles, the temperate zones, the tropics and the equator, in combination with factors of altitude, proximity to the sea, and wind directions. In each one, plants and animals have adapted to the environmental conditions of that zone. The environmental conditions are products of latitude, temperatures, precipitation, elevation, sun exposure, humidity, and the direction of the winds that traverse the region.

HARDINESS ZONES

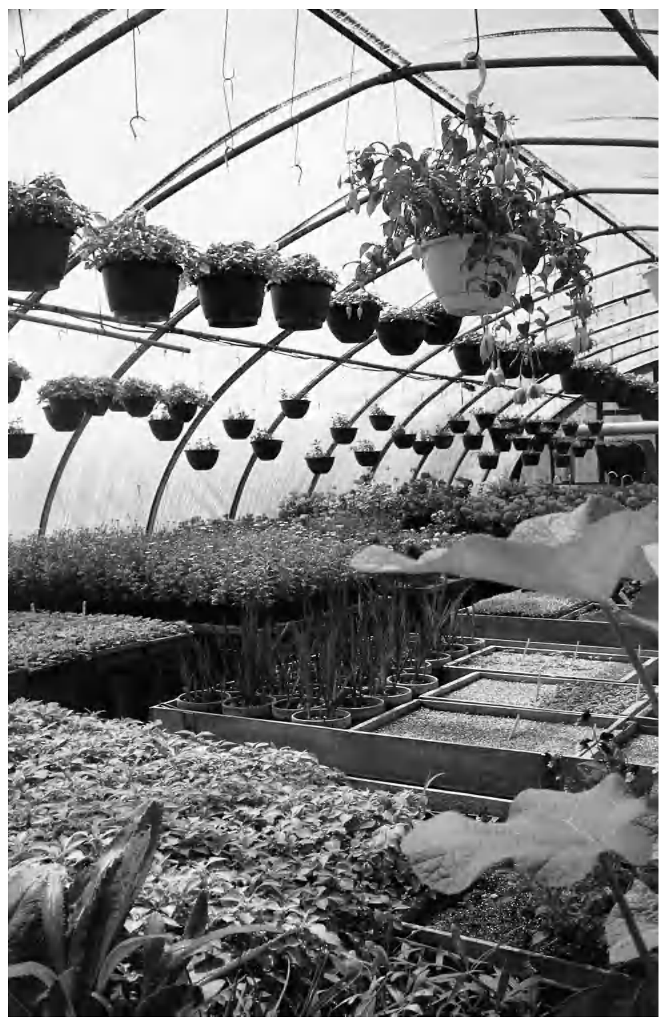
An important system of climate zones used for gardeners is that developed and maintained by the U.S. Department of Agriculture (USDA). The zones have been developed in cooperation with the National Weather Service (NWS). These zones have been called hardiness zones as well as climate zones. They are based upon 60 years of accumulated weather data recording wintertime temperatures. The hardiness zones are bands that straddle the North American continent including both the United States and Canada.

Maps of the hardiness zones are found on most packages of flower or vegetable seeds sold by professional growers in the United States. They are also put onto the tags that are tied to trees and shrubs or other plants sold by gardening centers or by professional nurseries. Similar standards have been applied in Europe and on other continents. When gardeners, landscapers, farmers, and others know their hardiness zones, they are able to choose more wisely plants that will flourish in that zone.

EFFECTS OF GLOBAL WARMING

Some scientists have issued warnings that the current climate zones may disappear. There will always be zones, as long as there is an atmosphere covering the Earth. However, the changes wrought by global warming are creating new, previously unknown climate zones with some warmer, others drier, others colder, and others still changing. Climate models that are global in scope are forecasting that several existing climate zones in a number of places around the world may completely disappear. The threatened zones include tropical highlands, regions near the poles, vast areas of the tropics, and the subtropics.

Among the areas most severely affected are the southeastern United States, southeastern Asia, parts of Africa, the Amazonian rain forest, and the African and South American mountain ranges. The shifting zones will develop new ecological systems, with the loss of many species from the area. In general, the climate zone models show changes will shift some zones to higher latitudes and to higher elevations. Species of flora and fauna that now flourish in current conditions at high altitudes will either adapt to the advances of lower elevations, or perish because they have no place higher to go. Shifting wind and rain patterns with warmer temperatures will affect ecological



The hardiness zone information on potted plants is based on 60 years of weather data and is related to climate zones.

systems. Because most species cannot migrate, there will probably be enormous losses in biodiversity.

SEE ALSO: Botany; Climate; Climate Models; Geography; Weather.

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Climatic Data, Atmospheric Observations

ATMOSPHERIC OBSERVATIONS FORM the basis for weather prediction and analysis, for monitoring climate and climate change, and for atmospheric and climate research. Observations are carried out routinely and in a well-coordinated manner by weather services and individuals using a variety of platforms and instruments. The range of intentions behind observing the atmosphere leads to different types of data products. For climate trend applications, a number of errors need to be carefully addressed. Climate variables have been measured for centuries, but it has only been possible to construct a consistent global picture of climate trends from these data since the late 1900s.

Atmospheric observations are partial descriptions of the state of the atmosphere, the statistics of which determine the state of the climate system. If these observations are carried out over long time periods, changes in the climate system can be addressed. Most of the observations are measurements, for example, a property of the atmosphere is quantified using instruments.

The most important examples of atmospheric measurement are air temperature, pressure, humidity, wind speed and direction, radiation, and the composition of the atmosphere. However, visual observations of cloud type and fraction, precipitation type, or weather type are also important.

Atmospheric observations require a variety of instruments. In-situ instruments measure the physical or chemical properties of the surrounding air. Remote sensing systems indirectly derive these properties from perturbations of electromagnetic signals passing through the air. Platforms used for atmospheric observations include ground-based stations, ships, buoys, weather balloons, aircraft, or satellites. Sometimes the atmosphere is sampled a posteriori, for example, air samples in glass flasks are analyzed chemically in a laboratory, or the composition of air in bubbles trapped millennia ago in ice are analyzed.

Systematic atmospheric observations require a high degree of coordination, and can be of vital strategic interest. Therefore, they are mostly performed by large, national organizations such as weather services. Global cooperation is achieved through the World Meteorological Organization (WMO), which issues standards and recommendations concerning instruments, calibrations, measurement practices, reporting, and quality control/quality assurance. The WMO also regulates data exchange. Observations are also performed within large research programs.

Atmospheric observations are performed with different intentions. The most common ones are meteorological and climatological applications. Important considerations for meteorological applications are real-time availability, precision, and spatial resolution. These data are typically used for weather forecasting and analysis. Important considerations for climate data are accuracy, representativeness, and long-term stability. These data are used for climate research, planning and risk assessment, or similar applications.

THE UNCERTAINTIES OF CLIMATIC DATA

Long time-series of climatic data are subject to several types of uncertainties. Systematic or random errors in the measurement instruments make up only part of the total uncertainty. Changes in instrumentation, measurement practices, reporting, location, and station environments also contribute to the total uncertainty and inevitably lead to heterogeneous data sets. In order to assess long-term climate trends reliably, systematic errors must be corrected to make different parts of a series comparable, which is termed *homogenization*. For this process, sufficient background information on the measurements (often termed *metadata*) is necessary. Mostly, data are homogenized with respect to a time average such as monthly means. Additional efforts are necessary to address changes in climate extremes. With daily climate data, for instance, it is necessary to homogenize the shape of the distribution function, as negative extremes might be affected differently by an inhomogeneity (such as change in location) than positive extremes.

Another type of uncertainty relates to the changing representativeness of the measurement location over time. Meteorological stations erected a century ago at the outskirts of a city are now often in the city center, and, therefore, represent a more local climate that is subject to urban effects. Depending on the application, this bias is undesired and must be accounted for (for example, when calculating long-term global climate trends).

THE HISTORY OF CLIMATE OBSERVATIONS

Climate observations were performed during the classical epoch. However, instrumental measurements started only in the 17th century with the advent of the Enlightenment. The longest continuous temperature time series is the Central England temperature, which reaches back to 1659. Early meteorological measurements were disseminated through scientific journals and private correspondence, and were studied by the scientists of the Enlightenment.

Around the 1850s, the number and spatial distribution of meteorological stations became such that a global view became possible. Many of the widely-used global climate data sets for the Earth's surface reach back to the second half of the 19th century, comprising surface air temperature, pressure, precipitation, and other variables. There are, however, changes within these data sets that affect the quality of the analyses. National meteorological networks, the Brussels Maritime Conference of 1853 and, after 1873, the International (now World) Meteorological Organization established standards for weather observations. The data quality and coverage over both the terrestrial and marine domains have increased.

Climate and weather data near the Earth's surface only provide a very limited view of the large-scale atmospheric circulation. Upper-air measurements started in the late 19th century, but were rather experimental in the beginning. In many countries, operational upper-air networks using aircraft, kites, and pilot balloons (free-flying balloons tracked from the ground to derive wind profiles) were gradually established during the 1900s to 1920s, while radiosonde networks (weather balloons measuring temperature, pressure, and humidity and transmitting the data to a receiver at the ground) began in the late 1930s and 1940s. The quality of atmospheric observations and international coordination was strongly improved during the International Geophysical Year (IGY) 1957–58. The IGY led to the establishment of meteorological stations in Antarctica, improved networks of weather balloon soundings, atmospheric ozone observations, and to measurements of carbon dioxide (CO_2) in the atmosphere.

Another important step in the history of climate observations was the onset of space-borne Earth observation in the 1970s. Satellites provide a near-global coverage of numerous climate variables, such as sea ice or snow coverage, cloud cover, and the vertical temperature structure, though radiosonde data still form the backbone of the upper-air network. In particular, satellites provide detailed information on the concentration of trace gases and on the amount and properties of aerosols. At least as important as for surface data, quality remains a fundamental issue for satellite data. In particular, the overlap between different sensors is often too short to obtain reliable transfer functions.

CONTEMPORARY METHODS

A huge amount of meteorological data is measured each day and is processed to produce meteorological analyses and weather forecasts. Although observations are irregular in time and space (with large gaps), these applications require three-dimensional data sets on a regular space-time grid. Such data sets are produced from all atmospheric observations (from the Earth's surface, ships, aircraft, balloons, and satellites) using a filtering and interpolation scheme combined with a numerical weather prediction model. The procedure is termed data assimilation, or analysis, and essentially consists of short-term forecasts that are corrected according to the incoming observations, providing new initial fields for the next forecasting time step, and so on.

In large reanalysis projects, this procedure is applied to past observations, thus providing global gridded meteorological data sets for the past approximately 50 years. Only a subset of the global meteorological network is needed for climate observations, but with particular requirements concerning quality and long-term stability. Ensuring the existence of suitable networks is the task of the Global Climate Observing System (GCOS), an institution that is co-sponsored by the WMO and other intergovernmental organizations. Climate data are used for climate monitoring, but also for climate research, such as detection and attribution of climate change or the validation of climate models.

SEE ALSO: Climate Models; Climatic Data, Historical Records; International Geophysical Year (IGY); University Corporation for Atmospheric Research; Vostock Core; World Meteorological Organization.

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Climatic Data, Cave Records

CAVES HAVE PROVIDED climate researchers with several useful ways to learn about past climates. In caves that are connected to the surface, plant (particularly pollen) and animal remains allow scientists to study floral and faunal successions over time, which often reflect concurrent climate shifts. Cave deposits, collectively called *speleothems* (for example, stalagmites and stalagtites) provide interesting information that, though geochemical techniques are still being refined, promises a detailed and well-constrained record of past climate variability.

Caves are commonly found in limestone (calcium carbonate, $CaCO_3$) bedrock settings. When precipitation moves through a soil horizon, it picks up dissolved carbon dioxide (CO_2) produced in organic decomposition, thereby becoming mildly acidic. The acidic groundwater then slowly dissolves $CaCO_3$ bedrock, forming caves over time. Speleothems form when dissolved $CaCO_3$ precipitates from groundwater upon interaction with cave air. As groundwater carrying dissolved CO_2 and $CaCO_3$ reaches the cave interior, CO_2 degasses as a result of the large difference in partial pressure of CO_2 between the soil and the cave air. The water is then supersaturated with respect to $CaCO_3$, causing mineral crystal precipitation on cave surfaces.

Speleothems are ideal terrestrial climate records because they can be accurately dated using uranium series dating, which circumvents problems in carbon dating that complicate other terrestrial records, and because they exist in relatively stable cave environments that experience little or no erosion and may therefore grow continuously, often for hundreds of thousands of years. They can also be found all over the world, at high and low latitudes and elevations, and, therefore, have the potential to provide a wide range of terrestrial climate records.

Climate records are interpreted from speleothems by examining growth rate, stable isotopic composition, organic matter inclusions, trace and minor element composition, and variations in banding or crystal structure.

A cross-section of a stalagmite, for instance, reveals a very thin banding pattern. Uranium series dating indicates that these bands are often annual, especially in areas with a strong rainy season signal (as in monsoon areas). The relative thickness of these bands represents changing growth rates and can provide information about relative amounts of rainfall from year to year, or even variations in biological activity at the surface.

Speleothems, such as these formations in Carlsbad Caverns National Park, may hold valuable climatic data.

Increased biological activity adds more CO_2 to the soil, making the groundwater more acidic and better able to dissolve $CaCO_3$, leading to increased mineral precipitation inside caves. Bands of sediment or sandy material indicate complete cessation of speleothem deposition, which is usually interpreted as severe drought, or severe cold, as in glacial times when there is less meltwater available and groundwater may be completely frozen. Sea-level changes can also be inferred from cave shapes, and mineral or organic growth layers on speleothems in seaside caves.

Stable isotopes of oxygen and carbon, and trace element concentrations are analyzed within the carbonate or in pockets of trapped water called "fluid inclusions." Minor or trace elements can be included in speleothem structure, either via groundwater or airborne dust particles, and can represent changes in temperature or air circulation, or geologic occurrences such as nearby volcanic eruptions. In-cave processes such as mineral recrystallization, evaporative processes (especially in caves near the surface), and whether or not the $CaCO_3$ was deposited in isotopic equilibrium with groundwater, may influence isotopic composition.

If these variations can be discounted, isotopic shifts can be cautiously interpreted. In most carbonate proxy records, shifts in oxygen isotopes reflect changing temperature. In caves, however, temperatures are fairly stable throughout the year, so oxygen isotope variations must reflect a different climate signal. Large variations over hundreds of thousands of years reflect changes in meteoritic water composition related to glacial/interglacial transitions. Smaller-scale changes have been interpreted as variations in surface temperature, residence time of the groundwater in bedrock reservoirs, or changes in moisture source and pathway of precipitation. Carbon isotopes are influenced by a complex suite of factors on the surface, such as biological activity (including variations in C_4 or C_3 type plant abundances), rainfall, and bedrock composition. As with other proxy records, it is often difficult to separate the actual climate signal from "noise" in the record. Comparison of cave data with other nearby climate records such as ice cores or sediment cores helps to identify real climate signals.

SEE ALSO: Climatic Data, Ice Observations; Climatic Data, Sediment Records.

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Climatic Data, Historical Records

HISTORICAL RECORDS OF climate data include the instrumental record and proxy climate data from human recorded history. Proxy records are a substitute for direct measurements by meteorological instruments. The principal sources of historical proxy records are written, archaeological, and iconographic evidence.

Accurate reconstruction of past climate relies on information from instruments that measure air pressure, wind speed, wind direction, precipitation, air temperature, and humidity made at weather or climate stations around the globe. But looking further back in time, the record declines, both in terms of the area of the world covered and the number of variables measured. By the late 1700s, it includes only a handful of places, mainly in Europe.

The time period covered is not the only consideration. The data must also be quality controlled. This requires the availability of so-called metadata concerning the type of instruments used, measurement practices and observation routines, information on the position and exposure of instruments, and facts on the setting in which the instruments are located (for example, urban or rural).

MEETING CRITERIA

Only a few records come close to meeting these criteria, and most of them suffer from multiple deficiencies, usually because the instruments were shifted to nearby, but different sites. Thus, most records are, in fact, composite series, containing data from a number of sites in one area. One notable exception is the record of the Armagh Observatory in Northern Ireland 1796–2002. The resulting historical climate record is the longest for any single site in the United Kingdom and Ireland (although a gap 1825–33 was filled by data from two stations in Dublin). Only two other European stations have records as long at the Armagh series: Stockholm and Uppsala, both in Sweden.

The central England time-series of air temperature is the longest instrumental record in the world. It puts together data from a number of climate stations in England, namely, Ringway, Malvern, Squires Gate, and Rothampsted, for 1772–present. It was not until 1840 that the first official national archive of climate data was set up, housed at the Royal Greenwich Observatory near London.

A formal system of weather observations did not begin in the United States until 1818. However, climate data have been gleaned from private sources for several years prior to this. Of note is the reconstruction by R.D. Erhardt for the southern United States, using data from the private journals of Winthrop Sargent and William Dunbar. Measurements were taken near Natchez, Mississippi, commencing in 1798 and 1799, respectively. The Dunbar record includes daily measurements of air temperature, barometric pressure, wind direction, precipitation, and state of the sky for the hours of 0600, 1500, and 2100 local time 1799–1818. It is regarded as one of the best early instrumental records in the United States.

H.E. Landsberg and others assembled a composite temperature series from 1795 for the eastern United States. The main sources of climate data 1820–70 are archived by the Smithsonian Institute and the U.S. Army Medical Corp. Data. Records became plentiful following the establishment of the U.S. Signal Service in 1870 and the U.S. Weather Service in 1891. L.J. Darter has assembled a comprehensive listing of archived U.S. data.

Globally, the total number of climate stations with records of daily air temperature grew steadily from about 100 in 1880, to a peak of approximately 1,500 in 1970. A decline set in after that, with a sudden loss of over half the stations around 1990, leaving a total of just over 5,000 in 2000. The loss in stations varied around the world. The biggest losses occurred in China, the former Soviet Union, Africa, and South America.

The number of stations used as the global historical climate network for calculation of mean global temperature is reduced by about two-thirds to remove records with insufficient continuity or quality control. The maximum number of acceptable station records over land regions of the globe was just over 3,000 1951–90. Prior to the 1940s, there are problems of accuracy and lack of standardization in the way climate variables are measured, making it difficult to reliably compare measurements made in different places. For marine regions, sea-surface temperature measurements taken on board ships are used. As most of them are made voluntarily, coverage is mainly along main shipping lanes and is sparse in the southern oceans. There has been increased reliance on highly-accurate satellite measurements of global temperature since measurements began in 1979.

It is common to use proxy data to extend the historical record of actual measurements. A common source of proxy data are written records, such as diaries, chronicles, and ships' logs, or accounts of things such as floods, droughts, lake levels, grape harvests, and wheat prices from which climate conditions can be inferred. Some of these records are quite long. For example, there are records of the variation of the level of Lake Victoria in equatorial Africa since 1860, wheat prices in Europe since 1200, the occurrence of sea ice off Iceland since 860 C.E., date of first bloom of cherry tress in Kyoto, Japan, since 812 C.E., and water level in the Nile at Cairo, since 622 C.E. Iconographic proxy data is assembled from old paintings and carvings that depict the type of vegetation and the position of glaciers and frozen rivers and lakes that give an indication of climate of the time.

Archaeological remains can provide proxy climate data and evidence of past migrations linked to climatic change. For example, from about 900 C.E., Vikings settled in southern Greenland and farmed soil, that by 1200 C.E., became too cold for agriculture. The remnants of these settlements provide evidence of what agricultural activities took place during this time, known as the Medieval Warm Period, which was brought to an end by the onset of a cold period known as the Little Ice Age.

Tree rings of long-lived trees also provide useful proxy data for extending the historical climate record. Tree rings are wider in wet years for trees growing in semi-arid climates, and wider in warm years for trees growing in cold climates. Reconstruction of past climates prior to the historical record requires the use of the paleoclimatic proxy data from the geological past based on investigations of fossils, sedimentary rocks, and ice and sea cores.

SEE ALSO: Climatic Data, Atmospheric Observations; Climatic Data, Nature of the Data; Cave Records; Climatic Data, Ice Observations; Climatic Data, Instrumental Records; Climatic Data, Climatic Data, Oceanic Observations; Climatic Data, Proxy Records; Climatic Data, Tree Ring Records.

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Climatic Data, Ice Observations

SEASONAL CHANGES IN snow and ice cover on the Earth's surface result largely from the Earth's position relative to the sun. However, because ice systems also respond to climate on longer timescales, they are considered good indicators of the Earth's climate as a whole. In addition to being good climatic indicators, glaciers and ice sheets influence the Earth's climate in two important ways. The first is their potential impact on sea-level rise and global water resources under declining ice regimes. Glaciers and ice sheets account for two-thirds of the Earth's freshwater and would contribute approximately 229 ft. (70 m.) to sea-level rise if they were to melt completely.

The majority of this ice is located in the Earth's polar regions, largely in the Greenland and Antarctic ice sheets, which combined account for approximately 97.5 percent of potential sea-level rise. Alternatively, glaciers located outside of the polar regions, commonly referred to as alpine glaciers, play a relatively small role in their overall contribution to global ice volume and, thus, sea-level rise. However, they are perhaps the most critical ice volumes when considering their locations with respect to populated areas. Alpine glaciers are found at the headwaters of river systems throughout the globe and, thus, are an important water source for many regions. These glaciers are also more susceptible to melt owing to their smaller size; as a result these systems have experienced the most visible decreases in ice volume.

Second, decreases in global ice and snow cover are considered particularly important to the Earth's climate system because such changes are considered to be part of a positive feedback loop, commonly referred to as the snow-ice albedo feedback. Under this scenario, as temperatures increase, the extent of snow and ice decreases, and the highly reflective snow or ice surface is replaced with the darker (more absorptive) ocean or land surface underlying it. The increased absorption of energy completes the feedback loop, as more solar radiation is absorbed by the Earth's surface, leading to an overall increase in air and sea surface temperatures, and further decreases in ice and snow volume.

Global air temperatures have increased in the past century. Climate observations indicate that increases in temperature over this timeframe have accelerated in recent decades, and are unlikely to slow under current climatic conditions. One key example of the positive feedback associated with the loss of ice mass is the increased rate of warming observed in the Arctic, which has warmed at nearly twice the global average. Global temperature increases are strongly correlated with decreases in global ice mass, which have been in a relatively constant state of decline throughout the last century. As global temperature rates increase, global ice volumes have experienced the largest rates of decline in recent decades.

Observations of global ice masses are a critical component of climate change research. They give scientists insight into how ice masses are changing over time, how quickly changes are taking place, and allow climate scientists to make informed predictions of how these ice masses are likely to change in the future. Improvements in technology have changed the way in which climate scientists make observations of glaciers, ice sheets, and sea ice. New techniques now include the use of satellite and remote-sensing data as a means of monitoring these systems.

Prior to the 19th century, records of weather and climate were rare. As a result, climate scientists use proxy records (such as ice cores, lake and ocean sediments, and ocean coral) to make inferences about how the Earth's climate and ice masses have changed in the past. The current understanding of changes to the Earth's cryosphere (snow and ice) is comprised, therefore, of a combination of data derived from proxy records (indirect observations) and from direct ice observations. Combined, direct and indirect observations provide insight into how global ice masses are changing over time and provide a context in which to view current changes in global ice masses.

INDIRECT ICE OBSERVATIONS

Proxy records are commonly used to reconstruct the Earth's climate beyond the period of direct scientific observation. Some commonly used proxy records include ice cores, tree rings, ocean sediments, and coral records. Consistent results in the historical climatic data derived from these proxy records indicate the reliability of these records as accurate means of reconstructing past climates.

Increased access to polar regions in the 20th century helped bring glaciers and ice sheets to the forefront of science.

These records indicate large-scale changes in the Earth's climate in the past, including periods of complete global glaciation (Snowball Earth) and contrasting ice-free periods. During the past 900,000 years, the Earth has fallen into a pattern of glacial-interglacial cycles operating on 100,000-year timescales. Glaciations are long periods of cold temperatures, resulting in the growth of large land and sea ice masses extending outward from the poles. These glaciations tend to come to an abrupt end with rapid warming and consequent ice recession.

The last glaciation, the Wisconsin glaciation, ended approximately 10,000 to 11,000 years ago. During this glaciation, ice caps in the Northern Hemisphere extended to latitudes of approximately 45 degrees N, and were 1.8–2.5 mi. (3–4 km.) thick. Since the end of the Wisconsin glaciation, the Earth's climate has been in a period of relative climatic stability, a period commonly referred to as the Holocene (the past 10,000 years).

Synthesis of proxy records for the past 1,000 years in the Northern Hemisphere shows a gradual cooling for 900 years, culminating in the Little Ice Age (1400–1850). During the Little Ice Age, sea ice throughout the Arctic increased, and alpine glaciers across Europe expanded down valleys, covering farmland and destroying agriculture. Since the end of the Little Ice Age, the world has been in a state of declining ice extent.

Proxy records from the Southern Hemisphere are not as unanimous in their observations of 20th century warming. Some regions in the Southern Hemisphere, including Australia, New Zealand, and South America indicate the 20th century as a period of unprecedented warmth in the last millennium. However, ice core records from Antarctica do not indicate this same 20th-century warming. The data derived from both proxy records, and direct observation, indicate that climate does not always operate on a global scale, rather, changes occur on a more regional scale.

DIRECT ICE OBSERVATIONS

While indigenous people have populated the Arctic for thousands of years, exploration of the Arctic by European explorers did not begin until the 16th century. While these voyages were initially motivated by the search for the Northwest Passage, they also provided the first real records of Arctic sea ice conditions. However, it was not until numerous expeditions to the Arctic and several attempts for the North Pole had been made that the distribution of sea ice in the Arctic became well understood.

While early theories speculated the existence of a large southern continent, Antarctica eluded explorers for several centuries, until it was first sighted by Captain James Cook in 1773, after which many voyages were made to the area for both sealing and exploration. Similar to the Arctic, by the mid-1800s, there were rough models of sea, ocean currents, and winds for the Antarctic region.

The first scientific literature discussing Arctic, sea ice properties and extent were published in the 1870s, but it was the organization of the First International Polar Year (IPY) in 1882–83 that spurred scientific exploration to both the globe's polar regions. From 1900–06, a major scientific expedition to the Arctic Ocean was undertaken by Fridtjof Nansen, aboard the *Fram,* to determine ocean currents and sea-ice extent. In the Southern Hemisphere, expeditions by Robert Falcon Scott, Erich von Dryglaski, and Ernest Shackleton to Antarctica marked the transition from early exploration to modern scientific expeditions.

MODERN ICE OBSERVATIONS IN THE POLAR REGIONS

In the 1950s, international scientific campaigns were undertaken on both the Greenland and Antarctic ice sheets. The scientific advances made during these research campaigns were unprecedented, and resulted in deep ice cores retrieved from both the Northern and Southern Hemispheres, as well as the establishment of long-term scientific monitoring sites. The information gained during these campaigns now form the foundations for the current understanding of ice volumes and ice-sheet dynamics in these regions, as well as providing high-resolution proxies of past climatic conditions. Insight into past glacial dynamics provides a context in which to view the current ice-sheet behavior.

Continued technological advances in transportation, computing, and communications have increased accessibility to the polar regions, and increased the number of scientists investigating glacial dynamics in these regions. In the late 1960s, an improved understanding of the potential environmental impacts associated with decreasing global ice volumes brought the study of glaciers and ice sheets to the forefront of scientific research. The current understanding of global ice volumes to serve a bellwethers of global climate change is largely the result of research done in the 1960s; it was during this time that glaciologists and climate scientists began expressing concern over 20th-century climate change.

In 1972, the Landsat 1 satellite was launched and provided the next major scientific advance in ice monitoring. The development of remote-sensing techniques has opened a whole new world for scientists studying sea ice, ice sheets, and glaciers. These techniques allow scientists to make observations of ice extents and changing surface heights, without having to make expensive and time-consuming visits to these remote regions.

ICE OBSERVATIONS OF ALPINE GLACIERS

While alpine glaciers compose a relatively small component of the Earth's cryospheric system, a large proportion of the world's population relies on the melted water from these systems for drinking water and hydroelectric power. Understanding how alpine glaciers are likely to respond to future climatic changes is, therefore, a crucial component of sustainable planning and development. Direct ice observations from alpine glaciers and ice fields have a longer history than those in the more remote polar regions, largely because they are situated closer to population centers.

The longest records of glacial dynamics come from Europe, where records extend over 150 years. These records include glacial mass balance measurements (measurements of snow accumulation and melt), ice extent, and thickness. The large number of alpine glaciers existing on the mountain ranges of Africa, North America, South America, Europe, and Asia mean that individual monitoring of all glaciers is not feasible. As a result, the same advances in remote-sensing technology that have improved monitoring of polar ice masses have also been an asset to the collection of information about alpine glaciers and ice fields.

SEE ALSO: Glaciers, Retreating; Global Warming; Ice Ages; Ice Albedo Feedback; Earth's Climate History.

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Climatic Data, Instrumental Records

DETECTION OF CURRENT global temperature and reconstruction of past trends rely on data from four sources: surface temperature from weather or climate stations, weather balloons, satellite mounted remote sensors, and proxy sources. Data from the first three categories are known as the instrumental record.

Until recently, measurements of global air-temperature change were based entirely on measurements taken on the ground at weather stations. Three authorities that have taken responsibility for the combined surface record are the Climate Research Unit (CRU) of the University of East Anglia (UEA), the National Aeronautics and Space Administration's (NASA's) Goddard Institute for Space Studies (GISS), and the Global Historical Climate Network (GHCN) run by the U.S. National Oceanographic and Atmospheric Administration (NOAA).

Given that the data come from weather stations unevenly distributed over the Earth's surface, mostly in the Northern Hemisphere, mainly on land, close to towns and cities, the question arises as to the extent to which these temperatures can be taken as representative of the atmosphere as a whole.

Modification of the surface by human activity can have a significant effect on local climate near the ground. The best-documented example is the urban heat island effect, in which localized warming due to asphalt and concrete replacing grass and trees can influence data from urban stations. This can make an urban area several degrees C warmer than its rural surroundings.

Several researchers have demonstrated that only very small changes in population are enough to induce a statistically significant local warming effect. Many weather stations are located at airports, which originally were located in rural areas on the outskirts of urban areas. But with rapid population growth, airports have made a transition from rural to heat island and it is difficult for the national agencies responsible for archiving climate data to take these influences into account. The problem has been made worse by the fact that two-thirds of the weather stations operating around 1975, mainly rural, have been closed down. For example, the GHCN network showed a peak of about 15,000 stations around 1970, which declined to 5,000 as stations deemed non-essential for operational purposes were closed down. The loss was mainly of rural stations.

Over 70 percent of the Earth's surface is covered by water. Because of this, land-based surface temperature data are supplemented by measurements taken at sea, usually by ships. Scientists have assumed that there is a link between the surface layer temperature of seawater and that of the air above it. Sea surface temperatures are estimated from the temperature of seawater as it is taken aboard as an engine coolant. Sometimes, a bucket tethered to a rope thrown overboard serves the purpose. The bucket is then hauled aboard, and the water temperature is measured with a thermometer. Other sea surface data are taken by combining data from several rather different sources, such as buoys, satellite infrared data, nighttime marine air temperatures measured aboard ships, and measurements made at small island stations.

Each method has problems that result in errors or differences among the data sets. The mean global surface temperature of the Earth shows a warming of 0.3–0.7 degrees C over the past century; this is an increase statistically of about 0.003 to 0.007 degrees C per year, a rate not far from the standard error for the data. The data sets from the various sources (CRU, GISS and GHCN) show slightly dissimilar trends as the data are processed in different ways.

WEATHER BALLOON DATA

Weather balloon data originate from a package of instruments called a radiosonde attached to a balloon that sends pressure, humidity, temperature, and wind data by radio transmitter to a ground-based receiving station as the balloon ascends. NOAA and the U.S. National Climate Data Center have assembled data on temperatures through the lower atmosphere (troposphere) based on radiosondes since 1958, and have assembled it into the Radiosonde Atmospheric Temperature Products for Assessing Climate (RATPAC) data set.

RATPAC consists of station and spatially averaged monthly mean temperature from 1958 to present derived from radiosonde observations taken at 87 weather stations across the globe. The data set consists of a timed series for 13 pressure levels from the surface to 30 mbar pressure level in the atmosphere and a seasonal time series for three layers of the atmosphere (850–300, 300–100, and 100–50 mbar). Although more limited in time and space, these data are free of the ground-based contamination that affect the surface temperature record. RATPAC data shows a global temperature increase of 0.17±0.05 degrees C per decade between 1979 and 2004 compared with the GHCN of 0.16±0.04 degrees C, GISS of 0.16±0.04 degrees C and CRU of 0.17±0.04 degrees C per decade for the same period.

SATELLITE DATA

NOAA polar-orbiting Tiros-N satellites have made temperature measurements of the atmosphere (troposphere and stratosphere) since 1979, using microwave radiometry called Microwave Sounding Units (MSU).

MSU instruments measure the microwave emissions of oxygen molecules, which are related to air temperature. By monitoring microwave emissions at different frequencies, it is possible to identify temperature changes in various layers of the atmosphere. Initial analyses of the MSU data were conducted by scientists at the University of Alabama, Huntsville (UAH), and later by scientists at the Remote Sensing Systems (RSS) facility in Santa Rosa, California.

TRULY GLOBAL

The MSU temperature data set is the only one that is truly global, highly accurate, and uses a completely homogeneous measurement over the entire planet. It also measures the part of the atmosphere that, according to the climate models, should be experiencing the greatest warming due to the enhanced greenhouse effect. The accuracy of the MSU measurements is 0.1 degrees C, which is considerably better than the accuracy of surface data.

Both the MSU UAH, and MSU RSS estimates indicate the middle part of the lower atmosphere (mid-troposphere) has warmed since 1979, but the RSS estimate at 0.18 degrees C per decade is higher than that of the UAH estimate at 0.14 degrees C per decade, both for the period extending from January 1979 to June 2006.

SEE ALSO: Climatic Data, Nature of the Data; Climatic Data, Oceanic Observations; National Oceanic and Atmospheric Administration (NOAA); National Aeronautics and Space Administration (NASA).

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Climatic Data, Lake Records

SEDIMENTS THAT ACCUMULATE in lakes and ponds are composed of many kinds of materials. Some, such as windborne dust, pollen, and soot, fall into lakes from the atmosphere. Others, such as clay, silt, sand, gravel, and large organic debris, such as charcoal and leaves, are washed into lakes by running water.

A third group of materials originates in lakes: the remains of aquatic organisms, most importantly the silica-based shells of diatoms (algae) and the calcium-based shells of zooplankton and some invertebrate animals. Core samples extracted with hollow drills from lakebeds show that sediment composition varies over time, suggesting that the materials accumulated under different environmental conditions. Sometimes, even seasonal variations are significant enough to produce annual layers, called varves. By extrapolating from modern observations of events and conditions that produce different kinds of sediments, and by determining the relative amounts of different chemical compounds present in different sediment layers, paleolimnologists have assembled local records that help show how climates have changed worldwide.

The presence of a particular material in a lake sediment sample represents a proxy, or stand-in, for some event that helped precipitate its deposition. Dating lake sediments usually involves analyzing and comparing several materials to produce a multi-proxy account. Relative dating, or chronostratigraphy, is a straightforward process, because younger sediments almost always overlie older ones. However, the action of waves, currents, and lake bottom springs can locally mix material from different strata. Even without such confounding effects, each type of material poses a different set of analytical challenges.

AEOLIAN SEDIMENTS

Windborne or aeolian materials that fall into a lake may have been blown overland for considerable distances. Fine, inorganic particles like dust and sand carried by winds are difficult to distinguish from similar, waterborne materials unless they are chemically or geologically unique, representing particular outcroppings exposed at a lower elevation than the lake, or otherwise outside its watershed. Abundant aeolian sediments can indicate drying climates, because they are more likely to be mobilized by winds when soils are dry and plant cover is sparse. Soot is deposited during fires, which are more common under drying conditions.

Pollen grains are often distinct enough that plant families, genera, and even species can be identified from pollens preserved in lake sediments. An abundance of particular pollens at any given sediment level can be taken as a proxy for climatic conditions favoring the plant species that produced them. However, not all pollens become windborne (particularly those adapted for insect borne dispersal), and those that are windborne are not equally durable, so sediment pollen records are always incomplete. Finally, unusual short-term weather patterns and major storms can produce unusual aeolian deposits, resulting in inaccurate or imprecise interpretations.

FLUVIAL AND FOSSIL SEDIMENTS

Waterborne or fluvial sediments include fine materials resembling aeolian deposits, but also larger particles such as gravel, pebbles, cobbles, and organic debris too dense or massive to be entrained by winds. Materials drop out of the water column in order of density; the denser the object, the more quickly it is deposited. As one result, the densest fluvial sediments accumulate closest to the point where the river or stream that carries them enters a lake, producing horizontal sorting patterns called facies.

As another result, larger and smaller particles that arrive together will not settle out at the same rates. In regions where runoff is seasonal, a pattern of alternating bands of coarse, dense materials and finer, lighter ones will develop. Once their seasonality is understood, such varved sediments provide a year-by-year account of relative precipitation on a particular watershed.

Some sediments accumulate in lakes because small, short-lived organisms reproduce and die off in large numbers. For paleolimnologists, some of the most useful organic sediments include the persistent shells and scales of diatoms, chrysophytes (golden-brown algae), mollusks, arthropods, and foraminifera. Diatoms are algae that develop hard, silicon structures called frustules, which can be used to identify different species. The presence of different diatom species in different sediments has been used as a proxy for variations in pH (acidity), temperature, salinity, nutrient concentration, and even the annual period of ice cover. Many invertebrate animals and smaller foraminifera secrete calcium carbonate- ($CaCO_3$) based shells.

In addition to species-based ecological proxies similar to those provided by diatoms, the carbon (C) content of these shells allows sediments up to about 60,000 years old to be dated using the radiocarbon (^{14}C) technique familiar to archaeologists. However, diatom frustules and foraminiferan shells are small enough to become windborne, and their presence in lake sediments must be interpreted with caution.

Leaves and other common plant remains composed of cellulose can also be dated with radioactive decay analysis of the unstable isotopes $\delta^{13}C$ and $\delta^{18}O$ (oxygen). Plant remains may also be blown or washed into lakes, so materials from identifiable species provide more precise proxies for climate effects. But, even the presence of pigments such as chlorophyll and carotenoids in sediments can provide a general proxy, indicating the growth of plants. Finally, any identifiable fossil remains of insects, fish, and other animals can provide further clues to the sorts of environments that existed at any particular time.

CHEMICAL PROXIES

Both organic and mineral lake sediments undergo reactions that vary depending on their chemical compositions, and on environmental factors such as temperature, and the light and nutrients available to organisms. Compounds containing arsenic (As) carbon (C), chlorine (Cl), iron (Fe), mercury (Hg), nitrogen (N), phosphorus (P), silicon (Si), Sodium (Na), and sulfur (S) are among those that have been used as proxies for the climate conditions prevailing at the time sediments were deposited. Iron-bearing compounds align themselves with the Earth's magnetic field; changing alignments in different strata track changes in the field itself. As some minerals form, they can even trap samples of lake water in microscopic spaces. Many different combinations of particle size, composition, and chemical interaction are possible, making it necessary to understand and account for many different processes in order to use lake sediments as effective proxies for the climatic conditions in the past.

SEE ALSO: Biogeochemical Cycles; Cenozoic Era; Chemistry; Climatic Data, Nature of the Data; Climatic Data, Proxy Records; Climatic Data, Sediment Records; Foraminifera; Phytoplankton; Plants; Salinity.

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Climatic Data, Nature of the Data

CLIMATE MODELING IS the process of trying to create mathematical models that represent to the highest possible level of accuracy the circulation of wind in the atmosphere and the exchange of heat into and out of it. Since efforts at modeling began in the 19th century, those efforts have become increasingly complex and sophisticated, particularly in recent decades. Two factors have contributed to that increasing sophistication: first, the dramatic improvement in computational power; second, the huge increases in the range and coverage of data that may be used in data sets for analysis in models. As new data become available, they enable researchers to propose modifications to existing models, while proposals to extend models prompt efforts to find ways to obtain the data necessary to determine the success of the proposal.

Climate models have now reached a third generation or series of iterations, which represents a high level of sophistication compared to the past. Land components of models take account of such variables as vegetation cover, elevation, albedo and salt circulation between land, sea and sea-ice. The same degree of sophistication is evident with respect to the ice and atmospheric components of models. The Goddard Institute of Space Studies (GISS) in New York manages a series of climate models in conjunction with the National Aeronautics and Space Administration (NASA). GISS models employ data collected since the 1850s, which are available on a grid basis for either annual or monthly average readings.

Accurate data only became available for most parts of the earth in recent decades, owing to the amount of resources required to make observations and because the perceived need for global observations has only comparatively recently emerged.

World War II provided the equipment and capability for collecting data, while it was the failure to complete satisfactory models on a regional or geographically-limited basis that did not properly integrate global effects that stimulated the increase in the scope of data collection. Nevertheless, GISS models provide datasets in the following categories: temperature; radiation; vertical heat fluxes; salt; water; pressure; height; velocity and horizontal mass fluxes.

Temperature is measured at data points in vertical and horizontal dimensions. Sophisticated climate models employ many layers within the atmosphere and data must be collected from each of these levels for models to be correctly computed. Meteorological equipment, such as weather balloons, which have become an advanced technology in their own right, is employed to collect temperature and other readings in the atmosphere.

In addition to raw temperature recordings, models are also able to use daily minimum and maximum temperatures and the variance between them (other periods may also be computed as required), as well as a composite ground temperature and the temperature of the ocean.

Radiation is a crucial data element because the heat exchange of the atmosphere determines global warming and, hence, climate change to a large extent. Data are collected on the amount of solar energy reflected nd absorbed by the surface of the Earth. The nature and extent of cloud cover is monitored, as is the extent of energy rebounding off that cloud cover. Aggregate and grid-specific releases of energy data are collected; one measure of atmospheric clarity that is employed is Boucher's Sulfate Burden, measured in milligrams per square meter.

This Sulfate Burden is one of the variables employed to examine various forcings in the model—that is, the weight given to different variables in the overall model. Because each model employs a different series of forcings, each will give slightly (possibly significantly) different results employing the same data sets. It is prudent, therefore, to use an overview of several different models to obtain a broad understanding of the issues concerned.

VARIABLES

Vertical fluxes are measured in terms of both precipitation and upwards movements of water vapor. These variables have an impact on the circulation of the atmosphere. The extent and temperature of the ocean also has an impact on this circulation and this is further affected by the extent of ice in the sea. These latter variables are included within the category of horizontal mass fluxes, which are measures of northward and eastward (and vice-versa) masses of ice, water vapor and liquid ocean, as well as air masses. Additional variables include the amount and movement of salt masses in the water.

These vary together with the amount of water and energy entering the ocean (for example, melting ice at the poles and level of precipitation) and are further affected by climate conditions, as well as affecting those conditions in turn. Salinity in oceans is measured by using devices that collect data on conductivity, temperature, and depth (CTDs).

Variables exist with respect to water. These include the composition of the water and of water in different states (for example, water vapor, ice, snow) and its movement in three dimensions. Both static and moving water are considered (lakes, oceans or seas, as well as rivers). Interactions between water in different states and land are also included.

Velocity variables measure the speed and direction by which air masses move in the atmosphere. These are overall or average measures, necessarily, because velocity varies rapidly and frequently in a unit period, depending on location and season. Height and pressure are other ways of measuring interactions between atmosphere and land or sea.

PROXY VARIABLES

In addition to measuring current data points using the most advanced equipment available, it is also possible to measure some historical data points. By digging deep into ice cores in permafrost areas, as well as ocean sediment, it is possible to determine certain conditions from the distant past. Variations in the rate of formation of ice or sediment (the same is true of the rings of some trees) indicate the favorability of conditions for formation, while the presence of trace elements can also indicate various atmospheric or climatic conditions. Ice cores are of such an age that they can be used to understand climatic conditions from half a million years in the past.

Unfortunately, of course, data observations are not always available. Only partial coverage may be possible for practical reasons, and it may not be possible to observe the desired data directly. In these cases, it is possible, with some precautions, to use proxy data. Proxy data act as substitutes for the desired data, but may differ in the time or place observed. An alternative method is to obtain data points on a proxy variable which acts in some way as an approximation of the desired data. An example of this would be the measurement of a single element or substance in the atmosphere may act as a proxy for contamination of the atmosphere as a whole, or for human impact on climate change.

There are many methodological problems with using proxies and the degree of confidence in results must generally be adjusted, accordingly. However, these are not insuperable and, when audiences are educated concerning the methods employed, their use should not lead to misunderstanding. Unfortunately, the quality of science teaching in many societies is not sufficient to enable large numbers of people to appreciate the issues concerned.

SEE ALSO: Climatic Data, Atmospheric Observations; Climatic Data, Cave Records; Climatic Data, Ice Observations; Climatic Data, Instrumental Records; Climatic Data, Oceanic Observations; Climatic Data, Proxy Records; Climatic Data, Tree Ring Records.

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Climatic Data, Oceanic Observations

CLIMATIC OCEANIC OBSERVATIONS are marine meteorological and deep ocean observations that are performed for a long time (at least over a few decades) using specialized oceanographic vessels, volunteer merchant ships, buoy arrays, floats, and drifters. Marine meteorological observations are performed over a few centuries. Voluntary observations by merchant ships (volunteer observing systems, or VOS) report most of these data. Standard marine meteorological observations include sea-level pressure, air and sea-surface temperatures, humidity, cloudiness, velocity, and direction of wind.

Marine meteorological observations have been collected and generalized in the Comprehensive Ocean-Atmosphere Data Sets (COADS). However, the differences in instruments and observation techniques, and construction and size of various ships, reduce the compatibility of different data for analysis of climate variability and change. One of the most comprehensive analyses of this problem has been done at the CLIMAR 99 WMO workshop.

Between 1948 and 1984, the Ocean Weather Station (OWS) network operated in the North Atlantic and Pacific Oceans. The principal goal of this network was to get oceanic meteorological and aerological data for improvement of the weather forecast in North America, Europe, the North Atlantic Ocean, and the Pacific Ocean. At the same time, OWS performed deep-ocean hydrographic casts and soundings. This network provided long-term and compatible deep-ocean time series of temperature and salinity, and aerological data on wind, pressure, temperature, and humidity within air columns up to about 19 mi. (30 km.). The OWS network initially consisted of 13 stations in the North Atlantic and nine stations in the Pacific. After 1973 (when a world economic crisis occurred), funding was cut off, and in 1984 (soon after beginning of the satellite era in meteorology), OWS observations ceased (with the exception of one Norwegian station in the North Atlantic that is still in operation).

Deep-sea hydrographic observations have been performed since 1872. Pre-1970s hydrographic casts were performed using Nansen bottles, and were the main source of deep-sea hydrographic data. Then, the expandable bathythermograph (XBT) and conductivity-temperature-depth (CTD) soundings replaced the Nansen bottles' measurements. However, the routine oceanographic observations are too sparse and noisy for the reliable detection of low-frequency (long-term) changes of the oceanic fields in the deep ocean (below 2,625 ft. [800 m.]), except near a few standard oceanographic sections and some specific regions with strong oceanographic activity.

Long-term buoy arrays have been deployed in a few key regions of the world's oceans, such as the tropical Pacific and Atlantic, since early 1990s. The Tropical Ocean-Global Atmosphere–Tropical Atmosphere Ocean (TOGA-TAO) and Pilot Research Moored Array in the Tropical Atlantic (PIRATA) mooring networks are in operation. They perform marine meteorological observations and subsurface oceanographic measurement in approximately the first 984 ft. (300 m.), and regularly transmit information to the satellite.

The Rapid Climate Change (RAPID) mooring array has monitored the meridional circulation in the North Atlantic along 26.5 degrees N since March of 2004. First results published by Stuart Cunningham, et al., showed that meridional overturning could be observed with errors smaller than 1.5 Sv (one Sv equals a flow of ocean water of 106 cu. m. per second). This shows the beginning of thermohaline catastrophy (which occurs when meridional overturning in the North Atlantic Ocean shuts down) at the early stage and superimposed high-magnitude interannual variability of meridional circulation.

Surface and subsurface drifters are numerous and effective tools for long-term monitoring, as shown, for instance, by David Fratantoni. They are based on a Lagrange principle of current measurement. Since the late 1980s, they have been the principal source of global data on ocean circulation. Now, ARGO technology is used as a key element of the Global Ocean Observing System (GOOS). This is a subsurface drifter that typically drifts at 1–1.25 mi. (1.5–2 km.) in depth, floats to the surface every 10 days, registers the profiles of temperature and salinity, transmits its information to the satellite, and then sinks back into the depths. The lifetime of each ARGO float is about two to four years. At the moment, there are about 3,000 ARGO floats on the world's oceans. This provides a density of observations of about one float per 776 sq. mi. (300 sq. km.) of water surface all over the globe.

SEE ALSO: Climatic Data, Sea Floor Records; Meridional Overturning Circulation; Ocean Component of Models; Oceanic Changes; Thermohaline Circulation.

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Climatic Data, Proxy Records

CLIMATE SCIENTISTS WOULD prefer to have all climate change information recorded by weather instruments, but suitable instrumentation was practically nonexistent before the 19th century. As a result, investigators of longer-term (paleoclimatic) climate changes rely on datable noninstrumental information. Climate scientists refer to noninstrumental records as proxy records, because they are substitutes for direct measurements taken by instruments. There are four principle proxy record sources: human/historical, glaciological, geological, and biological. The timespan and level of detailed information among the sources vary, but getting the right climate change signal is important, because proxy data play a central role in developing accurate climate prediction models.

Human (or historical) proxy evidence for climate change is taken from a diversity of sources, ranging from clues in prehistoric cave paintings, to remarks about the weather in old letters, diaries, and newspapers. Historical records of changes in crop production also provide valuable proxy information about changes in climate. The other three categories of proxy records are products of climate-related environmental processes. The proxy records can be hundreds, thousands, millions, or even billions of years old. Due to their long timespans, such records are the bases of most paleoclimatic studies.

Glaciological proxy records appear in glacial ice; as the climate changes, so do the physical and chemical characteristics of ice. Geological proxy data rely on the climate-related weathering of rocks and the transport, deposition, and chemistry of the weathered products (sediments) by streams, lakes, wind, and oceans. Plants keep biological proxy data, due to their dependence on climate, incorporated into their structure or reproductive capability. For instance, flowering plants of various climatic tolerances record their location, duration, and abundance by means of production of pollen, so that pollen becomes the plants' climate proxy record.

Climate scientists can infer climatic conditions from analyses of natural phenomena, but without an ability to date the material it is not possible to construct a chronology or calibrate a record. Fortunately, natural proxy records lend themselves to temporal analyses because they accumulate in datable layers, such as growth rings in trees, and layers of sediment and ice laid down in an undisturbed succession over long time intervals. Dating methods include the correlation of proxy records with radiometric (isotopic) dating of igneous rocks, radiocarbon dating of carbon-bearing sediments, and other proxy records, counting annual layers (such as in trees, ice, corals, and lake beds), and correlating proxy records with periods of Earth's orbital cycles.

The timespans of proxy records vary widely. Historical climate records are reliable for a few thousand years. The resolution of the data depends on the person recording the information. Cross-dating tree rings from various sources provide reliable records for tens of thousands of years. Ice cores, lake sediments, and coral reefs yield records for hundreds of thousands of years, and deep ocean sediments for hundreds of millions of years. The oldest climate proxy records are in marine sedimentary rocks that tectonic uplift has preserved on land. Such records are billions of years old, but they are not widely distributed. In general, the reliability, geographical range, and amount of useful climate information, increases rapidly toward the younger part of the record. The resolution of most proxy records that are in layered deposits also depends on the processes that disturb the climate after depositions and the rate of accumulation of the record, which determines how fast it gains protection from disturbances.

Natural proxy records are products of natural systems that depend on climate. Therefore, from these systems it may be possible to derive a climatic signal from the proxy records, but that signal may be embedded in a great deal of random (climatic) background noise. An important goal of climate scientists is to develop models that filter out the noise in order to characterize boundary conditions (such as the size of ice sheets) that they can use as inputs in models that attempt to replicate past and forecast future climates. A fundamental benefit of using proxy-based models is scientists' greater understanding of how Earth's temperature has changed in the past and how it is likely to change in the 21st century.

SEE ALSO: Climate Models; Climatic Data, Cave Records; Climatic Data, Ice Observations; Climatic Data, Lake Records; Climatic Data, Sea Floor Records; Climatic Data, Sediment Records; Climatic Data, Tree Ring Records; Greenland Cores; Paleoclimates; Vostok Core.

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Climatic Data, Reanalysis

REANALYSIS CLIMATIC DATA is a long-term consistent climatic dataset. The dataset is produced from a state-of-the-art data assimilation system combining both past observations from various sources and short-range forecasts from simulation models to obtain the best statistical estimate of the state of the atmospheric flow. For numerical weather prediction (NWP), the observations from sources irregularly distributed in space and time are analyzed in a unified and consistent manner with the aid of computer models to describe the state and evolution of the atmosphere. Such a procedure combining different data is generally denoted as "numerical analysis" or "data assimilation" and reanalysis climatic data is produced from a state-of-the-art data assimilation system.

Determining the initial conditions of the state of the atmosphere for forecast models is a key process in NWP, whose results heavily depend on these initial conditions. The equations of the motion of the atmosphere are integrated forward from predetermined initial conditions of the atmosphere and appropriate boundary conditions to forecast the atmosphere's evolution.

Ideally, initial conditions are expected to be specified from observations, but this never materializes due to various limitations in observation techniques, such as uneven distribution of observation stations, and errors and limitations inherent in satellite sensors. Due to clear limits in determining initial conditions solely from observations, the idea emerged that initial conditions could be determined by combining new observations of atmospheric variables and "first guess" or "background" estimates of the current state of the atmosphere. The first guess is computed by the forecast model based on earlier observations and is used to determine the initial conditions for the model, creating "analysis cycles." Therefore, the new observations are merged with the new first guesses from the forecast model, which uses initial conditions are estimated from the observations and the first guess. This process in NWP is known as "4-dimensional data assimilation (4DDA)" considering temporal progressions of the 3-D forecast model.

In summary, reanalysis can be understood as a climatic dataset of a past period produced by combining a wide range of reprocessed past observations and forecast models using the most up-to-date data assimilation techniques. Because the model and data assimilation system remain unchanged during the project, it provides an optimal estimate of the 4-D state of the atmosphere with better quality control.

Reanalysis provides a vast range of data encompassing pressure level data (for example, horizontal winds, omega [dP/dt], geopotential height, specific/relative humidity, absolute vorticity and divergence), isentropic level data (for example, horizontal winds, mass-weighted horizontal winds, omega, temperature, potential vorticity, and relative humidity), sigma level data (for example, divergence, temperature, specific humidity, horizontal winds, surface pressure, and geopotential height), radiation related quantities, clouds and precipitation, and others (for example, surface wind stress, latent/sensible heat flux, soil temperature/moisture, sea surface temperature, 2m temperature, 2m humidity, 10m winds, runoff, mean sea level pressure, surface pressure, snow).

GLOBAL AND REGIONAL SCALES

So far several different reanalysis projects have been carried out both at the global and regional scales by organizations in the United States, Japan, and Europe, including the National Center for Environmental Prediction (NCEP), National Center for Atmospheric Research (NCAR), United States Department of Energy (DoE), Japan Meteorological Agency (JMA) and the European Centre for Medium-Range Weather Forecasts (ECMWF).

The NCEP and NCAR commenced a joint project, in 1991, to produce a global reanalysis dataset over the period 1957-96 which is continuing beyond the initial period. The model has a T62 (about 130 mi. or 210 km.) horizontal resolution with 28 vertical levels; the data are provided at the 6-hour, daily, and monthly scales. This reanalysis product is often called NCEP/NCAR Reanalysis 1. Reanalysis 1 has been widely used in climate modeling communities to provide boundary conditions for general circulation models.

The NCEP/DoE AMIP-II Reanalysis (Reanalysis 2) is an updated version, but not the next generation of Reanalysis 1. Based on Reanalysis 1, Reanalysis 2 was developed by improving parameterization of physical processes and fixing errors in Reanalysis 1, with data coverage since 1979.

Japanese 25-year ReAnalysis (JRA-25) was created by JMA in collaboration with Central Research Institute of the Electric Power Industry for the period 1979–2004 and was transitioned to Japanese Reanalysis Project-Categorical Data Analysis System (JMA-CDAS) after 2005.

The global model has a T106 (about 68 mi. or 110 km.) horizontal resolution with 40 vertical layers. It is the first reanalysis project to use wind profile retrievals surrounding tropical cyclones (TCR), Special Sensor Microwave/Imager (SSM/I) snow coverage and digitized Chinese snow depth data.

The European Centre for Medium-Range Weather Forecasts (ECMWF) developed the ERA 15 Re-Analysis project in association with various organizations around the world. ERA 15 Re-Analysis incorporated various observational data including NOAA satellite radiance data for the 15-year period, the Comprehensive Ocean-Atmosphere Data Set (COADS) ship data, the First GARP Global Experiment (FGGE) and the Alpine Experiment (ALPEX) data, and pseudo-observational data from the Australian Bureau of Meteorology. The dataset spans from January 1979 through February 1994 and is available on a 2.5 degrees latitude × 2.5 degrees longitude grid.

North American Regional Reanalysis (NARR) is "a long-term, consistent, high-resolution climate dataset for the North American domain" with major improvements in both resolution and accuracy compared to previous global reanalysis datasets. It has a spatial resolution of 20 sq. mi. (32 sq. km.), a vertical resolution of 45 layers and a temporal resolution of 3 hours from 1979 to the present. It uses the NCEP Eta forecast model with lateral boundary conditions provided by the NCEP–DoE Reanalysis 2 and the Eta model Data Assimilation System. Data added or improved upon for NARR include precipitation measured over the United States, Mexico and Canada, wind and moisture from Reanalysis 2, pressure, wind, moisture from NCAR, ship and buoy data from NCEP/EMC (Environmental Modeling Center), snow depth from Air Force Weather Agency, Great Lakes sea-surface temperature, sea and lake ice data on Canadian lakes and Great Lakes, and tropical cyclones from Lawrence Livermore National Laboratory. The most striking feature of NARR is the successful assimilation of precipitation observations, which lead to the more realistic hydrological cycle.

SEE ALSO: Climate Models; Climatic Data, Cave Records; Climatic Data, Ice Observations; Climatic Data, Lake Records; Climatic Data, Sea Floor Records; Climatic Data, Sediment Records; Climatic Data, Tree Ring Records.

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Climatic Data, Sea Floor Records

THE SEA FLOOR is blanketed with sediments composed primarily of the remains of plants and animals that live in the oceans which cover three-quarters of the Earth's surface. Sea-floor sediments also include particles of soil, dust, volcanic ash, and fragments of vegetation that are washed off the land by rivers and floods, blown in by winds, or left by melting icebergs. In the deep oceans throughout the world, sea-floor sediments have piled up continuously over thousands to millions of year, silently recording the history of changes in climate and ocean conditions as far back as the time of the dinosaurs 60–80 million years ago.

Over the past 50 years, modern engineering and scientific techniques in paleoceanography have accessed these deep-water sea-floor archives and have read their messages about natural climate changes that occurred before the recent global warming started about 150 years ago. The importance of the sea-floor archives is that they allow an examination of past natural cycles of climate change and how the marine and land biological communities responded to fluctuations that include conditions hotter than the increase of 2–6 degrees C forecast for the present global warming.

Before about 1947, knowledge about climate change was mainly based on written historical records and the study of fossil plants and animals scattered over the continents in short sections that escaped destruction by glaciers during the Ice Age. In 1947, the new technology of piston coring and an international Deep Sea Drilling Program (DSDP) that enabled sampling of long sections of sea floor sediments revolutionized the science of climate change. Working from ships dedicated to scientific research, these new methods enabled the retrieval of unbroken sediment cores up to 2,625 ft. (800 m.) long, covering time spans of up to 10 million years. The archival data in the sea floor records consists mainly of tiny fossil marine phytoplankton and zooplankton called microfossils, mixed in with fine sand or mud swept off the land, and dust particles, including pollen grains from forests and grasslands on the continents. The oceanic microfossils, pollen, and sediment particles provide proxy (indirect) records of oceanographic or atmospheric conditions in ancient times.

The main oceanic plant microfossils are diatoms, dinoflagellate cysts, and coccoliths; the main animal microfossils are foraminifera and radiolarians, all of which are less than a few millimeters in length. The shells of even the tiniest (pinhead-size) marine microfossils carry an imprint of the ocean's temperature, salinity, and carbon production at the time they were alive.

When extracted in the thousands from the sea, floor sediments by sieving just a handful of ocean mud, the microfossils can be analyzed by chemical methods (stable isotope measurements), or by statistical analysis of their population composition, to reveal the oceanographic conditions at their time of death. The kinds of pollen found in the sediment samples tell us how much forest or grassland there was on the continents surrounding the ocean, while the amount of inorganic sediment provides a proxy-signal of river flooding or sea ice.

The results of the chemical and biological studies of the sea-floor sediment cores from all the world's oceans show a zigzag pattern of alternating warm and cold climates extending back at least 5 million years. To understand the cause of this saw-tooth climate record, methods were developed for calculating the age of the warm-cold cycles. Radiocarbon dating of the youngest sediments showed that the temperature peaks corresponded to warm periods lasting about 6,000 to 10,000 years, while the dips represented longer periods of glacial conditions lasting 20,000–30,000 years.

Paleomagnetic records of periodic reversals in the Earth's magnetic field, together with dating from the decay of radioactivity in rock fragments containing uranium or potassium and argon, allowed a timescale to be placed against the sea floor proxy-climate records. Cambridge University scientist Sir Nicholas Shackleton then showed that the oxygen in the marine microfossil shells came in two forms, one lighter, one heavier, called isotopes, and he showed that when ice sheets develop on the continents, the lighter oxygen-16 isotope diminishes in the oceans because it is locked up in the frozen water on land. When the ice sheets melt, however, the light oxygen returns to the oceans and again appears in the microfossil shells.

Using this proxy-climatic data from the sea floor records, in 1976, Nick Shackleton, Jim Hays, and John Imbrie were able to decipher the encoded climate messages in the sea-floor sediments and confirmed that the ice-volume cycles correspond to seasonal and geographical changes in the amount of the sun's energy received at the Earth's surface, because of shifts in the position of the Earth's movement around the Sun, as predicted in the early 20th century by Russian scientist Milutin Milankovitch. The sea floor records of climate change revealed a history of 40–50 ice age cycles in the Northern Hemisphere, completely revising the old idea that there were just four glacial intervals during the Pleistocene Ice Age.

The proxy-climate records from fossil phytoplankton (dinoflagellates) in sea-floor sediments in the Canadian Arctic region west of Greenland also confirm climate model estimations of summer ice-free conditions and sea-surface temperature increases of 4–6 degrees C that followed the end of the last glacial cycle. These arctic sea floor records show that the natural warming cycles took place over one to two centuries, long enough for marine and land plants and animals to adjust to the climate change.

Less is known about the older pre–Ice Age sea floor records, but oxygen isotope data from 40 DSDP and ODP sites now extend back over the past 124 million years. These show that several times 50–120 million years ago, temperatures as much as 12 degrees C warmer than today. These proxy-temperature data come from measurements of the ratio of magnesium to calcium (Mg/Ca) in fossil foraminifera. The boron isotopes in these microfossils also suggest that very high levels of carbon dioxide accompanied this hothouse ocean. The sea floor records also reveal several times, just before and after the extinction of the dinosaurs, when vast quantities of organic carbon were buried in some of the ocean basins during periods called Oceanic Anoxic Events (OAEs).

The OEAs seem to be related to times of extreme warmth and great variability of surface water in the subtropical to tropical latitudes of the Atlantic Ocean. The OEAs lasted about .5–1 million years and were accompanied by major extinctions of marine biota and wholesale changes in the composition and structure of marine animal populations. Overall, the sea-floor climate data show that very warm temperatures and hothouse conditions prevailed until about 55 million years ago, after which there was a slow drift toward the Pleistocene Ice Age and the oscillations between greenhouse and icehouse conditions.

SEE ALSO: Climatic Data, Oceanic Observations; Greenland Cores; Ice Ages; Ocean Component of Models; Oceanic Changes; Oceanography; Paleoclimates; Vostok Core.

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Climatic Data, Sediment Records

SEDIMENT LAYERS IN different types of depositional settings, which include floodplains, and the bottom of lakes, rivers, and oceans, can provide a useful archive of past climatic conditions over the last few decades to tens of thousands of years ago. Such sediment records are routinely used to reconstruct natural variability in past environmental conditions, as well as anthropogenic-driven changes in contemporary climate, including changes in effective moisture (the difference between precipitation and evaporation); temperature; atmospheric circulation patterns; wind regimes; sources, diversity, and productivity of organic matter; partial pressure of carbon dioxide (CO_2) in the atmosphere; and paleomagnetic properties of the surrounding environment.

The sedimentary record of past climate change can be made up of biogenic, radiochemical, and magnetic components. Derivation of such information from sediments is possible because changes in climate conditions, such as rainfall and consequent changes in aeration and alkalinity of bottom waters, can influence the rate of sediment input, formation of secondary minerals, and rates of biological productivity in the sediment layer.

The organic matter in sediment layers is a complex mixture of authochtonous and allochtonous (produced in situ or deposited with erosion, respectively) organic compounds from littoral, planktonic, and

With rates of sediment deposition up to two orders of magnitude faster than in the deep sea, lakes offer good climate records.

bacterial sources. Sedimentary basins contain biologically rich and diverse fossil records that can be used to reconstruct surface lake-water temperature (which is strongly correlated with air temperature), water chemistry, and other climatic factors that affect abundance and productivity of floral species. The most common sources of authochtonous organic matter in lacustrine and marine environments are diatom algal floras (diatoms are the most common type of phytoplankton and a major group of eukaryotic algae).

The ecological structure or community assemblages of indicator diatom species are highly correlated with the intensity and duration of some environmental conditions. For instance, the abundance and species composition of diatoms serve as proxies for past conditions in water-chemistry (including salinity and pH) and length of the growing season in the body of water.

On the other hand, allochtonous fossil records, including pollen and spores that are washed from surrounding catchments, give clues about past climatic conditions in the surrounding environment that could have produced the specific assemblage of plant communities. More precise information on factors influencing plant species abundance and productivity (of which climate is among the most important) in the surrounding environment can be retrieved from macrofossils, of large vegetation remains that are washed into the sedimentary basins. Fossils from insects such as chironomids also provide accurate records of lake-water temperature.

PAST CLIMATE CONDITIONS

The stable isotope composition of organic matter and carbonates in sedimentary basins can be used to provide information on past environmental and climate conditions.

Different types of terrestrial and aquatic plants and animals have variable isotopic composition, depending on their specific photosynthetic pathways, positions they hold on the food chain (trophic level), or their feed sources. Carbon and nitrogen isotope composition (δ13C and δ15N) of organic matter in sediment layers can be used to discern sources of organic matter.

Oxygen isotope composition (δ18O) of carbonate sources such as calcite (from ostracod and mollusk, or sedimentary minerals formed by precipitation or recrystallization during sedimentation), biogeonic silica, and organic matter can be used to reconstruct past conditions of temperature. Moreover, biological transfer functions for direct reconstruction of past temperatures are used with fossils of diatoms, chrysophytes (golden algae), chironomids (non-biting midges), and cladocera (water fleas), because presence of specific species in a given body of water and their abundance is strongly correlated with temperature.

Paleomagnetic information in sediment records is sometimes critical to establish chronologies, both to calibrate timescales for changes in source of minerals entering the sedimentary basin and to validate the integrity of the sediment record. The record of magnetism in sediments (variations in magnetic inclination and declination that is preserved in deposited sediments) is useful for interpreting past records of climate change. Temporal variations in the Earth's magnetic field are preserved in rocks and if magnetic particles are eroded from upland terrestrial environments and deposited in low-lying sedimentary basins they show small, but measurable, preferred orientation depending on the magnetic field at the time of sedimentation. This is a phenomenon referred to as depositional remnant magnetisms.

Several pre- and post-depositional factors can influence the utility of sediment records in reconstruction of past climatic conditions. The resolution of the sediment record can vary depending on rate of sediment delivery to the basin and type of the sedimentary basin considered.

For example, lake sediments provide a high-resolution record of past environmental conditions at the timescale of decades or a few centuries, while sediment records from oceans provide a lesser-resolution record of longer time periods. Lacustrine sediment records can provide a high-resolution record of paleoclimatic fluctuations, partly because rate of sediment deposition in lakes are up to two orders of magnitude faster than that in deep sea sediments.

Bioturbation (mixing due to biological activity) is another factor that affects integrity of sediment records and results in important changes to terrestrial sediment once it is deposited in a sedimentary basin. Pristine sediment records can be preserved when the currents at the bottom of a water column are weak and oxygen availability is too low to allow any mixing activity by living organisms. In the absence of bioturbation, contamination of the sedimentary record due to mixing of newly-deposited sediments with old sediments is limited.

Because most of the sediment in floodplains, or at the bottom of river, lake, or ocean floors is made up of mineral particles that were transported from adjacent areas, sediment records provide essential archives of past conditions, not only in the specific basin from which they are collected, but also in the surrounding areas. By investigating the stratigraphy of sediment cores, it is possible to get useful information about mineralogical composition of contributing catchments, rates of sediment transport, and biological productivity. It is important to note that within a basin, the sediment record can be stratified vertically or laterally. Sediment records that include vertical successions of strata are representative of chronology or sequential passage of time, while sediment records that include lateral successions of strata are representative of changes in depositional environments during sedimentation or diagenesis.

When interpreting sediment records, most sediments are derived from multiple sources, each with its own paleoenvironmental record. Moreover, sediment layers do not record direct information about climate change; therefore, scientists must calibrate the information obtained from sediment records (for example, the isotopic composition of δ18O for temperature) to known climatic data.

SEE ALSO: Climatic Data, Lake Records; Climatic Data, Oceanic Observations; Climatic Data, Proxy Records; Climatic Data, Sea Floor Records.

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Climatic Data, Tree Ring Records

PAST CLIMATES CAN be reconstructed by the use of the relationship between the climate and tree-growth parameters (dendroclimatology). Dendroclimatology is a sub-discipline of dendrochronology, which is the analysis of tree rings, including the dating of annual rings and study of patterns of ring characteristics, such as width, density, and isotopic composition. Annual growth rings of trees are natural recorders of climatic conditions (a proxy variable).

Outside the tropics, in the temperate and boreal zones with a distinct growing season and a strong seasonality in either temperature or rainfall, diameter growth of trees is distinguished by the formation of tree rings. Each growing season, new cells are produced by the vascular cambium (a cell layer that separates bark from wood).

While those cells formed toward the outside of the cambial layer become part of the bark, cells formed inward build up rigid wood and are the building blocks of tree rings. The actual tree rings are formed by a change in growth characteristics of wood formation through the season. Wood cells formed at the beginning of the growing season are large, thin-walled, and low in density, and are called earlywood. Toward the end of the growing season, cells become smaller and more thick-walled, forming the latewood. Finally, when the growth season ends, growth stops and cells die, with no new growth appearing until the next spring. The ring boundary is the contrast in cell size between the small latewood cells and the large earlywood cells.

Diameter growth of trees in arid and semi-arid environments strongly responds to changing soil water conditions and, thus, provides information on precipitation, while trees growing at high latitudes (poleward of 30 degrees), or high altitudes, are most sensitive to changing temperatures. In recent years, tree-ring studies have also been conducted in the tropical zone, where some tree species form distinct tree rings in reaction to dry and rainy seasons.

Analyses of tree rings have been carried out for several conifer species (such as spruce, pine, larch, fir, juniper, and cedar) and deciduous tree species (such as oak, beech, aspen, alder, birch, ash, and elm).

Moisture and a long growing season result in a wide ring, while drought and a short growing season results in a narrow ring.

However, deciduous species have not been studied as thoroughly as conifers, because of the more complicated structure and variability in their annual tree-ring growth patterns. Generally, tree species suitable for dendroclimatology are those that are sensitive to climate and show a variation in ring-to-ring growth, while those that lack ring variability are called complacent. Yet, tree-ring characteristics are not only influenced by a number of climate-related factors (soil and air temperature, precipitation or soil moisture, sunlight, wind, snow accumulation, or the length of the growing season), but also by non-climate-related factors such as soil fertility, atmospheric composition, slope gradient, fires, pests and diseases, grazing, logging, tree age, competition, genetic differences, and growth in previous years.

Climate-related factors may alter cell enlargement and subsequent maturation of wood cells by regulating hormone activity or availability, by influencing net carbon gain via restricted photosynthesis, or by modifying metabolic pathways associated with the different growth processes. Variations in temperature and water availability can have direct effects on the rates or duration of cell expansion and wall thickening, and indirect effects on carbon availability and growth-regulator levels. Temperature represents the most critical factor at the beginning of the growing season, when sufficient water reserves are available. As the growing season progresses and soil moisture decreases, radial growth is increasingly exposed to stress due to water deficit. Adequate moisture and a long growing season will result in a wide ring, while drought and a short growing season will result in a narrow ring.

Andrew E. Douglass of the University of Arizona discovered the basic technique of dendroclimatology in the early 1900s. For a good record of climate conditions, many trees need to be sampled to avoid the possibility of all the collected data showing a missing or extra ring. Information is acquired by taking small-diameter radial cores or horizontal cross sections through the trunk of a tree. These are prepared and total ring width, latewood width, maximum latewood density, and isotopic or chemical compositions are measured. Patterns of ring-growth characteristics are matched between several trees throughout a region in a process called cross-dating, which permits the assignation of exact calendar year dates to each individual ring. This matching is calculated by a number of computer programs.

Long-term growth trends associated with the aging of trees and forest dynamics represent an underlying disturbance for the purpose of climatic reconstruction and are removed statistically by detrending tree-ring growth series with a fitted smooth mathematical growth function (standardization). More complex modeling is used to remove the aftereffect of an adverse season to growth in the following years. Yearly growth measurements are then averaged from several trees in a region to form a master tree-ring chronology. This averaged tree-ring chronology enhances the common pattern of variations in growth (signal), while it dampens the non-common variance (confounding noise).

Cross-matching the patterns of a dated chronology with overlapping series of samples taken from dead trees of unknown age preserved in old buildings, river gravels, peat bogs, or lakes, allows chronologies to be extended into the past up to thousands of years (for example, chronology for Bristlecone pine greater than 8,500 years before the present time). By statistically comparing tree-ring chronologies with modern climate records, equations can be developed, which can be used in conjunction with the tree-ring data to reconstruct past climate values.

Tree-ring data are especially useful as climate proxies, in that they provide information of a high spatial and temporal resolution: the information is annually resolved, continuous, and abundant. However, tree ring data also have some limitations: confounding factors, geographic coverage (polar and oceanic climates are not covered), and annual resolution (dormant seasons are not covered). However, compared to corals and ice cores, tree-ring reconstructions show greater agreement with instrumental data over the last 100 years, both in terms of simple correlations and coherency on different timescales. Lake and ocean sediments have a lower time resolution, but provide climate information at multicentennial timescales that may not be captured by tree-ring data. By combining multiple tree-ring studies with the records taken from other climate proxy sources (multiproxy reconstruction), our understanding of past regional and global climates can be extended far beyond the instrumental record.

SEE ALSO: Climatic Data, Proxy Records; Climatic Data, Sediment Records; Detection of Climate Changes; Earth's Climate History; Forests.

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Climatic Research Unit

THE CLIMATIC RESEARCH Unit is regarded as one of the world's leading institutions concerned with the study of natural and anthropogenic climate change. It was founded in 1972 at the University of East Anglia in Norwich, England, by Professor Hubert Lamb (1913–97). The Unit, often known simply as CRU, was the first research center of its kind with a focus on research into climatology, in particular climatic change, and on interdisciplinary and historical research on the climate of the past. Lamb, one of the best known climatologists of his time, remained CRU's Director until 1978 when he became emeritus professor. In August 2006, the distinctive circular CRU building was named the Hubert Lamb Building. Subsequent directors of the Unit have been Tom Wigley, Trevor Davies and Jean Palutikof. The current Director is Phil Jones.

Lamb was employed by the United Kingdom's Meteorological Office from 1936 onwards. In 1950, he published a classic paper on weather types and natural seasons in Britain. The Lamb Weather Type (LWT) classification described in this paper began a new era in climatological research. In the 1960s, Lamb focused on reconstructions of monthly atmospheric circulation changes over the North Atlantic and Europe back to the 1750s. This research confirmed his growing conviction of the reality of natural climate change and its significance to humans. In 1970, he published a classic paper on the connections between volcanism and climatic change. His estimates of the dust ejected into the atmosphere by historical eruptions became known as the Lamb Dust Veil Index. Lamb was also one of the pioneers in the use of documentary evidence to reconstruct past changes in climate. This continues as a major focus of work in the CRU.

Although Lamb's work was crucial in the early years of the CRU, the Unit has had a number of other outstanding scientists on its staff. Their work has broadened the general aims of the CRU and helped to improve scientific understanding of past climate and its impact on humanity, the course and causes of climate change over the past century, and prospects for the future. The Unit currently employs 46 scientists and graduate students as well as hosting an M.Sc. course in Climate Change. CRU researchers have developed a number of data sets widely-used in climate research, including gridded data sets for surface temperature, precipitation, pressure, tree-ring records that have been important in reconstructing temperature variations over the past 1,000 years, and documentary records of climate and climate impacts. The user-friendly software package MAGICC/SCENGEN, used for making projections of future global-mean temperature, sea level, and patterns of climate change, was developed in the CRU (downloadable from http://www.cgd.ucar.edu).

Climate affects both social and natural systems through the occurrence of weather extremes, through inter-annual climate variability and through longer-term climate change. CRU researchers study aspects of all three of these scales of climate impact, with projects ranging from the United Kingdom to

Europe, Africa and Vietnam. A better understanding of the ways in which climate extremes and variability have affected society and the environment in the past is a pre-requisite for attempting to understand how serious the range of impacts associated with future climate change are likely to be. The results of analyses such as these feed directly into the design of climate-change response policies, whether these be mitigation or adaptation. Specific research areas include: paleoclimatology, dendroclimatology, present-day climate and climatological datasets, climate-change detection and attribution, construction of climate change scenarios, impacts of climate variability and change, links between atmospheric circulation and transport/deposition of air pollution, atmospheric sciences, and hydrology.

Climate Monitor, the seasonal data summary of work in the CRU changed from a printed to a online version in 1998. It is now available on http://www.cru.uea.ac.uk/cru/climon/ and brings together in one place regular updates of important climate and meteorological data, together with commentaries from the world's press and media. The CRU's website also contains a range of downloadable climate datasets and useful information pertaining to climate change.

SEE ALSO: Climatic Data, Historical Records; Climatic Data, Instrumental Records; Paleoclimates; Volcanism.

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Clinton Administration

WILLIAM JEFFERSON CLINTON (b. August 19, 1946) was the 42nd president of the United States, serving from January 20, 1993 until January 20, 2001. In the first year of his term, President Bill Clinton promised to bring justice to the practice of environmental racism as well as to work to resolve the tension regarding management of the Pacific Northwest federal forests, and yet throughout his term he would be known as the president who gave tax breaks to oil companies in the Gulf of Mexico, who no longer banned tuna that was not dolphin-safe, and who increased logging in the Tongass National Forest of Alaska.

Environmental racism refers to the fact that lower-income communities, which tend to house peoples of ethnic minorities, as well as communities of non-whites, are at a higher risk of being located near environmentally-toxic sites, such as landfills or hazardous waste dumping grounds. Consequently, people living in these communities are at an elevated risk of developing chronic disorders such as asthma or cancer.

On April 2, 2003, Clinton along with Vice-President Al Gore and several advisors and Cabinet members attended a meeting convened by Clinton to discuss the Pacific Northwest federal forests. This meeting was held in Portland, Oregon. After the meeting, President Clinton promised to develop a plan for sustainable and economic management of the forests, and this plan was released on July 1 of that year. It was called The Forest Plan for a Sustainable Economy and a Sustainable Environment.

The three chief purposes of the plan were forest management, economic development, and agency coordination; of the three, forest management had most to do with the environment. This theme set aside reserves with minimal activity allowed within them, although it did allow thinning and salvage for purposes of returning the forest to its old patterns of growth. Some environmental groups were nonetheless concerned that the salvage activities and thinning would be exploited for corporate gain. Other areas of the forest such as those designated as spotted owl habitat were slated for limited collection annually, in order to preserve the habitats while maintaining a sustainable timber harvest. Additionally, the plan called for improved sales of dead or dying timber within the forestland, in order to clear way for new trees.

After barely one month in office, on February 22 1993, President Clinton outlined his priority: "long-term economic growth that creates jobs and protects the environment." He did so in a Statement on Technology for America's Economic Growth. A significant contribution of the Clinton Administration to environmentalism was that trade agreements between the United States and other nations required that those countries observe environmental standards. This change in United States trade policies was praised for its environmentalism, but criticized for its potential to harm citizens of countries where employers and/or leaders exploited the environment while trying to succeed in the global economy.

To keep with his priority of environmentally safe economic growth, Clinton created a new watchdog position at the Department of State to monitor international environmental conditions. This position of Undersecretary for Global Affairs was assigned to Timothy E. Wirth. Wirth, a former Senator from Colorado, was a member of the Green party and acted as Undersecretary for Global Affairs from 1993 until 1997. Following in this environmentalist spirit, Secretary of State Warren Minor Christopher issued a statement on February 14, 1996 stating that U.S. foreign policy would from that point on keep the environment and its care in focus and that Department of State officials must consider this focus when designing international policies or meetings. Christopher also served from 1993–97.

This international environmental watchdog stance did not extend beyond trade and meeting policies. In 1996, the Clinton Administration challenged China's desire to build a dam to control the flooding of the Yangtze River to curb its enormously high death toll. The reason for the Clinton Administration's refusal of support was that the dam, called the Three Gorges Project, would threaten many species of wildlife, such as freshwater dolphins and Siberian cranes. The Clinton Administration attempted to influence commercial credits for American companies looking to capitalize on the Three Gorges project, and was accused of trying to use its voting power at the World Bank to impede funding for the dam.

Clinton had three Secretaries of Energy during his Administration. They were Hazel O'Leary (1993–97), Federico F. Peña (1997–98), and Bill Richardson (1998–2001). His Vice President, Al Gore, would go on to become a leading environmentalist. In an interview with CBS news in 2006, James Hansen, the Director of the Goddard Institute at the National Aeronautics and Space Administration (NASA), said that the Clinton administration sometimes wanted him to make global warming sound worse than it was. In contrast to this statement, Vice-President Gore was awarded the Nobel Prize for Peace in the year 2007 for his efforts to spread education about global warming and curtail its progress. He shared this award with the Intergovernmental Panel on Climate Change (IPCC).

SEE ALSO: Bush (George H.W.) Administration; Bush (George W.) Administration; Environmental Protection Agency (EPA).

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Cloud Feedback

INCREASES IN SURFACE and tropospheric temperatures produce changes in cloud properties that, in turn, produce changes in temperature. This effect is known as cloud feedback. Cloud feedback has been identified by the United Nations Intergovernmental Panel on Climate Change (IPCC) as one of the most uncertain processes in climate models. Cloud particles (hydrometers) affect both thermal and solar radiation. Cloud particle size and concentration are strongly-affected by updraft velocity, humidity, temperature, and cloud nuclei concentration. In addition, the lifetime of cloud particles depends on the humidity of the ambient air. Thus, cloud properties and coverage are sensitive to climate change.

Clouds produce extremely complex climate feedbacks that lead to large uncertainty in climate simulations because cloud processes are not well understood. Clouds cool the Earth by scattering solar radiation and increasing the amount of solar radiation returned to space. That is, clouds increase the planet's albedo. They also absorb solar radiation, increasing the atmosphere's temperature, and cooling the surface by reducing the amount of solar radiation reaching it. In addition, clouds produce a greenhouse effect by absorbing thermal radiation and re-emitting it at their own temperature. Clouds tend to keep nighttime surface temperatures warmer than they would be in their absence, and keep daytime temperatures cooler.

Cloud feedback is the combined result of changes in cloud cover, cloud height, cloud emissivity, and cloud albedo. Because various cloud processes contribute to cloud feedback, and because different types of clouds such as cumulus, stratus, and cirrus have different effects on the budget of solar and thermal radiation, cloud feedback is complicated. Climate models cannot even determine if the overall cloud feedback is positive or negative. High clouds, such as cirrus, are optically thin and cold. Because they are reasonably opaque to thermal radiation, they scatter a relatively small amount of solar radiation when compared to the amount of thermal radiation they emit. Thus, high clouds usually have a net warming effect on the planet.

Low clouds, such as stratus, are warm and highly opaque to solar and thermal radiation. However, because low clouds are not much colder than the surface, their main effect is to increase the amount of solar radiation scattered to space. Therefore, low clouds usually produce a net cooling of the planet. On the other hand, low clouds over bright and cold surfaces such as snow or ice can have a positive climate feedback. The net result depends on details of cloud properties, such a particle size distribution and concentration.

The effects of clouds on climate are uncertain, because they depend on the cloud particle number, size distribution, phase, cloud height, temperature, and many other physical parameters. Cloud feedback is the source of the largest uncertainty in the Global Climate Models (GCMs) used to calculate human-induced global climate changes. The International Satellite Cloud Climatology Project (ISCCP), started in 1983, was the first internationally-coordinated satellite cloud climatology project. This pioneering program served as a prototype to many other global satellite cloud climatology projects. The U.S. Department of Energy (DOE) Atmospheric Radiation Measurement Program (ARM) has focused on surface and cloud measurements. These measurements are used to study cloud processes to produce solid cloud climatology.

SEE ALSO: Climate Models; Clouds, Cirrus; Clouds, Cumulus; Clouds, Stratus.

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Clouds, Cirrus

CIRRUS CLOUDS ARE the thin and wisp-like clouds seen at high altitudes (higher than 20,000 to 26,000 ft., or 6,000 to 8,000 m.). The name cirrus comes from the Latin word for curl. They are composed predominantly of tiny ice crystals, because they form in the cold region of the troposphere. If cirrus clouds drop their ice crystals, these crystals evaporate before they arrive at the ground.

Cirrus clouds can take on a variety of formations, including a more tuft-like characteristic called cirrocumulus, which also include supercooled water droplets. Some cirrus clouds are called cirrostratus; this

Cirrus are the high, wispy clouds composed predominantly of tiny ice crystals formed in the cold region of the troposphere.

type of cloud formation occurs when the thin strands of clouds are so dense that they cannot be deciphered. Other formations include cirrus aviaticus (also called contrails, the artificial cirrus clouds generated by aircraft), cirrus castellanus (castle-like, with towers rising from a base), cirrus duplicatus (multiple sheets), cirrus fibratus (fibrous, and resembling a horse's tail), cirrus floccus (rounded above), cirrus intortus (tangled), cirrus Kelvin-Helmholtz (slender and signaling atmospheric turbulence), cirrus radiatus (with horizontal banding), cirrus spissatus (thick and gray in color when in front of the sun), cirrus uncinus (hooked, and reminiscent of cirrus fibratus but with more curling at the ends), cirrus vertebratus (rib-like horizontal strips of clouds), and cirrus with mammatus (rounded underneath).

Cirrus clouds are generally seen in fair weather, sometimes following a thunderstorm, and their wisps typically point in the direction of the high-altitude wind flow. In the case of Cirrus Kelvin-Helmholtz, the clouds lie in the turbulent atmospheric region. Cirrus clouds usually form in the summer and winter, when opposing weather fronts meet, such as warm, dry air and cool, dry air. Some meteorologists use cirrus clouds to predict rain.

Because of the high altitude of these clouds, their albedo effect is often overridden by their greenhouse effect. This imbalance is due to the fact that lower clouds are weaker at conserving solar heat, but are very good at reflecting it back into the atmosphere. In contrast, the high cirrus clouds can both conserve heat and reflect it, but are often better at conserving it. Studies are currently being conducted at the United States National Aeronautics and Space Administration (NASA) to determine the role of cirrus clouds in global warming and the Earth's climate. The modeling of these clouds and their effects is difficult, due to the irregular nature of the sizes and shapes of their ice crystals.

Clouds can be found in the atmospheric layer called the troposphere. The troposphere is the lowest atmospheric region and is where all weather takes place. At the equator, it reaches up to 11 mi. (18 km.) from the earth's surface. The next atmospheric layer is the stratosphere, extending to 31 mi. (50 km.) from the Earth's surface. A cloud forms when water vapor reaches its dewpoint and condenses to form a water droplet. These droplets condense around cloud condensation nuclei (CCN), which are often particles of aerosol providing a scaffold around which the cloud can form. Each CCN is approximately one one-hundredth the size of the cloud droplet, which is itself approximately one one-hundredth the size of a rain droplet (usually about .08 in. or 2 mm. in diameter). The nature of the clouds allows them to reflect sunlight away from the earth, known as the albedo effect, but also to trap infrared light beneath them on the earth's surface. This latter phenomenon adds to the greenhouse effect.

In 2007, investigations at the University of Alabama at Huntsville found that global warming might paradoxically be leading to a thinning of these greenhouse-inducing cirrus clouds.

SEE ALSO: Aerosols; Albedo; Clouds, Cumulus; Clouds, Stratus; Precipitation; Troposphere; Weather.

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Clouds, Cumulus

CUMULUS CLOUDS ARE puffy and usually have well-defined boundaries. They form from the condensation or deposition of moisture in particles known as cloud nuclei present in the moist updrafts of convective plumes. The cloud particles can be composed of liquid water, supercooled water, or ice. These cloud particles are denser than air; therefore they increase the density of cumulus updrafts. However, water vapor is lighter than dry air, and therefore, except for the effects of the cloud particles, the moist updraft air is lighter than dry air at the same temperature and pressure. This effect of moisture on air density is known as virtual temperature. Scientists have shown that the virtual temperature effect is responsible for about 50 percent of the buoyancy of convective plumes that form cumulus clouds in the tropics and subtropics, but has negligible or even negative effects over desert and semi-desert areas.

The base of cumulus clouds is usually flat, because they form when moist air rising from the surface reaches its lifting condensation level. The height of the lifting condensation level depends only on the properties of the updraft air, therefore it is constant in updrafts mixed by turbulent eddies. The height of the cloud bases usually ranges from a few hundred meters over the oceans, to more than 16,404 ft. (5,000 m.) over dry desert and semi-desert areas. The shape and size of cumulus clouds depends on the intensity of the updrafts causing them to form. Individual updrafts form the various cumulus towers that compose single cumulus clouds. The rounded tops of these towers are the boundaries of convective plumes reaching their level of neutral buoyancy. Cumulus clouds can develop into giant cumulonimbus in environments convectively unstable over large depths.

Cumulus are the puffy, tall clouds composed of liquid water, supercooled water, or ice.

Convective circulations are heat engines because they convert heat into bulk fluid motion such as convective updrafts, downdrafts, and the complete convective circulation. The efficiency of this conversion of heat into kinetic energy depends on the depth of the convective layer. Therefore, deeper convection produces stronger updrafts and more well defined cumulus towers than shallow convection. Cumulus clouds can cause showery rain. Over deserts and semi-arid regions, the rain evaporates before reaching the surface. This is known as virga.

Global climate warming will likely produce increases in the amount of cumulus clouds. This happens because surface warming, coupled with stratospheric cooling, increases convective instability. The height of the bases of cumulus clouds might increase over land because global warming is expected to increase the surface temperature and reduce humidity. Illumination and wind has strong effects on cumulus clouds, in particular, on their appearance and organization. Changes in illumination and background cause changes in color and the apparent surface relief of cumulus clouds. Wind shears can shred the top of cumulus clouds, forming the species known as cumulus fractus. Wind can also orient clouds into rolls or cloud streets and produce waves and lenticular clouds to form above them.

SEE ALSO: Clouds, Cirrus; Clouds, Stratus.

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Clouds, Stratus

STRATUS CLOUDS ARE those clouds that resemble a sheet across the atmosphere. These clouds typically rest at a low altitude, found below 6,000 ft. (2,000 m.). Their color can vary between white to dark gray. A stratus cloud that rests at ground level is known more commonly as fog. Stratus clouds a bit higher than fog block the sun from view and cause a cloudy day' The name stratus is the Latin word to spread out.

The formation of stratus clouds occurs when a sheet of cool air passes under a sheet of moist, warm air. At the layer where these two sheets meet, the warm upper air is cooled to condensation and forms a stratus cloud. The cloud will extend as far as the overlap between the sheets of air.

Because stratus clouds are typically fog that has been elevated, they usually do not bode precipitation. At the most, stratus clouds might bring a drizzle. A type of stratus cloud, nimbostratus, do bring precipitation. Weather associated with nimbostratus clouds might be rain or snow. These clouds are so named because nimbus means rain in Latin. They are dark gray and typically rest in lower altitudes, no higher than 8,000 ft. (2,400 m.).

Yet another form of stratus cloud is the combination of a stratus cloud and a cumulus cloud, called a stratocumulus cloud. Stratocumulus clouds bring light precipitation, often a drizzle, and are found at the same elevation as nimbostratus clouds. They are somewhat fluffy, due to their cumulus nature, but darker than typical cumulus clouds. Generally, stratocumulus clouds do not bring much in terms of weather; they are used to predict dull weather.

There are many variations of stratocumulus clouds. These variations are classified as one of two types: stratocumulus undulatus (undulated, or waved) or stratocumulus cumuliformis (cumulus-shaped). The types of clouds in the stratocumulus undulatus category are tratocumulus lenticularis (lens-shaped, elongated and flat), stratocumulus opacus (dark and thick), stratocumulus perlucidus (occasionally exhibiting pockets of inconsistency that allow sunlight through), and stratocumulus translucidus (sheets of stratocumulus clouds, between which a clear sky can be seen). Stratocumulus cumuliformis clouds include stratocumulus castellanus (towers of clouds billowing from a common base), stratocumulus diurnalis (low altitude clouds resulting from spreading of cumulus or cumulonimbus clouds), stratocumulus mammatus (from mamma, the Latin word for breast; having rounded clouds hanging underneath the stratus layer), and stratocumulus vesperalis (generated by air cooling patterns that occur in the evening).

High stratus clouds are called altostratus. Altostratus clouds are also translucent for sunlight. They are formed from great patches of air that are elevated and condensed, due to the cold temperature at higher altitudes. Altostratus clouds are composed of ice crystals and, therefore, threaten to deposit layers of ice on airplanes passing through. Altostratus undulatus clouds are similar to altostratus clouds, but with undulations, or waves, and therefore are often called billow or wave clouds.

A type of cloud, called cirrostratus, combines features of cirrus and stratus clouds. They are a sheet of wispy clouds made of ice crystals and tend to form at a higher altitude than regular stratus clouds. Because of their ice-crystal composition and high altitude, cirrostratus clouds are translucent; that is, sunlight and moonlight can be seen through them. Due to the ice crystals and their light refractive properties, cirrostratus clouds often cause a halo effect around the moon or sun when viewed from below.

Clouds can be found in the atmospheric layer called the troposphere. The troposphere is the lowest atmospheric region and is where all weather takes place. At the equator, it reaches up to 11 mi. (18 km.) from the Earth's surface. The next atmospheric layer is the stratosphere, extending to 31 mi. (50 km.) from the Earth's surface. A cloud forms when water vapor reaches its dewpoint and, thus, condenses to form a water droplet. These droplets condense around cloud condensation nuclei (CCN), which are often particles of aerosol providing a scaffold around which the cloud can form. Each CCN is approximately one one-hundredth the size of the cloud droplet, which is itself approximately one one-hundredth the size of a rain droplet (usually about 2 mm. in diameter). The nature of the clouds allows them to reflect sunlight away from the earth, known as the albedo effect, but also to trap infrared light beneath them on the Earth's surface. This latter phenomenon adds to the greenhouse effect.

SEE ALSO: Aerosols; Albedo; Clouds, Cirrus; Clouds, Cumulus; Precipitation; Troposphere; Weather.

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Coal

COAL IS ONE of a variety of energy sources that both developed and developing nations use. It is the fossil fuel that is relied upon most heavily for electricity generation in the United States. Organic matter from the Carboniferous period, which occurred approximately 360–286 million years ago, forms currently accessible coal deposits. There are several different types of coal, each with varying degrees of thermal value. In the process of electricity and heat generation, coal combustion releases many pollutants into the air, water, and land. These pollutants include mercury, sulfur oxides, nitrogen oxides, methane, and carbon oxides. The dispersal of such toxins into the environment has many ecological, human health, and economic effects. More specifically, coal combustion contributes to the climate-changing effect of increased atmospheric carbon. Because of this, alternatives to coal combustion are presently being researched and developed. Coal is presently a necessary and inexpensive way of producing electricity and heat; however, the use of this resource has significant consequences.

TYPES OF COAL

There are four main classifications of coal. Each type of coal is formed as a result of the exposure to assorted combinations of temperature and pressure during formation. For instance, coal that was exposed to low temperatures and pressures is usually moister, softer, and has lower energy content. The four coal classifications include lignite, subbituminous, bituminous, and anthracite.

The first type of coal, lignite, is soft with a high moisture content and low thermal value as compared with other types of coal. Lignite is usually light brown to brown-black in color and resembles deteriorating and compressed wood. In the United States, most lignite deposits are found in the western states; specifically, North Dakota is the state that produces the largest amount of lignite. This type of coal is relatively inexpensive and, thus, highly desirable, from an economic standpoint, to fuel electric power plants.

The next classification of coal is subbituminous. This type of coal is the intermediate between lignite and bituminous coal. It has a moisture content of between 20 and 30 percent. This is higher than bituminous coal and anthracite; however it is lower than lignite. Subbituminous is desirable from a pollution standpoint because it has a low relative sulfur and carbon content, but the thermal value of subbituminous coal is low. However, many power plants prefer to burn subbituminous coal, as it provides cleaner energy generation. Subbituminous coal is found primarily in Alaska, Montana, and Wyoming and is recognized by its unpolished black color.

POLLUTION CONTROLS

Bituminous coal is the third type of coal. Though it is harder than lignite or subbituminous coal, bituminous coal is often referred to as soft coal. This is due to the high sulfur content. Because bituminous coal has such a high amount of sulfur present, electricity generators that choose to burn this type of coal must equip their plants with sophisticated pollution-control systems. These mechanisms are called scrubbers because they scrub the pollution from the air by binding reactive toxins with inert, calcium-based substances located in the air stacks of power plants. The best available technology allows scrubbers to remove 98 percent of all sulfur emissions and 99 percent of all particulate matter from smoke stacks. Bituminous coal is dark black in color and may have dull-black bands striated throughout. This type of coal is typically found in Appalachian Mountain regions, the Great Lakes, the Mississippi Valley, and north and central Texas.

The final classification of coal is anthracitic coal. This is the hardest type of coal, thus, many people call it hard coal. This hardness is derived from the compact nature of the coal, which is a result of extremely high temperatures and pressure during coal formation. This coal is preferred because it has the highest thermal value and lowest sulfur content. This means that anthracite generates the most energy per unit of heat produced during combustion, and releases the smallest amount of sulfur pollutants per unit of heat emitted. Anthracite appears to be dark, shiny, and black. It has moisture content of 4 percent, and, in 2000, a ton of anthracite sold for about $40. This type of coal is found most frequently in Pennsylvania and other areas east of the Mississippi River.

Each of the four types if coal must be removed from the Earth's surface layer. Most coal is located in seams, ranging from .98 in. (2.5 cm.) to 98.4 ft. (30 m.) thick. These seams are relatively easy to locate, and, thus, most of the available supply in the United States is well-known. Therefore, industry and scientists can focus less time searching for new coal deposits and more time devising methods for remedying the effects of the associated pollution.

Coal is mined in two different ways: surface mining or subsurface mining. The kind of mining chosen depends on the surface conditions and the depth of the coal seam. Usually, mining companies pursue surface mining, also called strip mining, when the coal seam is located within 98.4 ft. (30 m.) of the surface. Through this process, the Earth's surface is scraped away and the coal is then removed using machinery. Approximately 60 percent of all the United States' coal supply is acquired through strip mining.

The most destructive type of surface mining is mountaintop removal. This occurs when dynamite is detonated and removes the surface material above the coal seam. Also, a dragline may be used to remove large portions of earth. This machine acts as a gigantic shovel. Debris from this removal process is then placed in nearby valleys and streams. Presently, 15 to 25 percent of all mountaintops in West Virginia have been subjected to this type of destruction.

Subsurface mining provides the United States with the other 40 percent of its coal supply. This method is used when the coal seam is located deep within the Earth's crust. Long networks of tunnels and shafts are dug underground along the coal seam. Miners then recover coal. This type of mining produces less landscape effects, however, compared to surface mining, the subsurface mining method is more expensive, less effective at removing all coal, and more dangerous to mine workers.

PRE-MINING CONDITIONS

The Surface Mining Control and Reclamation Act of 1977 (SMCRA) requires that the environment surrounding coalmines be restored to pre-mining conditions. Prior to the passage of this piece of legislation, mining companies left open pits, trenches, and large holes exposed. This created dangerous and unstable land conditions and often led to the collapse of such areas when disturbed by humans or wildlife. Also, sediment and contaminated soil and water were swept away by rain events, polluting nearby streams and rivers. SMCRA mandated regulations to prevent these types of activities. It also limited mining operations in national parks, national historic places, wildlife refuges, and wild and scenic rivers. Finally, SMCRA established a fund to restore mining areas that were abandoned prior to 1977.

EFFECTS OF COAL

While coal provides an affordable and easily accessible form of fuel for electricity generation, there are severe environmental, human health and economic effects of coal. The combustion of coal contributes more pollution than any other type of fossil fuel. Fifty percent of all U.S. electricity comes from coal combustion. Just one 500-megawatt coal-fired power plant produces about 3 million tons of carbon dioxide per year. Using this much coal for electricity generation causes environmental problems such as acid rain, land pollution, and global climate change. Coal has also been linked to increased incidence of respiratory ailments such as asthma, shortness of breath, and chest pains. Finally, remediating the damage done by coal combustion can cost thousands to millions of dollars.

The first major environmental problem associated with coal combustion is acid rain. This occurs when nitrogen oxides and sulfur oxides produced in burning coal are released into the atmosphere. These oxides then react with atmospheric moisture to produce dilute acids such as sulfuric acid, nitrous acid, and nitric acid. Dry particles can fall to Earth's surface as precipitation, as well. This is referred to as acid deposition or dry deposition. When these particles interact with clouds, the resulting rain events can have a lower pH than normal. The pH of normal rain is slightly acidic, usually between pH 5–6; however acid rain can have a pH as low as pH 2.

This can decrease the pH of water bodies, thus changing the aquatic chemistry, killing plants, fish, and other aquatic organisms. Because most freshwater lakes and ponds do not have high buffering capacities, small additions of acid have significant impacts. Acid rain can also cause the number of forest species to decline. This happens for a variety of reasons. First, acid rain can harm the leaves, bark, and seeds of trees, thus hindering both individual growth and community regeneration. Acid deposition can also affect root growth and impair nutrient uptake. Finally, years of prolonged exposure to acid rain can acidify the soil, thus leaching nutrients and releasing harmful minerals that may have been bound in the cation and anion exchange capacities.

Acid deposition and acid rain can fall upon buildings and monuments, reacting with building materials such as marble, concrete, and iron. In the United States, damages caused by acid deposition are estimated to be around $10 billion each year. Industrialized nations such as most of Europe, Russia, North America, and China are subject to the majority of effects of acid deposition and acid rain.

Land use and land-based pollution issues are the second problem created by the heavy use of coal for electricity production. The mountaintop removal method, for example, causes irreparable damage to the landscape. Once the topsoil and other soil horizons are removed, usually only the bedrock or other impermeable surfaces remain. In these areas, vegetation cannot grow, so erosion from water and wind usually carries away any remaining soil.

Also, abandoned mines can fill with water and then drain throughout the topography into nearby streams and valleys, creating acid mine drainage problems. This situation occurs when rainwater permeates the iron-sulfide-laden materials deep within subsurface mines and in mine waste. The water and iron sulfide react, creating sulfuric acid. Acid mine drainage can occur in most places where coal or metals have been mined. This is because carbon and metal compounds usually occur as sulfides. Acid mine drainage can quickly reduce the pH of an affected water body, devastating local fish, waterfowl, and plants in the watershed. Intense, or chronic, rain events can lead to highly-acidic conditions into a watershed.

GLOBAL CLIMATE CHANGE

The third major environmental, human, and economic problem associated with the use of coal as an energy source is global climate change. Evidence suggests that anthropogenic increases in atmospheric carbon are leading to increased mean global temperatures, and changes in regional climates.

Several gases, including methane, carbon dioxide, nitrous oxide, and ozone, known as greenhouse gases, absorb infrared radiation and lead to increased atmospheric temperatures. This, in turn, creates a negative feedback loop of increased ice melts at high latitudes and high elevations, and lower overall albedo. The Intergovernmental Panel on Climate Change (IPCC) has issued several reports suggesting that even if greenhouse gas emissions were reduced to zero, there is enough system-wide momentum that climate change impacts will be felt for years into the future. The IPCC reports also predict increased droughts in middle latitudes, as well as stronger storm events in coastal regions. If humans continue with "business as usual," mitigating the effects associated with global climate change is likely to cost billions of dollars.

MITIGATION OF COAL-BASED POLLUTION

Due to these significant environmental, human, and economic impacts, scientists are exploring potential solutions to coal-based pollution. Coal mining and electricity production are robust industries, which provide industrialized nations with inexpensive energy. Also, the supply of coal is large when compared with other fossil fuels.

However, industry and scientists are exploring several new technologies that will lessen the impacts associated with coal-fired power plants. These include alternative forms of energy, carbon capture and sequestration (CCS) methods, and Integrated Gasification Combined Cycle (IGCC) technology.

First, many nations are investing in renewable energy technologies. These include electricity generation by wind, solar, geothermal, biomass, and tidal and wave action. In recent years, renewable energy technology has become more affordable and widely utilized; however renewable technologies only account for a small portion of the world's total electricity supply. U.S. policies such as production tax credits for renewable technology, and state-mandated renewable portfolio standards, are lessening the need to use coal technologies and promoting the use of renewable ones.

Carbon capture and sequestration (CCS) methods hold promise for reducing the negative effects of coal combustion. Power plants and other large carbon dioxide emitters use this process. Carbon dioxide is captured in gaseous form, compressed, and then pumped miles underground for storage under impermeable substrate.

The carbon dioxide may react with calcium-rich substances forming calcium carbonate or other mineral carbonates. Presently, few power plants utilize this technology, because it is expensive and the long-term effects of underground carbon dioxide storage are not fully understood. Finally, IGCC is a process by which methane gas is produced from coal. Heating the solid coal produces the methane, referred to as syngas or synmethane. Then, the methane is burned to produce stream, which turns turbines and generates electricity.

The benefit of using this technology is that the syngas that it produces burns extremely cleanly. In particular, emissions of mercury and sulfur are reduced over 90 percent by utilizing this method. The disadvantage to IGCC is that the technology is not widely-used, and is still considered by many to be cost-prohibitive.

Coal is an abundant and inexpensive fossil fuel used for electricity generation in developed and developing nations. The four types of coal each have varying degrees of thermal value, moisture content, and pollution potential. Mining coal, either by surface or subsurface mining techniques, can create worker safety problems and environmental and landscape degradation. Also, the combustion of coal can lead to acid rain and acid deposition, irreversible landscape harm and acid mine-drainage, as well as increased global climate change effects. Because of this, new technologies are being developed to lessen these impacts and continue to make coal a viable energy source.

SEE ALSO: Alternative Energy, Overview; Carbon Cycle; Carbon Dioxide; Energy; Impacts of Global Warming; Pollution, Air; Pollution, Land; Pollution, Water.

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Colombia

COLOMBIA, LOCATED IN the northwest of South America, is a highly-diverse country in terms of environment and climate. Colombia is dominated by the Andes, where the tropical diurnal climate is characterized by small differences in monthly temperature (less than 3 degrees C), although daily fluctuations may be large (up to 20 degrees C), especially during dry seasons. Three Cordilleras of the northern Andes are described by approximately 22,966 ft. (7,000 m.) of altitudinal change; this altitudinal rise equates to a temperature change of nearly 30 degrees C, and results in a significant change in vegetation recorded over a relatively small area. For example, there are transitions from cool high-altitude grasslands, to temperate forests at mid-altitudes, and some of the most diverse tropical rainforests in the world within the Chocó Pacific region.

Away from the Andes, the extensive lowlands are also incredibly diverse, ranging from lowland rainforests in Amazonia, to extensive savannas of the Llanos Orientales. The diversity of lowland ecosystems is mirrored by the climate; precipitation is highest in the Chocó Pacific region, due to the proximity of the Pacific-based moisture source and the steeply-rising ground of the Western Cordillera. Within Andean Colombia, low rainfall is recorded within rain shadow areas of the inter-Andean plains.

Colombian paleoecological archives of vegetation change represent a remarkable record for Latin America and the wider tropics. The Colombian pollen data allows an understanding of regional environmental change and its impact on tropical vegetation composition and distribution that rivals the resolution commonly available from more temperate latitudes where Quaternary science research has a longer ancestry and wider research base.

For example, one record from the Funza sedimentary basin within the high plain of Bogotá (8,366 ft. or 2550 m.), situated on the eastern Cordillera of Colombia, is a 1,968 ft. (600 m.) sedimentary sequence that documents vegetation change over the past 3.5 million years, according to H. Hooghiemstra.

This exceptional record, possibly the best record of vegetation change in the world, has resulted as sediment infilling during the Quaternary was in balance with subsidence of the basin floor and Andean uplift, leading to a permanent lake environment. The record has shown that during interglacial periods, the upper forest limit of the northern Andes was located maximally between 11,155–11,483 ft. (3,400–3,500 m.). During glacial periods, the forest limits have been placed at approximately 6,562 ft. (2,000 m.), with the area surrounding the core site being characterized by an increase in grass-dominated communities.

The extensive paleoecological data from Colombia that cover all major ecosystem types and climatic zones have been used in several synthesis studies. The reconstructions successfully describe the composition and distribution of vegetation, and in particular, altitudinal shifts in vegetation associated with the northern Andean Cordilleras and transitions from Amazonian lowland rainforest to savanna, according to Rob Marchant, et al. Under climatic conditions of the last glacial period, montane vegetation types extended to low altitudes where there was a concentration of moist vegetation type and concomitant expansion of the savanna areas.

As climate ameliorated, the reverse situation occurred. For example, in the mid-Holocene, the vegetation is characteristic of warmer environmental conditions than those of the present day. This trend continues until between 4,000 and 3,000 years before the present era, when there is a shift to more mesic vegetation that is thought to reflect an increase in precipitation levels, according to Marchant and Hooghiemstra. The influence attributed to human-induced impact on the vegetation is recorded from 5,000 years before the present era, but is particularly important from 2,000 years before the present era. The extent of this impact increases over the late Holocene period, recorded at increasingly higher altitudes. Despite these changes, many sites do not change their vegetation, such as those with asynchronous vegetation response results from site location, non-linear response of vegetation to Late-Holocene environmental change, regionally differential signals, and localized human impacts.

SEE ALSO: Climatic Data, Nature of the Data; Paleoclimates; Plants.

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Colorado

HOME TO SIX national parks and recreation areas, more than 1,000 soaring Rocky Mountain peaks, and nearly 30 ski resorts, Colorado is a prime tourist destination. It is also a rapidly growing state. Its population expanded by 34 percent 1990–2000, and, in 2006, the U.S. Census Bureau identified it as the eighth fastest-growing state in the United States. The combination of rapid growth and a S2.4 billion tourist industry already place heavy pressure upon the state's resources. Between 1807 and 1907, Colorado's precipitation decreased as much as 20 percent in many parts of the state, and recent droughts have left Colorado facing half-full reservoirs. Predictions that global warming could bring hotter, drier summers that will affect all areas of the state's economy have prompted the state to take decisive action to lower greenhouse gas emissions and focus on sustainability.

Colorado's climate change plan, *Climate Change and Colorado—A Technical Assessment*, has been in effect since 1998. The state's carbon efficiency rate improved by 29 percent 1990–2001, the seventh best record in the nation. This improvement was accomplished with an economy growing by 91 percent. Although Colorado did not have the problems with air quality that more heavily-industrialized states did, carbon dioxide emissions were growing at a rate even faster than the population, a 39 percent increase 1990–2004. The state ranked 23rd in its emissions, but its increase rate was the fifth largest in the nation, more than double the national increase of 18 percent. Fossil fuel combustion created 78 percent of the state's greenhouse gas emissions in 1990.

By 2004, the state's snow pack had been below average for 14 of the last 18 years, and melting was occurring earlier in the spring. For a state that depended upon snowmelt for 70–90 percent of its water, the changes were alarming. A 2004 study, using a conservative climate model, concluded that in just one generation, the Colorado River basin could have 3 percent less precipitation, 24 percent less snow pack, 14 percent less runoff, and 36 percent less water storage. Such a scenario would mean increased droughts, more wildfires, and a range of changes in the ecosystem.

Such losses could ravage ski resorts, and yields of the state's two major crops, corn and wheat, could decline from 8–33 percent due to decreases in soil moisture and water available for irrigation. Habitats throughout the state would be threatened. Species from the endangered greenback cutthroat trout in Colorado's cold waters, to the migrating whooping cranes in the marshes of the Platte River basin, to the alpine-dwelling American pika, already extirpated in some locations that have grown too warm, would be at risk. Such loss of habitat and wildlife would lead

Colorado wind power has the potential to generate over 450 billion kilowatt-hours a year, enough to power the state.

to job losses and damage to the state's economy. The Intergovernmental Panel on Climate Change Report on Emissions offered two scenarios: unchanged emissions and more than a 50 percent snow pack reduction in most areas; or reduced emissions and 50 percent reduction in some areas.

Leaders in the public and private sector have begun working to find solutions. In November 2004, Colorado became the first U.S. state to create a renewable portfolio standard (RPS) by ballot initiative. With this act, utilities serving 40,000 or more customers were required to generate or purchase 10 percent of their retail electric sales from renewable-energy resources. In the summer of 2006, the Colorado Climate Project was launched. The mission statement of the Climate Action Panel is modeled after similar statements in other states; its purpose is to make recommendations that will render the state less vulnerable to climate changes without undue damage to the economy. But, the Colorado plan is unique in that the impetus came not from government action, but from the collaboration of elected officials, business leaders, and environmental activists on a private initiative.

In March 2007, Governor Bill Ritter signed into law a bill that increased Colorado's 2004 RPS. Under the new standard, large investor-owned utilities are required to produce 20 percent of their energy from renewable resources by 2020, 4 percent of which must come from solar-electric technologies. The law also requires municipal utilities and rural electric providers to provide 10 percent of their electricity from renewable sources by 2020. Although the act allows considerable choice concerning the source of the renewable energy, including solar, wind, geothermal, biomass, and small hydroelectric, wind power is likely the most popular choice. Colorado ranks 11th in the nation in its wind energy resources, and although some wind farms have developed, their numbers are few. Experts estimate that Colorado wind power has the potential to generate over 450 billion kilowatt-hours annually, more than enough to meet the state's needs.

Colorado cities have taken action, too. Aspen already generates enough energy from wind and hydropower to meet 75 percent of its electricity needs, and has set a goal of 100 percent within five years. In an effort to decrease carbon dioxide emissions, the city of Aspen provides free transit for residents and tourists and has purchased electric hybrid automobiles for city officials' use when traveling out of the city. Denver has initiated its own climate action plan to reduce carbon dioxide emissions by 4.4 million metric tons by 2020, the equivalent of eliminating two small coal-fired power plants or taking 500,000 cars off the road. The city of Boulder recently enacted the nation's first tax on carbon emissions from electricity.

SEE ALSO: Colorado Climate Center; Colorado State University; Intergovernmental Panel on Climate Change (IPCC).

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Colorado Climate Center

THE COLORADO CLIMATE Center (CCC) is part of the Department of Atmospheric Science in the College of Engineering at Colorado State University. The aim of the center is to assist the state of Colorado in monitoring climate change over time, ranging from weeks to years. The CCC provides climate-related services to business, government, industry, researchers, educators, and the general public. The center tries to understand the complex interactions between the atmosphere, oceans, continental glaciers, land, and vegetation processes. The CCC has stressed the importance of observation and data collection for climate monitoring, research, and service. It is involved in snow measurement research in collaboration with the National Weather Service.

The services provided by the center aim to reduce the state's vulnerability to climate variability and change. The CCC provides links to regional climate centers, and to the National Climate Data Center, where detailed climate information is provided. It also provides access to other important databases. The CCC website is the primary means with which information is supplied; it also center publishes its own magazine, *Colorado Climate*.

The CCC is recognized by the American Association of State Climatologists, and was established in 1974 by the state-funded Colorado State University Agricultural Experiment Station. Its primary aim was to provide information and expertise on Colorado's complex climate.

The CCC has a threefold program of Climate Monitoring (data acquisition, analysis, and archiving), Climate Research, and Climate Services that focus on climate-related questions and problems affecting the state of Colorado. The CCC is also home to State Climatologist Nolan J. Doesken. He has been with the center since 1977, and is also director of the historic Fort Collins Weather Station on the campus of Colorado State University.

The CCC is responsible for monitoring of daily weather conditions and the interpretations of seasonal and annual weather patterns and variations. The National Weather Service's Cooperative (COOP) Network has over 200 stations in the state, and reports daily on temperature and precipitations. These data provide the oldest continuous records to describe climate change, dating back to the 1880s.

The CCC also monitors weather through data from other organizations, such as the Natural Resource Conservation Service's snow survey, and Remote Snow Telemetry (SNOTEL) stations. SNOTEL is particularly useful to study drought and monitor water supply. The CCC also provides assistance to Colorado State University and to federal groups to maintain an automated network for weather observations to serve agriculture users. The Colorado Agricultural Meteorological Network provides hourly weather data from 60 stations throughout the state that represent different agricultural areas.

The CCC has also been involved in climate research since its foundation. Thomas McKee pioneered drought research and devised the Standardized Precipitation System, an index to monitor drought that has been adopted internationally. The CCC also closely collaborates with the National Weather Service to develop more accurate ways to observe weather from stations. The CCC is leading a national survey of automated snow measurement systems, and is involved in research on energy, crop production, and engineering applications of climate information.

In April 2007, the National Oceanic and Atmospheric Administration named Doesken one of 10 environmental heroes for the creation of an amateur precipitation-monitoring network that gathers 4,000 volunteers nationally. This network is part of the CCC's commitment to involve citizens in climate monitoring. Through the Community Collaborative Rain, Hail, and Snow network (CoCoRaHS), thousands of citizens of all ages take part in measuring and mapping precipitation patterns in Colorado and several other states.

SEE ALSO: Climatic Data, Atmospheric Observations; Colorado; University of Colorado.

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Colorado State University

COLORADO STATE UNIVERSITY is a premier system of public higher education committed to excellence, setting the standard in teaching, research, and service. The board of governors presides over Colorado State University (CSU), which is composed of Colorado State University (located in Fort Collins, Colorado) and CSU-Pueblo. At Colorado State, research and outreach from the sciences to the humanities are advancing on multiple fronts to explore climate-change phenomena and find solutions.

The Center for Earth-Atmosphere Studies fosters the training and education of scientists working on climate and radiation-cloud problems. Graeme Stephens has been the principal investigator of the National Aeronautics and Space Administration's (NASA's) CloudSat mission since 1993. His research focuses on atmospheric radiation and on the application of remote sensing in climate research, with particular emphasis on understanding the role of hydrological processes in climate change. The department offers a wide range of courses for students interested in climate research. Courses include large-scale atmospheric dynamics, analysis and diagnosis of observed climate variability, climate modeling, the global carbon cycle, the global hydrologic cycle, and radiative transfer.

The Colorado Climate Center is part of the Department of Atmospheric Science at CSU. The goal is to assist the state of Colorado in monitoring climate over time scales of weeks to years, as well as recognize that climate involves complex interactions between the atmosphere, the oceans, continental glaciers, and the land. Vegetation processes are an important component of the climate system. This service should contribute to a reduction in the state's vulnerability to climate variability and change. One of the latest efforts to address climate change began with the creation of a sustainability advisory committee. Vice President for Research Bill Farland and Vice Provost Lou Swanson, who leads Outreach and Strategic Partnerships programs at CSU, were appointed co-chair of the committee.

SEE ALSO: Colorado; Colorado Climate Center.

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Columbia University

ONE OF THE biggest developments of 1996, from the perspective of those who were interested in global warming and climate change, was the formation of the new Columbia University Earth Institute, designed to bring together 11 separate centers for research, education, and innovation. The move happened at a crucial time; 1995 and 1996 were among the warmest years yet recorded.

Columbia University, founded in the 1750s as Kings College, which boasted luminaries such as Alexander Hamilton among its early students, had long been in the forefront of the study of the Earth and its changes. Columbia had the nation's first full-time department of geology in the 19th century, and, as the school grew, so did the size of its Earth-oriented faculty.

THE LAMONT-DOHERTY EARTH OBSERVATORY

Columbia was already one of the leaders in the field when, in 1949, the widow of New York banker Thomas W. Lamont (1870–1948) announced she would give his estate, located on the banks of the Hudson River in Palisades, New York, to Columbia. Dwight D. Eisenhower, who was then president of Columbia, accepted the gift, and the Lamont Earth Observatory was founded in 1950. The *Columbia Geologist*, a school publication, heralded the event and proudly proclaimed on its masthead one of the guiding motifs of the Columbia geology program, "Speak to the Earth and it will teach Thee."

The observatory's first director was Professor Maurice "Doc" Ewing (1906–74). Born and raised in Texas, and the veteran of a number of summer building projects, he was the antithesis of the absent-minded professor. Keenly interested in the details of administration, he was also a hands-on leader, taking a three-masted schooner purchased by Columbia on a number of fact-finding missions. Ewing's principal contribution to science was his part in finding answers about plate tectonics, a theory that was accepted only in the latter part of his time at Lamont, but he also played a role in training hundreds of young scientists, many of whom went on to become department chairs around the country. By 1972, the year Ewing retired, Columbia was the leader in almost every aspect of studies of the Earth; he died in 1974.

In 1969, three years before Ewing's retirement, the Lamont Observatory was renamed the Lamont-Doherty Earth Observatory, in honor of a major bequest made by Thomas Doherty. This change, and Ewing's retirement, brought about a change at Lamont-Doherty, which soon found itself in the forefront of concern about the environment. The U.S. space program accelerated concerns about the environment (with the Apollo VIII photographs of the earth from space, for example). There was a growing connection between the National Aeronautics and Space Administration's (NASA's) Goddard research center and the Lamont-Doherty Observatory, both located at Columbia.

HOT SUMMERS AND THE EARTH INSTITUTE

At first, environmental concern was about global cooling. The 1960s were, climatologists now believe, the coldest decade of the 20th century, and several winters toward the end of the 1970s and beginning of the 1980s seemed to accelerate the trend. Numerous major magazines, such as *Time* and *Newsweek*, ran cover stories proclaiming the possibility of a new ice age, and the sudden rise in the price of home heating oil—starting with the Arab Oil Embargo of 1973–74—only increased worries about the Earth growing colder. Staff at the Lamont-Doherty Observatory were asked to comment on global cooling a number of times, but none of their pronouncements on the subject came anywhere close to the importance given to the first major statement about global warming, which came in the summer of 1988.

Although 1987 had a relatively cool summer, with plenty of dampness, 1988 started hot and stayed that way. A heat wave of unprecedented scale hit the East Coast and Midwest in late June, with temperatures soaring well above 100 degrees F (38 degrees C) in urban areas. New York and Washington, D.C., almost shut down for a few days at the peak of the heat wave, in late July. The trend did not reverse itself until about August 18, when a front of cool air moved in from Canada. This was the normal course of events in the American northeast, but it had taken about three weeks longer than normal to transpire. Near the height of this heatwave, Dr. James Hansen of the Goddard Center testified before U.S. Senators:

> If our climate model calculations are approximately correct, the greenhouse warming in the 1990s will be sufficient to shift the probabilities such that the chance of a hot summer in most of the country will be in the range of 55 to 80 percent…I believe it is obvious that the man in the street will notice by then that the dice are loaded. There will be more hot summers than now, and the hottest ones will be hotter than they used to be.

Had Hansen made this prediction in the summer of 1987, few people would have given it much notice; but as he did it in the heat of 1988, millions of people paid attention. Suddenly, Hansen and Columbia were at the forefront of the debate about global warming.

The summer of 1990 was even hotter than 1988, and 1991 surpassed 1990. The hottest summer to date was 1995, and one year later Columbia announced the creation of its new Earth Institute, intended to bring together the activities of 11 institutions: the Lamont-Doherty Earth Observatory; the Center for Environmental Research and Conservation; the Biosphere 2 Center; the Goddard Institute for Space Studies; the International Research Institute; the Laboratory of Populations; the Earth Policy Center; Columbia's School of Public Health; the Earth Engineering Center; the Center for Environment, Business, and Renewable Resources; and the Program on Information and Resources. All 11 institutions would retain their individual identities, but all 11 also became part of the new Earth Institute. Columbia did its best to hire top scientists away from other research universities and bring them to the New York campus.

CONTEMPORARY SCHOLARSHIP

For a few years, it seemed as if the new Earth Institute would be just another highly-endowed think tank for liberal environmentalists, with much of the nation paying little attention to its pronouncements. However, Columbia showed it was committed to hiring scholars from across the disciplines, and not all of them proved to be liberal or traditional environmentalist groups. There were sharp disagreements among Columbia scientists, about the extent of global warming, or if global cooling still remained an even greater threat. By 2000, the mainstream U.S. media paid more attention to Columbia's scientists than to those of almost any other major educational institution.

In 2002, Columbia hired Jeffrey Sachs away from Harvard, where he had been a professor of international trade for the previous 18 years. Born in Detroit in 1954, Sachs was a most unusual academic, one who spent as much time actually advancing change as discussing it. Sachs was a brilliant and controversial leader, one who had worked with numerous Third World nations in attempts to rebalance or pay off their debts to First World countries. Tireless and devoted, Sachs still ran into plenty of headaches as director of Earth Institute, an inevitable situation given the bright and challenging minds assembled there.

By 2006, the year Al Gore's *An Inconvenient Truth* was released in cinemas, most Americans had become conversant with the terms *global warming* and *climate change*, yet there was still plenty of controversy swirling around them. Columbia had over 200 top scientists watching the climate in that year, and they put out varying statistics about the state of the Earth. More importantly, they presented various alternatives to approach the problems. For example, Dr. James Hansen, while believing global warming was quite serious, believed that humans could make major progress against it over the course of one or two decades; and Dr. Walter Broeckner, a geochemist who believed that the state of the earth was a state of emergency, claimed that truly drastic cutbacks in greenhouse gases were essential.

A major source of controversy was the Kyoto Climate Accords, signed by most industrialized nations in 1997. The United States, under the George W. Bush administration, declined to participate in Kyoto, leading to outrage on the part of many environmentalists. But Hurricane Katrina, in the early autumn of 2005, provoked the greatest concern of all. Not only did New Orleans and the surrounding area endure a Category 3 hurricane, but the efforts of FEMA (Federal Emergency Management Administration) seemed either feeble or counterproductive. Americans looked to their scientists, who seemed quite certain that global warming was a reality, but who differed over how it could best be combated. Columbia's Earth Institute is one of the most prestigious and successful of all such institutions, yet it, too, lacks a clear directive on how the nation, and the world, should proceed.

SEE ALSO: *An Inconvenient Truth*; Hansen, James; Harvard University; Kyoto Protocol; New York.

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Comoros

AN ARCHIPELAGO OF four islands in the Indian Ocean, the Comoros Islands have a land area of 838 sq. mi. (2,235 sq. km.), with a population of 798,000 (2005 est.), and a population density of 710 people per sq. mi. (275 people per sq. km.), the highest population density of any African country. The Federal Islamic Republic of the Comoros, formerly a French colony, has 3.5 percent arable land, with an additional 7 percent used for meadows and pasture. Some 16 percent of the land area is forested, with a timber industry operating on the island of Njazidja.

The country is relatively poor and undeveloped, and even though it has a burgeoning tourism industry, it has a very low carbon dioxide emissions, with less than 0.1 metric tons per capita in 1990, rising to 0.12 metric tons per person in 2003. Some 89.4 percent of its electricity production is from fossil fuels, with the remainder from hydropower. All the country's carbon dioxide emissions are from liquid fuels, with much of this coming from automobiles and buses, and domestic electricity consumption. There is a small public transportation system in the islands.

Located in the Indian Ocean, global warming and climate change pose a severe risk of flooding for the islands, which are subjected to annual monsoons. Scientists envisage a loss of marine wildlife around the Comoros in the future, owing to the rising average temperature of the Indian Ocean. Scientists also foresee a shortage of drinking water.

The Comoros government took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, and ratified the Vienna Convention two years later. The government of President Azali Assoumani has not expressed an opinion on the Kyoto Protocol to the UN Framework Convention on Climate Change.

SEE ALSO: Indian Ocean; Oceanic Changes; Sea Level, Rising.

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Compliance

COMPLIANCE, ACCORDING TO the *American Heritage Dictionary,* is: "the act of complying with a wish, request, or demand; or acquiescence." In medicine, it is the willingness to follow a prescribed course of treatment. Generally, it is a disposition or tendency to yield to the will of others. In a machine, compliance is the extension or displacement of a loaded structure per unit load, or flexibility. In reference to the climate system as defined by the United Nations Framework Convention on Climate Change (UNFCCC), all the above meanings of compliance are relevant. The climate system is the totality of the atmosphere, hydrosphere, biosphere, and geosphere, and their interactions. Consequently, changes in the climate may have implications for the full range of human life.

In the context of law, compliance is sometimes referred to as conformity, where compliance is the intended outcome of law. Being out of compliance usually carries legal consequences that are provided for by the applicable rules. For example, the UNFCCC and the related Kyoto Protocol provide rules that are referred to in identifying compliance. Compliance is facilitated, promoted, and enforced by the appropriate authority that is specified and authorized to do so in the regulatory regime. In the case of international law, applicability of the regulatory regime is complicated and determined initially by voluntary commitment of a sovereign state. Only parties to the Kyoto Protocol would then be bound by the terms of its agreement and the compliance mechanism.

THE KYOTO PROTOCOL

In the Kyoto Protocol, as with many regulatory regimes, the compliance mechanism has multiple functions. It is intended to reinforce provisions in the protocol that are designed to address environmental integrity. It also enables the operation of the market for carbon, including the emissions-trading system envisioned by the protocol. A third function is to address and improve the transparency of accounting procedures used by the parties. The implementation of the legal regime relies on strong and effective compliance systems, processes, and enforcement.

To achieve compliance, the Kyoto legal regime uses a two-pronged approach in its organization. These components are the branch that facilitates compliance, and the branch that metes out consequences for those who remain out of compliance. The first is known as the facilitative branch, and the second as the enforcement branch. The decision to adopt a compliance regime to facilitate, promote, and enforce the protocol's commitments was made in October/November 2001 at COP 7 (Conference of the Parties 7), also known as the Marrakesh Accords. The text of the procedures and mechanisms related to the compliance was adopted by decision 24/CP.7 at the same COP 7 meeting.

Not all compliance mechanisms include a facilitative branch. Compliance mechanisms that do not include an enforcement component may rely on other methods to achieve compliance. These include a party's interest in membership in a group, altruistic interests, or social or peer pressure. Participation in the Kyoto Protocol is first an example of an interest in compliance with the practices in the international community, and not the result of the actions of a facilitative or an enforcement branch.

Whether facilitative or enforcement or otherwise structured, where compliance is through organized mechanisms, it requires procedural rules. Such rules may be provided in regulations included with the enabling legislation or agreements. As required by Article 18 of the Kyoto Protocol, the procedures and mechanisms to determine and address cases of non-compliance were adopted by the COP at their first meeting. The rules of procedure for the Compliance Committee were submitted and approved by the COP at their second meeting in November 2006. At the international and the national levels, critical issues in compliance mechanisms include the identification of specific consequences of noncompliance, as well as the membership of applicable decision-making bodies.

As with regulation, legal compliance within the jurisdiction of sovereign states is a domestic matter. Within a domestic sovereign state, compliance is relative to the particular regulatory regime. Compliance with planning regulations could refer to whether the regulations themselves comply with planning rules, and whether particular parties are in compliance with the planning regulations. In a more fundamental regulatory context such as constitutional law, the discussion would need to consider if the constitution is in compliance with the intentions of the population. At that point, compliance between the legal and political realms is significant and determinative in the formulation of policy, and will be accorded some interpretive consideration in judicial processes.

SPECIFIC CONSEQUENCES

Judicial processes and bodies must themselves be in compliance with their enabling legislation and rules. Rules of procedure applicable to the judiciary are as significant as the specific consequences for noncompliance by a party. In some jurisdictions, the right to be heard and the right to a fair hearing in judicial processes are enshrined in the constitution. Compliance, in such cases, requires procedural and substantive compliance.

Frequently, compliance involves acquiescence in particular circumstances. Where a party is within the rules, acquiescence would preserve compliance. Similarly, if one were not within the rules, the same disposition would mean noncompliance. In this sense, acquiescence as inertia may mean either compliance, or its lack.

Intent may or may not be relevant to a consideration of compliance. Statutory rules can provide for a determination of compliance regardless of intent, or may require intent. For example, intent in operating a vehicle at speeds higher than permitted by law is usually irrelevant to a determination of compliance to the legal speed limit. On the other hand, intent to cause injury will typically escalate the gravity of an offense and will be relevant to compliance with a principle of not causing injury.

HEALTH

Adaptation and responsiveness to changing climatic conditions is relevant to all species living on the planet. In a changing climate, all species face the fundamental issue of survival. For species that can survive, there is an issue about maintaining health. Compliance in this context involves two dimensions: that of compliance with the rules of nature, or the context in which the species must live to gain and maintain health; and compliance with regimes that the individuals and species must maintain in restoring health from illness. The renewed recognition of the forces of nature and its rules as the context in which the health of a species relies, is partially relevant to the interest in climate change and its regulation. Determination of the rules of nature leads to the necessity of compliance with such rules for survival of a species.

Theoretically, there is an option to modify the rules of nature by human intervention. This approach has been considered and attempted in experiments to modify weather. Such meteorological experiments were used, for example, in seeking to precipitate rain by seeding clouds with silver iodide crystals, and in proposals to install orbital systems to strategically modify weather patterns for security reasons. Whether climate change is the result of intentional or unintentional anthropogenic actions, compliance with the rules of nature as they exist does not appear to be optional for the survival of the species.

Because species are interconnected as a web, survival or extinction of any species results in changing circumstances for all species with attendant consequences. In this approach, human compliance with the rules of nature is determinative of the health of all species, not just of humans, and is so, regardless of whether or not anthropogenic emissions are responsible for climate change. Should such emissions and human decision-making be a relevant contributory factor in climate change, anthropological compliance, or noncompliance would be more significant. The health of a species is contingent on compliance with the rules of nature.

With the interconnectedness of species, compliance with the rules of nature by each species may mean a radical change in the continuity of species or, possibly, be a matter of survival for all. With human health, compliance may involve a proactive approach to healthy living that is advocated by some alternative health regimes or a pathological approach such as in conventional allopathic medicine. This distinction approximates the twin approach of the Kyoto compliance mechanism with its facilitative and enforcement branches. Both approaches can include preventive and remedial features in achieving compliance.

MACHINES AND TECHNOLOGY

For climate systems at the local level, technological compliance with regulations has long been recognized as the consequence of human decision-making. Machines can be designed with more or less flexibility, which can also be described as having more or less compliance. As with judicial systems, technological processes and management systems are inseparable from machines and technology in determining compliance, and are also susceptible to compliance issues.

Compliance of a machine is the extension or displacement of a loaded structure per unit load. Originally conceived in mechanical terms, the concept of a load now includes energy loads, and in the emergent context of the internet, virtual loads. Regardless of the form of the load, extension or displacement occurs and constitutes compliance. If the climate system is understood as a closed system and a machine or a technological entity, and compliance is the extension or displacement of the atmosphere per unit load, the application of the principle of cause and effect leads from compliance to inescapable consequences. The cause of the compliance is of interest in relation to human decision-making if the intent is to vary the result. Because acquiescence can be compliance, acquiescence can also occur in the context of climate change.

Multiple meanings of compliance indicate a plurality and hence a possible conflict in contemporaneous compliance. For instance, the capacity of a human being or other species to remain in compliance within the laws of nature in a changing climate may be divergent from compliance with human laws. Such competing compliances would necessitate decision-making with consequences for the climate system and survival of the species. Specifically, if global warming occurs, and human beings comply with such climate changes by acquiescence, then the increase in the global mean temperature will lead to a point at which the survival of the species will be an issue.

Compliance in the context of climate change is not a singularity, but a plurality of compliances that may be contemporaneous and intersect, compete, or diverge at various points. Human decision-making and anthropogenic causes will have consequences in determining which compliance is to continue and which is to die. The complexity of compliance may be understood by its correspondence to the complexity of atmospheric modeling and contributory systems. Anthropogenic compliance is also complex, involving the various dimensions of human life, which will contribute directly or indirectly to changes in the climate system.

SEE ALSO: Climate Models; Climate Sensitivity and Feedbacks; Health; Kyoto Protocol; Technology.

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Computer Models

A CLIMATE MODEL is a computer-based representation of the Earth system. Climate models solve mathematical equations that describe the planetary energy budget, with the aim of understanding and reproducing the processes that control climate. Climate models differ widely in their complexities; some consider only the balance of energy entering and leaving the Earth, whereas others attempt to describe the entire climate system, including the complex interactions between different components of the planet (such as the ocean and the atmosphere).

The first climate models were developed to study fundamental processes in the Earth system. These models attempted to capture the broad features of the climate and tried to reproduce the current climate state. Since this time, the issue of human-induced (anthropogenic) climate change has changed the focus of climate modeling; now many models are designed to investigate the effect of changing human emissions on climate and the prediction of future climates. Climate prediction is done with Earth System Models (ESM). These models are very complex and require large computer resources to run. Even so, many important processes must be simplified before they can be represented in a climate model.

Climate prediction models attempt to forecast the climate many years in the future. They do not aim to predict particular small-scale events (in comparison to weather forecasting, which attempts to predict, for example, the occurrence of a storm on a particular day). Instead, climate prediction takes a statistical approach in which the general properties of the climate are predicted; often the mean and the variance of the climate variable are predicted (such as the average temperature in July).

Climate models consider a number of different climate variables; some of which can be modeled with a relatively high degree of confidence (such as temperature), while others remain much more uncertain (such as precipitation). Climate models must capture different types of variability in the Earth system; natural and human-induced changes must be captured, along with variability that occurs on a range of timescales (from a few days to many years).

HIERARCHY OF MODELS

There is a range (or hierarchy) of climate models with very different levels of complexity and, correspondingly, different strengths and weaknesses. This hierarchy allows scientists to use computer resources efficiently and run models with the complexity needed for the experiment of interest.

The simplest are the Energy Balance Models (EBMs), which model the climate in terms of the global energy budget. EBMs are normally zero-dimensional or one-dimensional models that ignore many features of the Earth system (such as atmosphere/ocean dynamics). These models simply consider the energy entering and leaving the planet. This simple approach is sufficient for the reasonable simulation of many large-scale climate features, like the seasonal cycle in temperature. The simplicity of EBMs gives them a number of advantages; they are very fast, which means many experiments can be run and long time periods can be considered. In addition, they neglect many of the features that can complicate analysis, thus they allow the study of the more fundamental factors affecting climate.

EARTH SYSTEM MODELS

At the other end of the hierarchy, Earth System Models are the most complex climate models; they take a holistic approach and attempt to treat all the components of the climate system and the interactions among them. ESMs are based on a type of model called a General Circulation Model (GCM). GCMs represent the movement and properties of air and water throughout the globe and, thus, form the core of ESMs. ESMs are more complex than GCMs as they also treat other components of the Earth system, such as the cryosphere (regions of ice and snow) and the biosphere (vegetation).

For a full climate simulation, ESMs must account for the interactions among the different components of the Earth system. For example, ocean circulation is driven partly by wind stress on the ocean surface. Changes in wind patterns (such as, those due to climate change) may, therefore, alter ocean dynamics. In turn, changes in ocean dynamics can alter atmospheric dynamics and wind speeds. Thus, wind speed and ocean dynamics are somewhat affected by each other. To represent this two-way interaction between the atmosphere and the ocean, the two components must be coupled in the model. Coupling those in models is challenging as the atmosphere and ocean react on very different timescales; ocean processes are typically much slower and take longer to reach equilibrium.

There is a growing body of work to couple other climate components in ESMs; many models now contain coupled vegetation models so the modeled atmospheric conditions (such as temperature and rainfall) are used to predict the growth of vegetation. If the model is fully coupled, then these changes in vegetation will be taken into account in the simulation of atmospheric conditions. For example, vegetation can take up carbon dioxide, thus, changes in vegetative cover may affect the amount of carbon dioxide in the atmosphere, which affects temperature. Including these carbon feedbacks in models is important for predicting future climates.

This coupling of components in an ESM is important because many of the interactions in the climate system can act together to produce greater (or smaller) net effects. For example, warming in the Arctic could melt some of the highly-reflective snow and ice, exposing dark land beneath. As the newly-exposed dark land is able to absorb more solar radiation than the bright white snow, the region will be able to absorb more of the available solar radiation. Thus the change in surface reflectance (albedo) produced by the melting snow could contribute to further warming, potentially leading to further snowmelt and even more warming.

To capture this positive feedback in a climate model, the atmosphere model must be coupled to an interactive snow/ice scheme. Failure to include this coupling could underestimate the rate of future warming. There are many potential feedbacks in the climate system and work is still ongoing to represent many of them in ESMs. Some positive feedbacks have the potential to cause rapid temperature changes (such as the melting of the Greenland Ice Sheet), ESMs are well-placed to investigate these feedbacks.

For experimental purposes, researchers can run simplified ESMs (or GCMs) with differing complexities, depending on the nature of the experiment. For example, atmosphere-only GCMs can be run in which the main ocean characteristics are prescribed (not simulated). This is useful, as running the ocean component of a model is very computationally expensive. Another possibility would be to run a GCM with a slab ocean in which only the top 164 ft. (50 m.) of the ocean is represented (with the main properties of the deep ocean treated in a simplified manner). Again, this is much faster than running a full ocean model. This spectrum of ESM and GCM complexities allows scientists to target the model used to the experiment chosen, for example, complex ocean models have been run with simple atmospheric models to study trends in ocean circulation, work that could have been done with a coupled atmosphere/ocean GCM, but with a much larger computational overhead.

Earth System Models of Intermediate Complexity (EMIC) also have been used for climate simulations. These models bridge the gap between simple models and full ESMs. They are similar to ESMs, in that they treat the full Earth system, but they use a much simpler representation of physical processes and lower resolution, making them much more computationally efficient. These intermediate complexity models can be used to simulate the long time periods (tens of thousands of years) important for studying natural climate variability and paleoclimate (the pre-historic climate). Results from EMICs can only provide information on large scales; their output is too uncertain for it to be applied to regional studies. Regional climate models, which represent particular geographical areas in higher resolution, have recently been developed and used for climate studies. These are useful for investigating geographical regions with extreme topography (as in mountainous regions), which are not well-represented in lower resolution models.

MODEL GRIDS

GCM (and ESM) models divide the planet into a three-dimensional lattice of grid points. In the atmosphere, global climate models typically have a horizontal resolution of 124–186 mi. (200–300 km). and a vertical resolution from a few hundred yards (m.) to 0.6–1.2 mi. (1–2 km.). The vertical resolution of the models is generally finer at the surface (where it is needed to resolve important small-scale processes) and becomes coarser at higher altitudes. At the surface, the model levels are normally terrain-following (the levels run parallel to the surface topography), but at higher model levels the effect of the surface topography is less, and the model levels become flat. The ocean component of an ESM/GCM typically has a finer resolution than the atmosphere component because small-scale structures such as eddies are important for heat transport in the ocean. The ocean resolution is typically about 410–820 ft. (125–250 m.) in the horizontal and 656–1,312 ft. (200–400 m.) in the vertical.

In the horizontal direction, the grid points typically run parallel to the lines of latitude and longitude, creating rectangular grid boxes that are grouped more closely together at the poles than at the equator. This is a waste of computational effort at the poles where there are lots of small grid boxes. In addition, this bunching of grid points at the poles can lead to computational instabilities. To avoid this problem, some researchers are developing models that run on non-rectangular grids such as Geodesic grids made up of hexagons and pentagons rather than rectangles, but this is still in the relatively early stages of development. In addition, tri-polar ocean grids have been developed; these grids have three regions where the grid points bunch together, each of which is located over land (so there is no need to treat the ocean in these areas). This removes the problem of numerical instabilities in the ocean model.

MODEL FORMULATION

GCMs solve equations of motion to simulate the movement and properties of fluid (air and water) around the globe. The physics used to represent these processes can be divided into three categories. First, some of the physics can be calculated from first principles; well-known concepts such as the conservation of energy can be utilized. The second category includes physics that is well-known in theory, but that in practice must be approximated. For example, fluid flow is treated using the Navier-Stokes equations, which cannot be solved analytically. Finally, the third category contains empirically-known physics (derived from observations), such as formulas for evaporation as a function of humidity and wind speed.

Some important climate processes occur on scales smaller than a model grid box. These processes cannot be explicitly resolved in a climate model. One example is the process of cloud formation. Individual clouds are often smaller than the model grid boxes in which they form, so a climate model cannot distinguish between the cloudy and non-cloudy regions within a grid box. Instead, an average value representing the fraction of cloud in the grid box is predicted. This representation of small-scale processes to produce average grid box values is called parameterization. Developing parameterizations is a complex process; the goal is to identify the key effects of the sub-grid process and represent them in a simple manner. If a process is parameterized, it is not explicitly treated; instead, the impact of the process on the large-scale processes is estimated.

Sub-grid parameterization is not the only form of simplification used in a climate model. Simplifications are also used to treat processes that are not well understood and processes that are too complex to be included. For example, most vegetation models consider only a few general types of vegetation such as forest or grassland. It would be too computationally expensive to represent individual plant types or even to treat a large number of general types. This simplification of complex and sub-grid process is vital: without it, ESMs would be far too complex to run, but simplifying complex processes can introduce uncertainties in to the model, which must be assessed carefully. There are many parameterizations used in ESMs, some of which represent complex processes very well. Others (such as cloud formation) are more difficult to parameterize, and, thus, are the subject of ongoing research.

To run an ESM over a period of time (to do past and future simulations), scientists need to provide the model with information about changes in external factors, such as solar irradiance and also the variation of natural and anthropogenic emissions over the time period. For past time periods, much of this information is available, although uncertainties do exist. To simulate future periods, modelers typically consider a range of different emissions scenarios, which range from scenarios with lots of anthropogenic emissions reductions, to scenarios with large increases in future emissions.

MODELING STRATEGIES

Uncertainties in the parameterizations used in climate models contribute to uncertainty in the climate predictions. To investigate the sensitivity of the model to these uncertainties, scientists carry out ensemble simulations in which they run multiple model simulations are run. For an ensemble experiment, the different model simulations vary only in the detail of the parameterizations used. For example, if a model parameterization makes use of a parameter, X, but the exact value of this parameter is yet to be fully determined, multiple model simulations are run, each with a slightly different value of X. In this way, scientists can explore the sensitivity of the model to this parameter, which helps them to assess the uncertainties involved. Ensemble simulations help scientists estimate the model error and highlight key uncertainties that have a large effect on the model results (areas that can then be targeted in future research).

The largest ensemble climate model experiment run to date is that of www.climateprediction.net, in which members of the public are encouraged to run different versions of a climate model on their home computers. Ensemble simulations can only be carried out with relatively fast-running climate models (those with lower resolution or a low degree of coupling between different components) as multiple simulations must be run.

SEE ALSO: Climate Models; Historical Development of Climate Models; Technology; Validation of Climate Models.

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Condensation

CONDENSATION IS THE change of phase of a substance from vapor to liquid. It is the opposite of evaporation, the change of phase from liquid to vapor. The condensation of water is one of the most important physical processes of the Earth's climate system. Condensation forms cloud particles and precipitation. It is the main sink of atmospheric water. On Earth, water can be found in the solid, liquid, and gas phases. Evaporation (and sublimation) of water substance, the transport of water vapor, and condensation away from its sources, is the most important heat transport mechanism in the Earth's climate system. Condensation is an extremely important process in the earth's water cycle because it is responsible for the formation of clouds and precipitation.

Weak forces between molecules cause them to stick to each other and produce the various phases of a substance. Random thermal motions cause some molecules to overcome these intermolecular forces and escape from the liquid and form a gas phase around it. The number of molecules that leave the liquid phase increases with its temperature because of the increase in the thermal energy, and, therefore, kinetic energy, of the substance. The molecules in the gas phase jiggle and move randomly because of their thermal energy. Some of the gas molecules stick to the liquid when they strike it. The numbers of molecules that return to the liquid phase increases with their concentration.

Condensation is integral to the most important heat transport mechanism in the earth's climate system.

Thus, the concentration of molecules in the gas phase increases until a balance between molecules leaving and returning to the liquid surface is reached. This is called thermodynamic equilibrium. The concentration of molecules in the gas phase, in equilibrium with the liquid phase at a given temperature, is defined as the saturation value.

The molecules that leave the liquid phase are the ones moving faster than the average molecule in the liquid. That is, they have larger kinetic energy than the average molecule. This is the reason a liquid cools while it evaporates. There is a sudden large attraction when a molecule of water vapor approaches the surface of liquid water. This speeds up the incoming molecule and increases its kinetic energy. Thus, a liquid releases heat while it condenses. This is known as the latent heat of condensation. The saturation vapor pressure depends on the curvature of the surface of the liquid phase.

This has important implications for climate processes. In a curved surface, such as that of a cloud droplet, each water molecule has fewer nearby neighbors than on a flat surface. Thus, the intermolecular attractive forces holding them together are smaller; a water molecule can escape a curved surface easier than a flat surface. At equilibrium, the concentration of water molecules in the gas phase has to be larger than over a curved surface over a flat surface to compensate for the fact that a larger number of molecules leave the liquid at a given temperature. Therefore, the saturation water vapor pressure is larger over curved surfaces.

Condensation occurs when the concentration of molecules in the gas phase exceeds the equilibrium, or saturation value, at a given temperature. Relative humidity is defined as the ratio of the water vapor concentration to the saturation value, with respect to a flat surface of pure water. Thus, the relative humidity of the air in equilibrium with a cloud droplet can be much greater than 100 percent, depending on the curvature (or size) of the droplet. This frequently occurs in clouds and is called supersaturation. Therefore, condensation and cloud droplets form preferentially over impurities that reduce the curvature of the surface of the liquid phase. These impurities are called cloud condensation nuclei.

When the temperature of the liquid phase is lowered, a smaller number of molecules leave it, and the saturation water vapor concentration is reduced. This is what occurs when moist air rises in convective updrafts and cools adiabatically. Thus, when the air rises sufficiently for saturation to occur, clouds form. This is the process by which convective clouds form. The cloud base is at the saturation condensation level of the rising air parcels. However, the fraction of the condensate that falls as rain, as opposed to evaporating and moistening the environment, is not easily determined. In fact, this is one of the most uncertain processes in cloud models. Cloud processes have been identified by various researchers, and more recently by the United Nations Intergovernmental Panel on Climate Change (IPCC), as one of the most uncertain processes in climate models. Condensation partially controls the content of vertical distribution of water vapor, the most important greenhouse gas in the Earth's atmosphere.

SEE ALSO: Cloud Feedback; Clouds, Cirrus; Clouds, Cumulus; Clouds, Stratus; Evaporation and Transpiration; Evaporation Feedbacks.

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Congo

THE REPUBLIC OF the Congo, a former French colony, has a land area of 132,047 sq. mi. (342,000 sq. km.), with a population of 3,999,000 (2006 est.), and a population density of 31 people per sq. mi. (12 people per sq. km.). Forests cover 62 percent of the country, with less than one percent of arable land, and 29 percent used for meadows and pasture, mainly for low-intensity grazing. The substantial cattle industry contributes to the country's methane emissions.

The carbon dioxide emissions from the Congo, on a per capita level, are relatively low: 0.5 metric tons in 1990, rising to 0.8 metric tons in 1997, and falling to 0.37 metric tons in 2003. This low rate is because of the dense forests that cover a large part of the country, and the fact that 99.3 percent of the electricity production in the country comes from hydropower. Most of the carbon dioxide emissions (91 percent) come from liquid fuels, some from gas flaring from the recently established petroleum industry, and the remainder from gaseous fuels. Most emissions are contributed by transportation, due to a poor system of public transportation, and limited train service.

The Congo government of Denis Sassou-Nguesso took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, and his successor, Pascal Lissouba, ratified the Vienna Convention. The Congo ratified the Kyoto Protocol to the UN Framework Convention on Climate Change on February 12, 2007, the 167th country to do so.

SEE ALSO: Congo, Democratic Republic; Forests; Methane Cycle.

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Congo, Democratic Republic of

THE DEMOCRATIC REPUBLIC of the Congo, formerly known as Zaire, has a land area of 905,351 sq. mi. (2,344,858 sq. km.), with a population of 63,655,000 (2007 est.), and a population density of 65 people per sq. mi. (25 people per sq. km.). Forests cover 80 percent of the country, with only three percent of the land arable, and 7 percent is used for pasture, mainly grazing cattle and sheep.

Only two percent of electricity production comes from fossil fuels, with 98 percent produced from hydropower. Most of the hydropower is generated from the hydroelectric plants at the Inga Dams, located on the Congo River. The two plants Inga I and Inga II provide electricity for the Shaha province, with plans to build Inga III and the Grand Inga plants, which would generate 4,500 megawatts and 39,000 megawatts, respectively. Grand Inga provides more hydroelectric power than is currently consumed by the entire African continent.

As a result of this hydroelectricity, and the undeveloped nature of the country, the Democratic Republic of the Congo has one of the lowest per capita rates of carbon dioxide emissions in the world, with less than 0.1 metric tons per person in 1990, which fell to 0.03 metric tons per person by 2003. Only three countries have lower per capita emissions: Afghanistan, Chad, and Somalia. Manufacturing and construction account for 28 percent of carbon dioxide emissions from the country, with transport accounting for 19 percent, and residential use, 11 percent. As a result, the overall level of carbon monoxide emissions is high, making up nearly 13 percent of all carbon monoxide emissions in sub-Saharan Africa.

The government of Mobutu Sese Seko took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, and two years later ratified the Vienna Convention. The Democratic Republic of the Congo, under Joseph Kabila, was the 143rd country to agree to the Kyoto Protocol to the UN Framework Convention on Climate Change, signing it on March 23, 2005.

SEE ALSO: Congo; Developing Countries; Forests.

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Connecticut

THE THIRD SMALLEST state in the United States in land area, Connecticut is a state with multiple identities. Its western border with New York makes it part suburban, its northern border shared with Massachusetts makes it part historic New England, and its 250-mi. (402 km.) Long Island Sound shoreline makes it a $4 billion-a-year tourist retreat. Such geographic and cultural diversity means that the state's environmental concerns are equally diverse. They include the poor air quality common to dense metropolitan areas, the protection of forests that constitute nearly 60 percent of the state, coastal erosion, and wetlands preservation.

The nonprofit organization Environmental Defense reported in 2004 that temperatures in Conneticut increased during the 20th century at a higher rate than the rest of New England. Estimates of the accelerated rise in temperature due to unchecked global warming indicate temperatures in the state could rise around 4 degrees F (.5 degrees C) by 2100. Connecticut has responded to the challenge through unprecedented regional cooperation and strong measures within the state to check greenhouse gas emissions.

Connecticut ranks in the lowest 10 percent of the states in its per capita carbon dioxide emissions. Because the state is largely a service economy, with the largest industries being finance, insurance, and real estate, energy consumption is comparatively low. Nearly 40 percent of Connecticut's greenhouse gas pollution is produced by the transportation sector. The state's oldest and most heavily populated cities, such as Hartford and New Haven, home to thousands of commuters, help to keep the state's emissions low. In contrast, residents of Connecticut's exurbs, fast-growing bedroom communities at the far margins of large cities where cars are the only form of transportation, produce about three times more carbon dioxide per person than those who live in the city. Transportation is the leading source of global warming pollution in Connecticut, and much of it from the 96 percent of exurban residents who commute in vehicles carrying only the driver.

DEFORESTATION

The effects of global warming are not limited to metropolitan areas. Reforestation began in Connecticut in the early part of the 20th century as farmland was abandoned and reverted to forests; the change leveled off in the early 1970s. In the early 21st century, about 85 percent of Connecticut's forests are privately owned. Many believe private ownership makes the forests more likely to be sold to developers. Researchers at the U.S. Department of Agriculture's Forest Service predict that by 2050, more than 60 percent of Connecticut will be urbanized. Development of this magnitude will mean deforestation that will increase the effects of global warming. Surviving forests could change substantially, as the conifers, sugar maples, oaks, and hickories that are left lose the spectacular colors that have made Connecticut autumns famous. In an environmental spiral, species of songbirds could disappear from the state's forests, leaving invasive pests, such as the gypsy moth, to decimate the vegetation.

In the past century, sea level in Connecticut has risen by 8 in. (20 cm.), and the state's current rate is above the global mean. A two-year study of Knell's Island, part of the Charles E. Wheeler Wildlife Sanctuary, reveals an erosion rate of as much as 3.3 ft. (1 m.) annually. Predictions suggest increases of at least 5.1 in. (13 cm.) by 2020, to a minimum of 11.2 in. (28 cm.) by 2080. These increases, and the storm surge increases that would accompany them, place rail lines, roadways, an airport, the University of Bridgeport, the Navy Reserve Center, sewage-disposal plants, and the oil tanks at Johnson Creek at flood risk. Stewart B. McKinney National Wildlife Refuge, home to the endangered roseate tern, would also be at risk. A large portion of Connecticut's wetlands, already suffering from the effects of development, could disappear.

The scenarios are grim, but Connecticut has begun implementing strategies to reduce greenhouse gas emissions. The American Council for an Energy-Efficient Economy (ACEEE) ranked Connecticut, along with Vermont and California, as tops in the nation in overall energy efficiency. In 2001, Connecticut joined other New England states and provinces in eastern Canada in developing a Climate Action Plan that adopted the Kyoto target of reducing greenhouse gas emissions to 10 percent below the 1990 base; the group set 2020 as their target date. In 2003, Connecticut became a member of the Regional Greenhouse Gas Initiative (RGGI), a cooperative of nine northeastern and mid-Atlantic states committed to a cap-and-trade program covering carbon dioxide emissions from power plants. RGGI requires carbon dioxide emissions to be stabilized by 2015, with a 10 percent reduction by 2019, and, eventually, to achieve sharp reductions in all greenhouse gases.

In 2007, after a two-year period of legislative debate, Connecticut passed an omnibus energy bill that required that RGGI requirements be implemented. The action also extended the state's Renewable Portfolio Standard (RPS) to require utilities to provide at least 20 percent of Connecticut's electricity from clean, renewable sources, such as wind and solar by the year 2020. It also required utilities to purchase all cost-effective energy efficiency and similar measures before expensive and polluting new generation resources, and provided incentives and sales tax exemptions for solar power, efficient furnaces, air conditioners, and cars getting over 40 miles per gallon in fuel efficiency.

Connecticut has also adopted the California Clean Cars tailpipe pollution standards, reducing greenhouse gas emissions from new cars 30 percent by 2016. Other recent measures include major investments in mass transit, a fund established for the preservation of farmland, and the purchase of a fleet of more than 500 alternative-fuel and hybrid state vehicles.

The state also initiated one of the nation's strongest renewable energy standards with the goal of seven percent of electricity coming from clean, renewable sources by 2010.

SEE ALSO: Deforestation; Sea Level, Rising; Transportation.

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Conservation

CONSERVATION IS A line of environmental thought and action that emerged in the United States during the last half of the 1800s. Conservationists are often seen as opposing growth, but this universal judgment is problematic. The underlying premise of the predominant branch of conservation's philosophy is wise use, that is, the preservation of the land's natural resources through efficient management based on science, strategic planning, and carefully-monitored extraction. This approach is dedicated to lessening polluting emissions into the environment and opposes growth in cases where there will be unnecessary environmental damage.

Another significant branch of conservation thought focuses on preservation of lands in their natural state as a haven for humans to recuperate from the stress and strains of everyday life. Land is viewed for its intrinsic value, rather than its economic worth. Proponents of this branch of conservation are clearly opposed to growth that threatens tracts of land that remain relatively untouched by human activity. Preservationists believe people need to recognize that there are limits to growth, which is causing widespread damage to the Earth's fragile ecosystems. Lands need to be left in their natural state, not only as havens, but also to filter the waste released into the environment.

APPROACHES TO CONSERVATION

Conservation, sometimes called the conservation movement, gradually emerged in the United States in the context of rapid population and industrial growth during the 19th century. It was a reaction to widespread, rapacious exploitation of what most people saw as seemingly limitless natural resources. The movement's leaders in the late 19th century included Theodore Roosevelt, the avid outdoorsman who later became president; Gifford Pinchot, head of the U.S. Forest Service and a governor of Pennsylvania; and John Muir, founder of the Sierra Club.

From its beginnings, the conservation movement has been split into two major camps. Mainstream conservationists are pragmatic. They believe natural resources are for human use, for the benefit of everyone, not just a few. Conservation also has a strong element of stewardship. Natural resources need to be used efficiently now for the benefit of future generations. Conservation emphasizes the economic value of natural resources, based on efficiency in minimizing waste that occurs while extracting and processing those resources.

This was a major departure from the predominant path of development during the 19th century, which was based almost entirely on immediate needs, with no regard for the future. By the turn of the 20th century, Roosevelt and Pinchot's conservation views were ascendant, focusing mainly on forestry, which included soil and water conservation. Their approach was widely implemented by the U.S. Forest Service, which evolved in the 1870s and was established in 1891 in the U.S. Department of Agriculture. This agency manages National Forests for multiple uses, such as timber-harvesting, mineral extraction, and recreation.

Muir led the alternative branch of conservation, focusing on preservation without use to leave vast tracts of land virtually untouched by humans. Human use of wilderness areas should be limited almost exclusively to recreation, which Muir believed was sorely needed for escape from a rapidly-urbanizing society. Muir, who was born in Scotland, successfully worked to preserve natural treasures such as Yosemite in California. His philosophy has been carried out, not only through the Sierra Club, but also through the National Park Service, whose charter makes it responsible for preserving land in relatively pristine condition.

Muir's preservationist ideas blended well with the New England Transcendentalism of Henry David Thoreau and Ralph Waldo Emerson, who saw human interactions with nature as a transformative experience that left people richer spiritually. Muir's activist emphasis on preserving the wilderness continues to create lively tension among environmentalists, eco-philosophers, social scientists, politicians, and business leaders. The preservationist stand is seen as opposing growth. The notion that the land has value in and of itself challenges the mainstream conservationist position of management for efficient human use.

Nature, in the mainstream view, has economic value related to its most productive use; it is not to be left on its own. Yet, the preservationist view can complement the utilitarian view. The burden for preservationists has been to prove the value of pristine land, and the needs to conserve it. Arguments for preservation of natural areas often rely on emotion and aesthetic values, although economic models developed in recent years now account for values such as carbon sequestration, watersheds, and recreation.

Given the environmental context of raiding natural resources during the Gilded Age of the late 1800s, Pinchot's conservation stand offered a compromise to balance the rapidly-growing economy with preservation for future generations. Scientific forest management allows for using forests and their products while conserving the country's forest base. Pinchot, a trained forester, understood the biological constraints on forest production and the possibility for conserving, or renewing, that resource by calculating the maximum sustainable yield. In this view, forests are an economic resource. Conservation assures an adequate supply of wood and wood products for production to keep the economy moving.

Despite these economic arguments, conservation faced considerable resistance. The idea was new to the United States, and not yet recognized as a way to increase corporate efficiency and profits. Proponents of laissez-faire capitalism argued that conservation represented undue government interference in business, which would stop profitable logging and damage overall economic growth. Pinchot believed government could, and should, play a role in managing natural resources for the good of all people, and to keep the economy moving. Muir, who also believed the government had a role in preserving pristine areas for the future, stretched the boundaries of thinking about conservation to include aesthetics and human needs; this approach would later be extended to include the economic value of preserved land for its role in cleaning the environment and for recreation.

ROOTS OF CONSERVATION

Early on, the U.S. conservation movement was rooted in a growing recognition of the impact of forest destruction after European contact in the 1600s, when much of the continent was heavily wooded. The establishment of the U.S. Department of the Interior, in 1849, to oversee natural resources on federal lands suggests rising consciousness across the country about how to handle the settlement of western lands, with peripheral concern for the future of the environment. Congressional approval of the U.S. Department of Agriculture, in 1862, recognized the importance of the government's role in educating farmers about best practices to make their land use operations more profitable; these best practices emerged during the first part of the 20th century as conservation techniques to increase production, preserve soil, and improve water quality.

Logging and mining intensified tremendously during the 1850s and 1860s. Farmers deforested land for market-oriented production to serve the burgeoning urban population. Increasing industrialization demanded timber for railroad ties, coalmine supports, and housing for workers. Federal land sales at bargain-basement prices to corporate interests and land speculators spurred the rapid spread of people across the land, often in company with poor land-use practices. In the widely accepted view of citizens and policymakers, little, if any, value was placed on land in its natural state, so cheap land became a subsidy for natural-resource-based industries that were building national and international markets for their commodities.

Few loggers thought about resource depletion, much less conservation; the supply of wood seemed unlimited. Loggers adopted "cut and run" practices, leaving vast tracts of unused wood to dry out. As a result, huge forest fires destroyed remaining forests and nearby towns. For example, the 1871 forest fire near Peshtigo, Wisconsin, killed about 1,500 people and burned 1.3 million acres. Across the south, forest fires preceded farming as a way of clearing the land. Fires and poor logging practices exposed the forest floor, which eroded, silting and killing waterways and contributing to widespread flooding. Communities were left impoverished as loggers moved from state to state, in search of new forests.

In Europe, regenerative forest practices emerged, in Germany in the 1750s, to counter widespread deforestation that had occurred over centuries. The abundance of forest in the United States slowed the adoption of these conservative practices here until several reports published during the 1860s and 1870s pointed out the risks of natural resource depletion, especially in the nation's forests. The scientific basis for conservation began to emerge in the United States, with the growing recognition that widespread clear-cutting not only threatened future supplies of wood, but also damaged watersheds.

Destruction from poor farming practices matched the damage from over-cutting of timber. Repeated cultivation of tobacco depleted the rich soils of the Virginia Piedmont during the 1700s, followed later by other areas of the south leached by cotton. Throughout the country, thousands of tons of topsoil were blown or washed away from poorly managed farms. The soil fouled streams, caused flooding, and killed wildlife. The worst example of wind erosion occurred during the prolonged drought of the mid-1930s, when the Dust Bowl clouded skies across the country with precious soils stripped from the midwestern wheat belt.

ROMANTICISM AND CONSERVATION

Researchers and other intellectuals, including artists, began to recognize the local impacts of environmental degradation around the turn of the 19th century in the United States and Europe. For scientists, powers of observation were based on empiricism and the scientific method that were honed during the Enlightenment. Artists and intellectuals observed natural beauty and captured it in the painting, music, and literature of the Romantic period. Romanticism emerged along with the Industrial Revolution, which was a practical expression of technical knowledge garnered during the Enlightenment.

Romanticism was, in part, a reaction to industrialization's impact on nature and was a precursor of the conservation movement. Transcendentalism, as one facet of Romanticism, stirred a persistent place-based heritage that fostered nature-inspired artistic endeavors and a heightened sense of spiritualism. These efforts, in turn, led to the preservation of wild areas based on the intrinsic value of nature and the land. This view helped widen the possibilities for the conservation movement and fit well with Muir's later efforts to preserve pristine landscapes in the United States.

Romanticists played a vital role in launching the conservation movement on multiple fronts. They were uniquely capable of communicating the beauties of nature and were sensitive to environmental changes in their communities. While many Romanticists worked to reconcile industrial changes on the landscape, others reacted negatively, noting the environmental damage and seeking ways to preserve the rural countryside and its lifestyle. Even as they reveled in the glories of nature, many noted soil erosion, the loss of wildlife, dirtier air, and changes in streams and lakes. Their observations about local environmental decline found support in scientific observations. By the 1820s, for example, scientists were developing a rudimentary understanding of carbon dioxide as a greenhouse gas. By about 1850, researchers were documenting acid precipitation around English industrial cities, a climate change brought on by coal-burning for factories and homes.

Perhaps the most significant work to bridge Romanticism and conservation as a physical and biological science and a social science came from Aldo Leopold, a forester, writer, astute observer of nature and human activities, teacher, and internationally-known conservationist and ecologist. Leopold's contribution to conservation comes from his conceptualization of healthy land and its relationship to human communities. Leopold did not separate the land from human activities. Rather, he extended the definition of community to include not only the places where people reside and interact with each other, but also the surrounding ecology in the landscape. Leopold added a rich component to conservation by giving it an ethical basis.

His land ethic puts environmental considerations at the front of community decision-making, demanding consideration for soil, water, air, and other living creatures. Natural resources are for human use, but the surrounding ecology has intrinsic worth that is vital to the immediate quality of life and long-run community sustainability. Leopold's land ethic moved the conservation movement toward increased consciousness of the relationship of humans to the larger environment. His *Sand County Almanac* stands as a conservation classic, linking the wonder of nature with human activity, and, more importantly, human responsibility for taking care of the environment as an integral component of community. Leopold's thinking opens the way for an ethical systems approach to conserving the environment.

CONSERVATION AND CLIMATE CHANGE

Knowledge about climate change has come slowly alongside the emergence of the conservation and, later, environmental movements. Differing approaches to conservation moved toward a more holistic understanding of human impact on dynamic environmental processes. For example, in an 1867 report to the Wisconsin Legislature, I.A. Lapham showed the relation of forests to stream flow. His suggestion about the need to plant more trees to protect watersheds foreshadowed the conservation movement. At about the same time, researchers also began to speculate about possible climate change related to forest removal, reflecting increased knowledge about the role of forests in cleansing the environment.

Emphasis on conservation helped feed understanding about interconnections between human activities and the environmental impact of pollution, raising human consciousness about wasteful practices. While pollution was easily visible at the local level, understanding its broader impact depended on the development of more sophisticated measurement tools, with computers capable of analyzing massive amounts of data taken from complex and dynamic ecosystems. The planning required for widespread conservation efforts demands a systems approach to human-environmental relationships, especially those associated with burning nonrenewable fossil fuels.

After World War II, increased understanding of the sources of smog and acid rain and their negative environmental impact, led to pressure from conservationists to clean up pollutants from coal-fired plants and motor vehicles. Improved combustion and scrubbing technologies, developed partly in response to government prodding in the Clean Air Act and state emissions laws, led to more efficient use of coal, and mitigated some smokestack emissions. In addition, new technologies helped increase auto fuel economy and reduce tailpipe emissions. Environmental economics developed as a specialty field to develop cost-benefits models to show the impacts of conservation and anti-pollution policies on firms and the economy. More recently, interdisciplinary teams of scientists have made significant strides by finding crucial links between pollutants and climate change. The gradual evolution of conservation helped spur techniques that reduced waste and conserved resources for future generations.

SEE ALSO: Agriculture; Capitalism; Forests; Industrialization; Maximum Sustainable Yield.

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Convection

CURRENTS MOVING IN fluids are convection. More specifically, fluids—liquids, gases, and rheids—undergo movements as convection currents. Convection plays a major role in heat transfers. In fluids, both movement of mass in the fluid, and the heat it contains, occurs in a random way, if Brownian motion occurs. However, in the process of advection, large motions develop in the fluid, which move not only its mass, but also the energy it contains. Convection means the transfer of mass and heat by diffusive and advective movements. Heat is the transfer of energy from one body to another. Heat is a cause of convection currents in fluids, because the fluid motion is initiated and continued by the energy transfers occurring in the fluid.

As a fluid is heated, it expands. If a part of the fluid is cooler than another part, then its density is greater, and it sinks in the fluid. However, the opposite occurs to a part of the fluid that is heated to an energy state that is greater than surrounding parts of the fluid. As a consequence, it acquires buoyancy and rises because gravity is causing the denser part(s) of the fluid to sink. The effect is called a convection current. The convection current allows the fluid to engage in convective heat transfers. Convection is a very common occurrence in nature. Convection currents cause movements in water, in the atmosphere, and in the mantle of the earth. It is familiar as rising warm air over a fire, or the steam rising off of a heated pan of water or soup. These familiar examples are very localized; however, in the atmosphere the same principles are at work on a grand scale.

The surface of the Earth is heated by solar energy. However, the sunlight that strikes the Earth does not do so in an even manner. Clouds block parts of the solar energy; it hits bright surfaces such as the ice caps and is reflected, or it hits dark areas and is absorbed so that the heating of the Earth's surface is very uneven. The energy that does hit is transferred to the atmosphere as radiant energy. The ground, trees, grasses, water, or other surfaces radiate energy, but very unevenly, so the air above these surfaces is heated unevenly. Local convection currents combine to form larger convection currents in the atmosphere over larger and larger areas. The results are winds or other atmospheric phenomena. As the heated air rises, its lighter density causes lower pressure at the surface from which it is rising to be lower than the surrounding, cooler, pressures. The denser air then moves in to fill the lower pressure area that now functions like a vacuum. The warmer air also displaces cooler air above it, so that as the warmer air rises, the cooler air sinks, contributing to convection currents and to heat transfer.

Very localized convection currents visible in desert areas are dust devils. These are thermal convection currents composed of rising hot air that has begun to spin, resembling a miniature tornado. All of the grand weather phenomena, such as thunderstorms, cyclones, hurricanes, and, ultimately global atmospheric circulation, are forged from convection. A convection cell is a single region of air that is alternately heated and cooled. Its convection currents can give rise to lateral movements that cause breezes, winds, and other weather phenomena.

The oceans are affected by the variable distribution of solar radiation they receive. Tropical waters receive tremendous amounts of direct sunlight. They warm in the open oceans and, in the summer months become quite warm, especially in relatively shallow areas such as the Gulf of Mexico. The warm water then moves toward the polar regions, and colder water moves toward the tropics in order to fill in the lower pressure areas that the warmer waters have created. However, convection can also occur without the involvement of heat. For example, a convention current that is not due to heat is the movement of air masses due to variation in the amount of water vapor they contain.

Buoyancy can be caused by variations in the density of substances apart from the application of heat. For example, ocean convention currents can be caused by variations in the salinity of ocean water. The ocean currents are powered by differences in the salinity of the ocean waters. The saline differences create thermohaline convection. The differences in the density of warm salty water and cooler, lower salinity water are such that the dense, warm salty waters sink, bringing up less dense, cooler water. At the same time, heat is transferred and transported.

Free convection is the natural heat convection found in nature. It is not the same as forced heat convection. In forced convection, the heat transfer is not due to natural buoyancy forces. Rather, it is the result of movements in fluid inserted by artificial means. Fans, pumps, convection ovens, and other forms of circulating hot air or fluid cause a disequilibrium in the system.

The resulting disequilibrium is applied to various tasks by the forced convection. The core of the Earth is heated under enormous pressures. Part of its heat is due to radioactive decay. Movements in the core are usually convection currents. The outer core has dense metals, mainly nickel and iron, that are a part of the Earth's magnetic field. As they move in a fluid way under enormous pressure, they give off electricity, which generates magnetic fields.

SEE ALSO: Cloud Feedback; Hurricanes and Typhoons; Sunlight; Weather.

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THE COOPERATIVE INSTITUTE for Arctic Research (CIFAR) was created in 1994, at the University of Alaska following several years of teamwork between the university and the National Oceanic and Atmospheric Administration's (NOAA) Environmental Research Laboratories (ERL). Among the 13 NOAA-university joint institutes established to promote greater collaboration between researchers from NOAA laboratories and U.S. universities, CIFAR is the only one solely concerned with the study of the Arctic. Global warming is expected to change the Arctic more than any other area of the world. CIFAR is located at the University of Alaska at Fairbanks (UAF), in the International Arctic Research Center. CIFAR maintains affiliations with the Center for Global Change (CGC), the Institute of Marine Sciences, the Institute of Arctic Biology, the UAF's Geophysical Institute, and School of Agriculture and Land Resource Management.

CIFAR also maintains strong partnerships with NOAA's Pacific Marine Environmental Laboratory, Arctic Research Office, National Marine Fisheries Service, Ocean Exploration Program, and the National Weather Service. CIFAR's research supports NOAA's aim to recognize and anticipate shifts in the Earth's environment, and utilize natural resources in an integrated manner that fulfills the economic and environmental needs of the United States. CIFAR's nine research areas include Arctic atmospheric and climate research, fisheries oceanography, tsunami research, climate dynamics and variability, and environmental assessment and statistical modeling. Additionally, CIFAR oversees the administration of the Arctic Climate Impact Assessment, an international project that evaluates and integrates research on climate change and variability.

CIFAR plays a major role in communication and scientific exchange regarding the Western Arctic/Bering Sea region, which, because of its rich natural resources and troubling changes caused by climate warming, is of greater interest and study by the global community than ever before. During its 1997 fiscal year, NOAA's Office of Oceanic and Atmospheric Research, in partnership with the Cooperative Institute for Arctic Research, used a 1996 appropriation of $1 million by the U.S. Congress to initiate support of 15 research projects focused on the Western Arctic/Bering Sea ecosystem. CIFAR's integral role in the execution of programs that fall within NOAA's Arctic Research Office ensures that NOAA's priorities receive further support from experienced Arctic scientists.

CIFAR researchers disseminate their findings through the release of 18 scientific publications annually, the majority of which are peer-reviewed. Included among the 2006 published writings based on research that received partial or full funding through CIFAR, were articles appearing in *Geophysical Research Letters*, *Journal of Geophysical Research*, *Marine Resource Economics*, *Journal of Climate*, *Science*, and *Science of Tsunami Hazards*. Areas of research ranged from marine ecosystem restoration, an ecosystem shift in the northern Bering Sea, trends of snowfall and snow cover, to tide-tsunami interactions.

Publications in 2006 included several Ph.D. dissertations, representing the School of Fisheries and Ocean Sciences, and the Institute of Marine Science. CIFAR is a key partner and collaborator in the Center for Global Change's annual Student Research Grant Competition, established in 1992 to promote interdisciplinary research with a focus on the Arctic and sub-Arctic, and further supports student research efforts in areas that promote NOAA's mission and capacity-building in Alaska. Seventeen awards were granted to support 23 students working on a range of polar issues in the biological, physical, and social sciences during the International Polar Year 2007–08. Participation in the Student Research Grant Competition provides students with the experience of crafting proposals in an environment similar to that utilized by science funders. Three of the projects approved in 2007 were funded by CIFAR. Research and academic work at CIFAR is supported by the Keith Mather Library, which serves the International Arctic Research Center and the Geophysical Institute.

SEE ALSO: Arctic Ocean; Ocean Component of Models; Oceanic Changes; Oceanography.

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Robin K. Dillow
Rotary International Archives

Coriolis Force

BECAUSE EARTH SPINS on its axis, the Coriolis Force bends wind right or left from the direction of its flow. The Coriolis Force, therefore, causes wind to deviate from a straight path. If Earth did not spin on its axis, wind would blow following the Earth's curvature, with no deviation. A wind blowing from south to north would not deviate northeast or northwest. In 1835, French mathematician Gustave Gaspard Coriolis discovered the force that bears his name, and derived the mathematical equations that describe the Coriolis Force.

The Coriolis Force is weak, compared to other meteorological phenomena. At the equator, the Coriolis Force is nonexistent because wind does not rotate at the equator as it does at the poles. At the equator, wind follows the Earth's curvature, without deviating right or left. The absence of the Coriolis Force explains why hurricanes do not form at the equator, but rather in tropical waters, at least 5 degrees north and south of the equator. Absent the Coriolis Force at the equator, a hurricane or other tropical storm that formed in the north will not cross into the Southern Hemisphere, nor will one in the south cross into the Northern Hemisphere. The equator, therefore, acts as a barrier against the movement of tropical storms. The Coriolis Force keeps tropical storms in the hemisphere of their origin. By contrast to the weakness of the Coriolis Force as one nears the equator, the force gains strength as one approaches the poles and reaches a maximum at the poles, where winds experience the full effect of the Earth's rotation on its axis. At the poles, wind rotates sharply right in the Northern Hemisphere or left in the Southern Hemisphere with maximum force.

The Coriolis Force accounts for the trade winds that mariners used to navigate the ocean in past eras. So predictable are these winds in direction and force that Christopher Columbus used them in his later voyages to retrace the route of his first voyage. The winds originating in the Northern Hemisphere are called the Westerlies, whereas those that originate in the Southern Hemisphere are called the Easterlies.

On land, the Coriolis Force can form tornados. A tornado will rotate counterclockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere. The direction of rotation may seem counterintuitive, however, because wind flows to the right in the Northern Hemisphere, one might expect that it would rotate clockwise rather than counterclockwise. The same rationale applies in the Southern Hemisphere, where the flow of wind to the left might be expected to produce counterclockwise rotation, rather than clockwise rotation. However, a countervailing force, the difference in air pressure at the center and at the periphery of a tornado, forces a tornado to rotate counterclockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere. The counterintuitive rotation of tornados underscores the weakness of the Coriolis Force. The Coriolis Force could be compared to gravity; both are relatively weak, unseen forces, whose existences were undefined for centuries.

SEE ALSO: Cyclones; Hurricanes and Typhoons; Meridional Overturning Circulation; North Atlantic Oscillation; Southern Oscillation.

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Christopher Cumo
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Cornell University

CORNELL UNIVERSITY, AN Ivy League school and land-grant college located in the scenic Finger Lakes region of central New York, has seven small to mid-sized undergraduate colleges. The Department of Earth and Atmospheric Sciences offers undergraduate and graduate courses of study in the colleges of Arts and Sciences, Agriculture and Life Sciences, and Engineering. The Science of Earth Systems major is offered in all three colleges, while the College of Agriculture and Life Sciences also offers the Atmospheric Science major.

Established in 1983, the Northeast Regional Climate Center (NRCC) is located in the Department of Earth and Atmospheric Sciences. It serves the 12-state region that includes: Connecticut, Delaware, Massachusetts, Maryland, Maine, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and West Virginia. Major funding is provided by a grant from the National Oceanic and Atmospheric Administration. The NRCC's staff works cooperatively with the National Climatic Data Center, state climate offices, and other scientists in the northeast to acquire and disseminate climate data. The NRCC conducts research studies that focus on the development of new climate information products, data analysis techniques, and applications of climate data. Researchers also seek to understand and characterize regional climate and variability as it may affect the economic or societal well-being of the northeastern United States.

Examples of research include: the development of methods to estimate soil frost depths, monitor water resources, predict agricultural crop development, and characterize extremes of snow-pack water equivalent in the northeast. Arthur DeGaetano, associate professor and director of NRCC research, focuses on weather and climate extremes by enhancing the use and utility of climate data and information in weather-sensitive decisions. Observed climate variability investigates the interannual variability of such meteorological phenomena as East Coast winter storms and extreme temperature occurrences.

Such studies look at trends in these data through time, as well as causal mechanisms associated with year-to-year variations. The accuracy of the climate data archive is important for documenting observed climate variability, as well as the use of these data by decision-makers. Work in this area involves detecting nonclimatic changes in the data record due to changes in observing practices, and time-dependent shifts in the environment of the observing site.

The Center for the Environment is a Cornell University-sponsored unit that specializes in crafting interdisciplinary collaborations among scientists and professors from Cornell and partnering institutions, and applying new knowledge to environmental problems and needs around the world. The center plans and organizes lectures, seminars, conferences, student grants, and scholars' visits, and publishes a weekly electronic newsletter. It brings a prominent environmental leader to Cornell through the endowed Jill and Ken Iscol Distinguished Environmental Lecture Series every spring. The center also awards student research grants to Cornell University graduate students researching environmental topics. With its own ongoing research efforts, the center serves the Cornell academic community and partnering institutions with grant applications, team development, and administrative support. Current projects address pollution mitigation, marine and coastal environments, environmental complexity, and sustainability on local, state, and international levels.

The Doris Duke Charitable Foundation (DDCF) Climate Change Initiative is a five-year, $100 million program, launched in 2007 to help build a clean-energy economy. Many research projects at Cornell are funded through this initiative. The DDCF awards funding for research performed in three areas: pricing policies for greenhouse gases, technology deployment and development policies, and adaptation strategies. The DDCF will support the development of optimal domestic and international pricing policies for carbon and other greenhouse gases becoming competitive in the marketplace. It will also promote the development of policies that bring available technologies to market more quickly, particularly technologies related to energy efficiency. The foundation supports efforts to assess the likely effects of climate change and identify adjustments that can be made to reduce their impact. Given the DDCF Environment Program's mission to preserve wildlife through habitat protection, the foundation may focus on examining the impact of climate change on biodiversity conservation.

Cornell University, as well as performing research and promotion of climate change on a global scale, acts locally with student-run programs. The Cornell Sustainability Hub is a student-run organization dedicated to promoting and furthering sustainability on campus. The Hub is a coordinating body for a number of students and pre-existing organizations and seeks to aid them in the development of their goals and campaigns. It serves as a meeting place for various efforts, and an outreach committee focuses on publicizing their achievements to the Cornell community. Through the Hub, students have a chance to realize their visions of what Cornell could do to make itself more sustainable.

SEE ALSO: National Oceanic and Atmospheric Administration (NOAA); New York.

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Costa Rica

THIS CENTRAL AMERICAN Republic, which has coastlines on the Pacific Ocean and the Caribbean Sea, has a land area of 19,725 sq. mi. (51,100 sq. km.), with a population of 4,238,000 (2005 est.), and a population density of 220 people per sq. mi. (85 people per sq. km.). Only 6 percent of the country is arable, the smallest percentage of any of the Central American countries; 46 percent is meadow and pasture, much of it used for raising cattle, which, in turn, contribute to an increase in methane. Over 34 percent of the country is still forested, and there have been stringent ecological controls, with the Costa Rican tourist industry relying on an eco-friendly image. Twenty-seven percent of Costa Rica is covered by a system of national parks, wildlife refuges, and biological reserves.

The most prosperous country in Central America, there is extensive public transportation throughout Costa Rica, with the local bus service regarded as the best in Central America. There has been a recent promotion of the use of bicycles. The carbon dioxide emissions per capita for Costa Rica have risen from 0.9 metric tons per person in 1990, to 1.5 metric tons per person in 1994, and then stabilized between 1.3 and 1.5 metric tons per person per year. Carbon dioxide emissions come from liquid fuels (88 percent), and from the manufacture of cement (12 percent), with negligible use of solid fuels or gaseous fuels.

Partly because of the increasing reliance on ecotourism, there have been many studies of wildlife in the country. The reduction of the dry-season mists, owing to the increase in the temperature of the Pacific Ocean, has been linked to the disappearance of about 20 species of frogs and toads previously found in the Monteverde Cloud Forest, northwest of the capital, San José. Medical studies have also shown that there has been an increase in the spread of dengue fever, which had previously not been known over 3,300 ft. (1,006 m.), now being found at 4,000 ft. (1,219 m.).

The Costa Rican government of Rafael Ángel Calderón Fournier took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, and on April 27, 1994, in its last month in office, the government of José María Figueres Olsen signed the Kyoto Protocol to the UN Framework Convention on Climate Change, a decision that was ratified on August 9, 2002, and took effect on February 16, 2005. Support for the Costa Rican government's role has been given by the National Biodiversity Institute, located in San José, with N. Mateo addressing the Fifth World Bank Conference on Environmentally and Socially Sustainable Development at Washington, D.C., in October 1997. The increase in cyclones through global warming and climate change was discussed at the World Meteorological Organization's 6th International Workshop on Tropical Cyclones, held at San José in November 2006.

SEE ALSO: Forests; Hurricanes and Typhoons; Tourism; Transportation.

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Côte d'Ivoire

LOCATED IN WEST Africa, the former French colony of Côte d'Ivoire (formerly known as the Ivory Coast) has a land area of 124,502 sq. mi. (322,460 sq. km.), with a population of 17,654,843 (2006 est.), and a population density of 145 people per sq. mi. (56 people per sq. km.). Over 26 percent of the country is forested, much of it equatorial rainforest, with an extensive timber industry. Arable land accounts for only 8 percent of the country, with a significant amount used for the production of coffee. Forty-one percent of the land is used for meadows and pasture, mainly low-intensity grazing of cattle, sheep, and goats.

The country generates 75.4 percent of its electricity production from fossil fuels, with the remainder from hydropower. Because of low electricity use in the country, per capita carbon dioxide emissions are also low, at 0.4 metric tons per person in 1990, falling to 0.32 metric tons per person by 2003. Some 98 percent of these emissions come from the use of liquid fuels, with the remainder from cement manufacturing.

The generation of electricity accounts for 48 percent of emissions, with 21 percent from transportation. The high use of liquid fuels is due to the poor public transport infrastructure. The one train route in the country connects Abidjan, the capital of Côte d'Ivoire, with Ouagadougou, the capital of Burkina Faso. It is notoriously inefficient, leading most people to use private bus companies to make the journey. Côte d'Ivoire makes up 1.3 percent of the carbon monoxide emissions in sub-Saharan Africa.

The government of longtime president Félix Houphouët-Boigny took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, and ratified the Vienna Convention in the following year. Côte d'Ivoire was the 169th country to agree to the Kyoto Protocol to the UN Framework Convention on Climate Change, which took place on April 23, 2007.

SEE ALSO: Forests; Transportation.

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Cretaceous Era

THE CRETACEOUS ERA spanned the time period from 144 to 65 million years ago. It was the final epoch of the dinosaurs. It ended when the dinosaurs became extinct. At its height, the Cretaceous was a period of great warmth. The poles were ice-free, and warm ocean currents spread from the equator to the poles. The concentration of carbon dioxide was higher than it is today, causing a greenhouse effect. The abundance of plants was not enough to lower the amount of carbon dioxide in the atmosphere. The vigor of their growth implies that the Cretaceous climate was warm and wet, although, curiously, rainfall in the tropics was not heavy enough to support rainforests. Plants grew as far north as the Arctic Circle, proving that high latitudes were far warmer than they are today. The climate cooled, however, and rainfall diminished during the Late Cretaceous. The Cretaceous climate reached its nadir 65 million years ago, when a meteor impacted earth, ejecting debris, dust, and ash into the atmosphere, blocking out sunlight and cooling the Earth.

The sun was not the reason the Cretaceous era had a warmer climate than today; it produced 1–2 percent less heat. Earth was warmer during the Cretaceous era because the atmosphere contained 3–6 times more carbon dioxide than the current era. Carbon dioxide formed from the decay of large amounts of dead plants. Moreover, the Cretaceous, particularly the mid-Cretaceous, was a period of extreme volcanism, with the eruption of volcanoes releasing carbon dioxide into the atmosphere. The weathering of carbonaceous rocks also liberated carbon dioxide. All of this carbon dioxide created a greenhouse effect, in which carbon dioxide trapped sunlight as heat, warming the atmosphere.

A reservoir of heat, the ocean displayed the consequences of the greenhouse effect in its warmth, particularly in the tropics. During the Cretaceous Era, tropical waters were between 82–111 degrees F (28–44 degrees C). At 30 degrees latitude, ocean temperatures dipped to 68 degrees F (20 degrees C). At 60 degrees latitude, ocean temperatures were 54 degrees F (12 degrees C), and at 90 degrees latitude, temperatures were a cold 40 degrees F (4.5 degrees C). Polar temperatures, thus, though cold, were nonetheless above freezing and the poles did not have ice, at least not during the Late Cretaceous, though climatologists are less certain about the earlier periods of the Cretaceous. As is true today, the Cretaceous era oceans were cooler at lower depths, yet even at great depths they were warmer than today's oceans.

Plants absorbed carbon dioxide during the Cretaceous, though they may not have absorbed as much of the gas as they do today, accounting for the greenhouse effect during the Cretaceous. The tropics were drier during the Cretaceous than they are today, and so did not support a rainforest. The absence of a rainforest may have meant that Cretaceous plants were not numerous enough and did not grow vigorously enough to absorb as much carbon dioxide as today. Although this may have been true of the tropics, high latitudes had forests where today there is only tundra. These forests must have taken carbon dioxide out of the atmosphere, but on balance, plants did not remove carbon dioxide in sufficient quantities during the Cretaceous to reduce the greenhouse effect.

Plants reveal that the Cretaceous had a tropical climate, even at high latitudes. The plant *Heilungia* grew in Alaska. Although it is extinct, its relatives grow in Mexico and the Caribbean, suggesting that Alaska had a tropical climate during the Cretaceous. Temperatures must have varied little, staying around 80 degrees F (27 degrees C) year-round at high latitude. Rainfall must have exceeded 80 in. (203 cm.) a year.

The fact that Alaska had swamps during the Cretaceous also suggests that rainfall was abundant. Moreover, plants grew in profusion and density in Alaska, implying high rainfall and warm temperatures. Tree rings were wide, suggesting a warm, wet climate. Conifers grew at lower latitudes, implying that the climate was less moist and that the climate became drier toward the equator, the opposite of conditions today.

In Siberia, plants grew in the Arctic Circle. Summer temperatures averaged 70 degrees F (21 degrees C), whereas winter temperatures averaged only 43 degrees F (6 degrees C). Arctic Siberia therefore had seasons, with summer 27 degrees F (15 degrees C) warmer than winter. The difference between summer and winter temperatures during the Cretaceous is less than the seasonal difference today at high latitudes. The climate was warm enough this far north to permit plant growth for more than seven months each year. Autumn was brief, with the transition from summer to winter coming rapidly. South of Siberia, in what is Czechoslovakia today, temperatures averaged 68 degrees F (20 degrees C). Summer temperatures averaged 82 degrees F (28 degrees C), whereas winter temperatures averaged 52 degrees F (11 degrees C).

The climate of the Late Cretaceous is an enigma. The oceans remained warm and the poles ice-free, but on land, temperatures and rainfall decreased. The final blow came at the end of the Cretaceous 65 million years ago, when a meteor hit Earth, ejecting debris into the atmosphere and blocking out sunlight, cooling the Earth. The meteor impact ended the Cretaceous, temperatures continued to decrease, falling low enough to cause ice ages, the last of which ended only 10,000 years ago. As the concentration of carbon dioxide diminished and ice collected at the poles, tundra replaced forests at high latitudes. Rainfall increased in the tropics, giving rise to the rainforests.

SEE ALSO: Climate; Greenhouse Effect; Greenhouse Gases; Volcanism.

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Christopher Cumo
Independent Scholar

Croatia

ONE OF THE constituent republics of the former Yugoslavia, the Republic of Croatia is located in the Balkans and has a land area of 21,831 sq. mi. (56,542 sq. km.), with a population of 4,493,312 (2006 est.), and a population density of 208 people per sq. mi. (81 people per sq. km.). Some 21 percent of Croatia is arable, with another 20 percent used for meadow or pasture. In addition, 37 percent of the country is forested, the pine from the region has been used for making ships since ancient times. The forestry and the lack of heavy industry have helped the environment in Croatia for many centuries, but there is now increased logging; also, up to half of the forests are affected by acid rain created by other countries.

For electricity generation, 45 percent of Croatian power comes from fossil fuels, with 55 percent from hydropower. This is generated from four hydroelectric power plants, one near the Slovenian-Hungarian border at Varazdin, and the other three are at Senj, Obrova and Zakucac, along the Adriatic Coastline. As a result of this heavy use of hydropower, Croatia has a relatively low rate of greenhouse gas emissions, given the prosperity of the country and the high automobiles ownership.

In 1992, Croatia was responsible for 3.7 metric tons per person of carbon dioxide, rising gradually to 5.3 metric tons per person in 2003. Of this, 65 percent comes from liquid fuels, 25 percent from gaseous fuels, 5 percent from solid fuels such as coal, and the remaining 5 percent from cement manufacturing. By sector, electricity production and transportation account for, respectively, 26 percent and 24 percent of all carbon dioxide emissions, with manufacturing industry accounting for another 19 percent, and other energy industries accounting for 12 percent.

Croatia became independent in 1991, and soon afterward it ratified the Vienna Convention. In May of the following year, it took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, and signed the Kyoto Protocol to the UN Framework Convention on Climate Change on March 11, 1999. It was ratified eight years later, on April 27, 2007.

SEE ALSO: Climate Change, Effects; Coal; Deforestation; Forests.

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Croll, James (1821–90)

JAMES CROLL WAS a 19th-century Scottish scientist who developed a theory of climate change based on variations in the Earth's orbit. Croll was the leading proponent of an astronomical theory of climate change during the 19th century. Taking into account the precession of the equinoxes, variations in the eccentricity of the orbit, and tilt of the axis, Croll proposed that climate change must be the result of the relation of the Earth to the Sun.

He further speculated, "geological and cosmical phenomena are physically related by a bond of causation." Although his theory has often been criticized, it influenced the work of Serbian geophysicist Milutin Milanković and provided important insights into the interplay of astronomical and geological elements.

James Croll was the second son of David Croll, a stonemason, and Janet Ellis. He was born in the village of Little Whitefield, Perthshire, Scotland, on January 2, 1821. He grew up on a farm and received almost no formal education. However, Croll was attracted to philosophy and science from an early age and began to read widely in those subjects. He initially preferred those two disciplines to geology. Croll held a variety of odd jobs, including tea merchant, innkeeper, insurance salesman, and caretaker at the Andersonian College and Museum in Glasgow. All these jobs allowed Croll to read and write about his favorite subjects. His first book, *Philosophy of Theism*, was published in 1857, at the age of 36. This was followed by a number of scientific publications on electricity, heat, and most importantly, on astronomical controls on geological climate.

His paper, "On the Physical Cause of the Change of Climate During Geological Epochs," published in *Philosophical Magazine* in 1864, provoked the interest of leading scientists in Scotland and England. In this paper, Croll introduced changes in the Earth's orbital elements as periodic and extraterrestrial mechanisms responsible for the beginning of multiple glacial epochs. Croll argued that the eccentricity of the Earth's orbit was sufficiently great to explain every extreme of climatic change evidenced by geology. His theory of ice ages was built on the precession of the equinoxes and variations in the shape of the Earth's orbit. It forecast that one of the two hemispheres would experience an ice age whenever two conditions occur simultaneously: a markedly elongate orbit, and a winter solstice that occurs far from the Sun.

FELLOW OF THE ROYAL SOCIETY

In 1867, Croll accepted a job in Edinburgh with the Scottish Geological Survey as secretary and accountant. This employment came "more by accident than by choice," as Croll himself admitted. Croll's tasks included ordering, printing, coloring, and selling maps and keeping the accounts and stores in order. The director, Archibald Geikie, encouraged Croll to carry out his own research. In addition to his work on orbital theory, Croll made field excursions on glacial deposits and discovered a pre-glacial riverbed running from Edinburgh to Glasgow. Although in later life he suffered from severe headaches that limited his intellectual work, he still produced numerous papers on climate change, glacier motion, geological time, ocean currents, and astrophysics.

In 1875, Croll published his major book, *Climate and Time*, a work that his ill-health delayed by several years, but that, once published, was widely admired. The publication of this book led to his election as a Fellow of the Royal Society. The University of St. Andrews also awarded him an honorary degree. He was invited to lecture at the Royal Institution, but turned down the invitation due to ill-health and his reserved character.

He rarely attended the meetings of the British Society for the Advancement of Science. By 1871, Croll was growing increasingly dissatisfied with geological subjects and wanted to devote most of his time to the study of philosophy. In 1880, Croll retired from the Survey, expecting a full pension because of his advanced age. He was only given credit for 13 years of employment and saw his income drop dramatically. Because of this precarious financial situation, Croll was forced to give up housekeeping and go into rented lodgings.

During his retirement, Croll wrote two more scientific books: *Discussions on Climate and Cosmology* (1886), and *Stellar Evolution and its Relations to Geologic Time* (1889). The former was largely a reply to his critics and further developed his theory of the secular change of the Earth's climate.

His health increasingly deteriorating, Croll returned to his first love, philosophy, and saw the publication of his fifth book, *The Philosophical Basis of Evolution* (1890), a response to Darwinism and Spencerianism, in the year of his death. He died on December 15, 1890.

The astronomical theory of climate change emerged 1864–90 thanks to the work of James Croll. However, because of uncertainties in the timing of ice ages and in the stratigraphic record, and because Croll's theory envisaged glaciation in only one hemisphere, the theory was criticized and largely dismissed for at least three decades.

The astronomical theory reemerged from obscurity, thanks to the work of Milutin Milanković, who reformulated it into a mathematical theory 1920–41. Even in the case of Milanković's theory, consensus was far from unanimous because of thermal lags in the climate system and, in part, because of the unexplained lack of continental glaciation prior to the Pleistocene.

However, in 1976, the paleostratigraphic work of James Hayes, John Imbrie, Nicholas Shackelton, and others who documented the astronomical signals in a number of independent proxy climate records confirmed the theory.

SEE ALSO: Earth's Climate History; Ice Ages; Orbital Parameters, Eccentricity; Orbital Parameters, Obliquity; Orbital Parameters, Precession.

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Cuba

LOCATED IN THE Caribbean, the Republic of Cuba has a land area of 42,803 sq. mi. (110,861 sq. km.), with a population of 11,382,820 (2006 est.), and a population density of 102 people per sq. mi. (264 people per sq. km.). Traditionally, the Cuban economy has been closely tied to the tobacco and sugar industries (the latter still accounts for nearly half of the country's exports).

A total of 24 percent of Cuba is arable land, with a further 27 percent of the country devoted to meadows and pasture. Approximately 94.6 percent of electricity production comes from fossil fuels, mostly petrol sourced from Venezuela. Hydropower is responsible for only 0.4 percent of all electricity. Although there is low automobile use in Cuba, many of the automobiles in the country are older models with heavy fuel consumption, and many still use lead-based gasoline.

For this reason, the vast majority of the carbon dioxide emissions from Cuba (96 percent) are from the use of liquid fuels, while most of the remainder come from the manufacture of cement. By sector, electricity and heat production account for 39 percent of carbon dioxide emissions, with manufacturing and construction making up nearly 40 percent of the emissions, and transport only 7 percent, with residential use some 3 percent. About 24 percent of the country is forested, with much mahogany used for export, and cedar turned into cigar boxes.

Global warming and climate change have had the effect of raising the temperature of the waters in the Caribbean, and it seems likely that this trend will continue, along with higher average temperatures. These higher water temperatures are already having a detrimental effect on the fish in the Caribbean Sea, affecting the local fishing industry, which is the third most important industry in the country, after sugar and nickel.

The Cuban government ratified the Vienna Convention in 1992, and took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992. It signed the Kyoto Protocol to the UN Framework Convention on Climate Change on March 15, 1999, and ratified it on April 30, 2002, with it taking effect on February 16, 2005.

SEE ALSO: Alternative Energy, Ethanol; Automobiles; Oceanic Changes; Venezuela.

Rising water temperatures in the Caribbean Sea are affecting Cuba's fishing industry—its third most important industry.

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Culture

A FUNDAMENTAL CONCEPT in social sciences and philosophy, culture gathers all human productions of a specific group or society at a given moment. What is known as culture includes a given language, art and literature, history and traditions, religious beliefs, the media, and comprises the way people live and prepare food. Usually, groups recognize themselves and identify with their own culture. However, a culture is different from a civilization: for instance, the civilization of Ancient Greece does not exist anymore as all of its people are dead, but their culture remains accessible because of their monuments, art, and the knowledge of their philosophers and poets through books and translations. The same applies to the culture of the Ancient Egypt: modern Egyptians no longer believe in the ancient gods and goddesses, but there is still a fascination with ancient structures.

Today, what we know as the American way of life is understood to be the way most people in the United States live and consume, based on a system that encourages and values consumption. American tourists who travel to other countries discover many cultural differences while abroad. They may be surprised to find frogs and snails on the menu at France's finest restaurants, served by peopel who would never think of eating the American staple of peanut butter.

A culture is often specific to a country, a nation, or a group; culture is a part of a group's identity. Culture is not limited to the borders of a given country. For example, even Americans who visit Louisiana acknowledge the fact there is a unique culture and way of life in New Orleans. Whenever U.S. citizens go to England, they feel that although the language is quite similar, they are into a much different context: that difference is mainly cultural.

Understanding culture is essential to understand how individuals rely on their group or society. Cultural practices are studied by anthropologists, sociologists, and media experts. Strategists in marketing observe how people consume, and what motivates them to buy a product. In many cases, the strategies crucial to lessen society's effect on climate change, or to reduce greenhouse gas emissions, require a change in the way people live: partaking in recycling, using automobiles less frequently, carpooling, perhaps even choosing a job closer to home to reduce commuting distances.

The adoption of ideas such as "consuming creates global warming" contradicts the models of the consumer-based societies in which most individuals in industrial countries live.

The media are an essential part of our culture. A popular topic of social interaction is to discuss what they have seen on television, or what they have read in the newspapers. For instance, media experts have studied how a certain groups use television, particularly channels pertaining to the weather. Researchers have found that about 10 percent are obsessed by any unusual event related to the weather; they do not use forecasts as an instant information, but rather as a dramatized narrative about what could happen tomorrow.

The distinction between culture and ideologies are fundamental in philosophy and social sciences. To summarize, it could be said that the ideology is what you generally think and believe in, while culture is what you generally do. In other words, ideologies are a set of coherent ideas that are linked together, while culture is a set of practices related to a group. There are many opposing ideologies related to climate change and global warming: those who agree with the idea of climate change and those who reject the idea of a global warming. These beliefs are organized into ideologies that guide our attitudes, behaviors, and actions.

Although there are exceptions, most individuals try to act according to their beliefs. Whenever they do not, they usually become aware that their actions are not aligned with their convictions. For instance, a bus or truck driver might neglect to turn the engine's motor off while waiting for passengers for a long period, knowing that he is contributing to air pollution. The bus driver employed by the city would not be affected by wasting energy or consuming too much because he does not have to pay for the gasoline that is consumed. An independent, private truck driver may turn off the engine, because he pays for the fuel consumed.

CULTURE OF ENTERPRISES

Corporate cultures are a set of practices that are encouraged for employees during working hours at a given company. Some corporations will encourage

Children learn about the environmental at the U.S. Fish and Wildlife Service's San Luis National Wildlife Refuge. Researchers in the United Kingdom found in a 2007 study that 50 percent of children are anxious about the effects of global warming.

employees to take action to reduce consumption. For instance, in order to encourage employees who use their bicycles, corporations may upgrade their facilities to include bathrooms with showers. Other initiatives are created as well, sometimes within governmental policies, which can have an impact on workers who change or adapt their habits and behaviors.

MEDIA AND CULTURE

In his book, *Cultural Citizenship*, Toby Miller investigates the obsession that can be created by the weather for some of the population. He also analyzes sponsors for such programs and networks.

There have been numerous films touching on the subject of global warming, including *The Day after Tomorrow*, and *State of Fear*. The film *Waterworld* told the story of a flood that suddenly engulfed many countries. In 2006, a film titled *The Great Global Warming Swindle*, by Martin Durkin, challenged Al Gore's influential documentary, *An Inconvenient Truth*.

Books about global warming have been written especially for children. These books are not only tools for environmental education, but they demonstrate to the youngest readers that the idea of global warming is present. More than one generation of children have been taught about climate change and global warming in schools, and therefore echo these debates in their families and circles of friends. Many museums, not only those dedicated to science, organize exhibitions related to climate change and global warming.

The growing presence of news, debates, and narratives about climate change and global warming confirm that these issues are part of our culture, and are an element in every sphere of society, not only of importance in scientific research, or solely in the Arctic. These issues are debated by nonscientists, like politicians, citizens, environmental groups (such as Greenpeace), other nongovernmental organizations, and in the media.

SEE ALSO: *An Inconvenient Truth;* Climate Change, Effects; Education; Needs and Wants; Media, Books and Journals; Media, TV; Population; Transportation; Weather.

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Current

A CURRENT IS the ordered movement of a fluid in time. A number of different physical factors including tides, landslides, winds, horizontal pressure gradients, and changes in water density can put water into motion. Of these factors, regional winds, horizontal pressure gradients, and density changes can drive currents on basin-wide or global spatial scale. These moving water parcels, in turn, transport not only matter, but also heat. Therefore, changes in the strength or location of currents that cover sufficiently large distances can alter global climate.

Wind-driven currents are produced when winds transfer energy into the surface layer of the water column. Once the water is set into motion, the Coriolis force acts upon it, and the surface layer is deflected 45 degrees to the right of the wind stress in the Northern Hemisphere, and 45 degrees to the left of the wind stress in the Southern Hemisphere. Friction occurs between each of the infinite number of layers composing the water column. Therefore, as it moves deeper, the Coriolis force further deflects each layer, and its velocity is diminished. The depth at which the layer of water no longer is influenced by the wind is called the depth of frictional influence. The parcel of water from the surface to the depth of frictional influence is referred to as the surface Ekman layer. The surface Ekman layer flows 90 degrees to the right of the wind stress in the Northern Hemisphere, and 90 degrees to the left of the wind stress in the Southern Hemisphere. Movement of the surface Ekman layer can lead to a change in sea-surface height over a distance, producing the conditions favorable for geostrophic circulation.

Horizontal pressure gradients serve as another mechanism that causes and maintains large-scale ocean currents. The balance between the horizontal pressure gradient forces drives geostrophic currents, resulting from the change in sea-surface height and/or water density over a distance, and the Coriolis force. Variability in sea-surface height may be produced by winds, tides, or proximity to a coastal boundary. When a difference in sea-surface height occurs, water tends to flow "downhill," or move from areas of high to low pressure. Once in motion, the Coriolis force deflects the water until its motion directly opposes that of the horizontal pressure gradient. The net result is a geostrophic current flowing 90 degrees to the right of the pressure gradient force in the Northern Hemisphere, and 90 degrees to the left of the pressure gradient force in the Southern Hemisphere.

A combination of wind-driven currents and geostrophic flow sets up the circulation in ocean gyres, or ocean-basin scale (at least 621 mi. or 1,000 km.) circular currents. Subtropical gyres, or those that occur at mid-latitudes, are driven by a combination of westerlies and trade winds, which force them to flow anticyclonically. The eastern boundary currents of subtropical gyres can bring cool water toward the equator, and are relatively slow and diffuse. In contrast, western boundary currents, such as the Gulf Stream, are concentrated and fast, quickly transporting warm, salty water from the equator toward the poles.

In addition to winds and pressure gradients, changes in water density can drive global-scale ocean circulation. Thermohaline circulation, or meridional overturning circulation, results from sinking of high-density surface water. This sinking process is usually localized in the north and south Atlantic oceans. High-density water in these regions is made from both seasonal cooling of saline water, and freezing of sea ice. This dense water sinks, and moves equatorward. Because water mass and heat must be conserved, the equatorward movement of cold, dense bottom waters is compensated for with poleward movement of warm surface waters. It has been suggested that melting of ice sheets caused by global warming has already reduced, and will continue to decrease, the intensity of global thermohaline circulation and cause climate to change significantly.

In addition to global-scale circulation patterns, regional currents, such as those driven by upwelling and downwelling circulation, can affect local climate. Upwelling circulation occurs when surface waters diverge from either a coastal boundary or another water mass. To conserve mass, deeper, cooler water moves in to take the place of the surface water. An example of this is seen off the coast of California, where surface waters flow offshore and are replaced with cooler deep water. This leads to a well-mixed water column near shore, and, subsequently, a highly-productive marine ecosystem. Conversely, downwelling circulation occurs when water piles up along a coast or converges with another water mass and sinks. Downwelling is observed in the centers of subtropical gyres, leading to low primary production, or low phytoplankton growth there.

Currents may be measured or studied using two different approaches: Eulerian and Lagrangian methods. In a Eulerian approach, a stationary instrument is placed in the water, and currents at that location are measured over time. While an Eulerian design, such as a moored array of current meters, provides a detailed description of flow in a specific location and may resolve vertical current shear, it lacks spatial coverage, and cannot track water flow over long distances. In contrast, a Lagrangian method follows water parcel trajectories by employing instruments such as drifting buoys. This approach works well for producing realistic water parcel tracks, but must be repeated numerous times to account for the sensitivity of a particle track to its starting location. Historical changes in the strength and position of currents may be studied using paleoceanographic methods. One approach is to take sediment cores from regions throughout the world and compare the distribution of fossils of planktonic organisms over time. Variability of the ranges of species through time suggests long-term shifts in water temperatures or circulation, which may indicate changes in global climate.

SEE ALSO: Coriolis Force; Ekman Layer; Meridional Overturning Circulation; North Atlantic Oscillation; Southern Oscillation.

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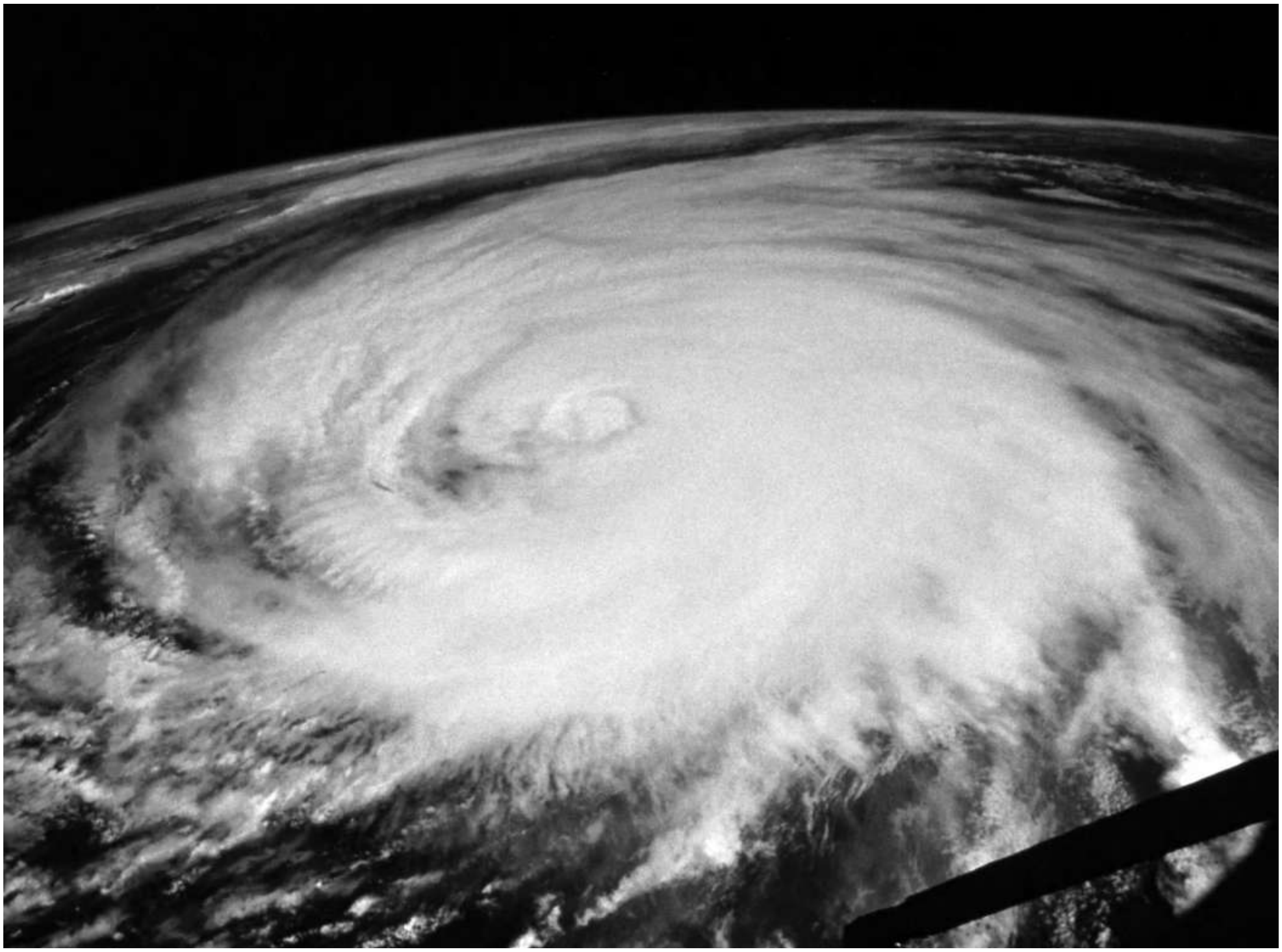
Cyclones

CYCLONES ARE METEOROLOGICAL systems consisting of areas of low pressure where the winds in the Northern Hemisphere and Southern Hemisphere rotate counter-clockwise and clockwise, respectively. The biggest storms around the world, such as cyclones, are intensifying. It is reported that the number of category four and five tropical cyclones, which are very intense, have increased over time. One reason for this is the impact of global warming, in particular, the effect of increased sea-surface temperature. Cyclones are often subdivided into other types, which include tropical cyclones and extra-tropical cyclones. Other types of cyclones include polar, polar low, subtropical, and mesoscale cyclones.

Tropical cyclones are low-pressure systems consisting of large rotating systems of clouds and winds, which occur over tropical and subtropical waters. They also have thunderstorm activity and cyclonic surface wind circulation. Depending on their location and strength, there are various terms by which tropi-



The number of category four and five tropical cyclones, which are very intense, has increased over time. One reason for this is the impact of increased sea surface temperatures due to global warming.

cal cyclones are known, such as hurricane, typhoon, tropical storm, cyclonic storm. and tropical depression. These cyclones have no fronts and the center of the storm is warmer than the surrounding air. They are known as tropical storms if the wind reaches 56 ft. (17 m.) per second and hurricanes if the winds reach 108 ft. (33 m.) per second. Hurricanes occur in the North Atlantic Ocean and the northeast Pacific Ocean, east of the dateline. There are several environmental conditions favoring tropical cyclones, such as warm ocean waters, winds that do not vary greatly with height, and a minimum distance of 311 mi. (500 km.) from the equator. There are seven tropical cyclone basins where storms occur on a regular basis. These are the Atlantic basin, Northeast Pacific and Northwest Pacific basins, North Indian basin, Southwest Indian basin, Southeast Indian/Australian basin, and Australian/Southwest Pacific basin.

Extratropical cyclones, sometimes called mid-latitude cyclones, are storms that form outside the tropics, sometimes as a tropical storm or hurricane changes, such that they have neither tropical nor polar characteristics. They form where cold and warm air masses come into contact with each other, and are formed in middle or high latitudes, in frontal zones. The center of the storm is generally colder than the surrounding air.

A subtropical cyclone is a non-frontal low-pressure system that has characteristics of both tropical and extratropical cyclones. Compared with tropical systems, they have a broad zone of maximum winds located further from the center. They also have a less symmetric wind field and distribution of convection.

They can be formed in a wide band of latitude, from the equator to 50 degrees both North and South. A subtropical cyclone is known as a depression if the winds reach wind speed of 38 mi. (62 km.) per hour or less and as a storm if the speed reaches 39 mi. (63 km.) per hour or more. Many times, these subtropical storms transform into true tropical cyclones.

There is another type of subtropical cyclone known as a mesoscale. This is a cyclonic vortex of air with an average diameter of 1–6 mi. (2–10 km.) within a convective storm. They are often associated with supercells, which are rare thunderstorms with a rotating updraft (current of rising air).

Some supercell thunderstorms can maintain themselves for several hours and are responsible for many extreme weather events, such as tornadoes. There are many other characteristics that are associated with supercell thunderstorms, such as a flanking line (a line of cumulus clouds) and a thunderstorm with back-shaped anvil (the flat top of a cumulonimbus cloud; back-shaped anvils have high severe weather potential).

A mesocyclone is an area of vertical atmospheric rotation, typically 2–6 mi. (3–8 km.) across. Mesocyclones are formed when change in wind speed or direction occur dramatically, with changes in height; this sets the lower part of the atmosphere spinning horizontally. Polar cyclones are low-pressure systems in which the air circulates counterclockwise in the Northern Hemisphere.

Usually, polar cyclones range from 60–600 mi. (96–965 km.) across, with surface winds of 30–100 mi. (48–160 km.) per hour. Polar cyclones may occur through any time of the year, however, as they usually occur in areas with little or no population, they are viewed as less destructive than other types of cyclones.

SEE ALSO: Atmospheric General Circulation Models; Hurricanes and Typhoons; Thunderstorms; Weather; Wind Driven Circulation.

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Cyprus

CYPRUS IS AN island in the eastern Mediterranean separated territorially between the Republic of Cyprus and the Turkish Republic of Northern Cyprus, an independent state formed in 1983, but only recognized by Turkey. Cyprus buffers the three continents of Europe, Asia, and Africa, in the Mediterranean basin.

The island presents diverse landscapes, including two mountain ranges, the central plains of Messariois, and a differentiated coastline. The political and territorial partition of the island shapes the fragmented contemporary national environmental response to climate change and pollution.

The exodus of a large number of refugees from the north of the island, following the Turkish deployment of troops in 1974, triggered rapid development of the Greek-Cypriot region, a process notable in the construction of a vibrant tourist industry, which has evolved from attracting mass tourism to targeted flows of visitors seeking first-class amenities. This led to the construction of golf courses, swimming pools, and elite resorts, resulting in disturbed wildlife habitats and increased demands on scarce natural resources, including water. A large military environmental footprint also disturbs fragile resources.

The growth in the tourist sector and expanding material wealth has created challenges in controlling waste management, including industrial, human, and animal waste. The expansion of the Port in Limassol, and the escalation of sea freight generated by exports to other European Union members, has generated marine pollution beyond the Akrotiri Bay from ballast and foreign algae, which is degrading the wider coastal environment. Water is a key resource issue in Cyprus. Having no extensive natural reservoirs or water catchments, groundwater contamination from agriculture and surface contamination linked to industrial pollution in chemical substances and aggressive organic compound emissions, are compromising the sustainability of freshwater reserves. Lower rainfall linked to climate change is producing droughts.

The Republic of Cyprus's membership in the European Union and its need to comply with environmental legislation in air quality and emission standards is producing positive change. Various bodies, such as the Petitions Committee within the European Parliament Health, frequently debate issues related to expanding technologies (for example, mobile telecommunications masts), but progress is often uneven and contentious. In the Turkish sector, domestic water supplies are often precarious, culminating in serious supply issues that impact public health.

POLLUTION CONTROL

With border restrictions increasingly relaxed, and a willingness from the Turkish Republic of Northern Cyprus to become a member of the European Union, it is possible that coordinated policies on specific issues will stem the challenges arising from climate change. The increased tourist flow, however, to the northern part of the island, and improved living standards, will place additional demands on existing resources. For the island as a whole, there is no generic strategy that controls the management of policies on water sustainability, pollution arising from industry, and expanded marine pollution control.

SEE ALSO: Drought; European Union; Tourism; Turkey.

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Czech Republic

FORMERLY THE WESTERN part of Czechoslovakia, in Central Europe, the Czech Republic has a land area of 30,450 sq. mi. (78,866 sq. km.), with a population of 10,306,709 (2006 est.), and a population density of 337 people per sq. mi. (130 people per sq. km.). Approximately 41 percent of the land is used for arable purposes, 11 percent for meadows and pasture, and 34 percent is forested. In 1992, the Czech Republic recorded per capita carbon dioxide emissions of 13.1 metric tons per person, which had fallen to 11.4 metric tons per person by 2003. Some 67 percent of the carbon dioxide emission comes from solid fuels, with coal providing much of the electricity production in the country.

About 77.8 percent of the electricity comes from the burning of fossil fuels, with 18.5 percent from nuclear power, and only 2.5 percent from hydropower. Most of that hydroelectricity comes from the Dalescie Dam, located on the Jihlava River, which was built 1970–78.

Liquid fuels account for 16 percent of the country's carbon dioxide emissions, with 15 percent from gaseous fuels. By sector, electricity production accounts for 54 percent of carbon dioxide emissions, with manufacturing and construction industries causing 23 percent, and transportation, 10 percent, despite a good public transport system, the use of electric trams, and also the heavy promotion of carpooling, cycling, and car-free parts of some towns and cities. The Czech government of Václav Klaus took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, and the government of Václav Havel signed the Kyoto Protocol to the UN Framework Convention on Climate Change on November 23, 1998. It was approved by the Czech parliament on November 15, 2001, and took effect on February 16, 2005.

SEE ALSO: Coal; Slovakia; Transportation.

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David Suzuki Foundation

THE DAVID SUZUKI Foundation is an independent Canadian charity, based in Vancouver, British Columbia, which has worked since 1990 to protect biological diversity and quality of life. Through science and education, the foundation works broadly to advance principles of sustainability. Dr. David Suzuki, one of Canada's best-known contemporary environmental advocates, built his career first as a geneticist, and then as a broadcaster, journalist, and popular educator. In November 2004, Dr. Suzuki was voted fifth in the Canadian Broadcasting Corporation's (CBC's) Top Ten Greatest Canadians. Other significant awards include: 15 honorary doctorate degrees, a United Nations Educational, Scientific and Cultural Organization (UNESCO) prize for science, a United Nations Environment Program medal, various honors from Canada's First Nation peoples, and induction as an Officer of the Order of Canada (Canada's highest civilian honor for outstanding lifetime achievement).

Dr. Suzuki has hosted the CBC's award-winning *The Nature of Things* since 1979, and excels at relaying scientific concepts to the lay public. Much like other environmental icons (notably, Rachel Carson, Carl Sagan, and E.O. Wilson), Suzuki has helped to shift popular consciousness in favor of environmental protection. He founded the David Suzuki Foundation, in 1990, to identify and advance new ways for society to live in greater harmony with the natural world. Supported by donations from approximately 40,000 individuals from across Canada and around the world, and by grants from other charitable organizations, the foundation does not generally accept government grants (though some scientific research is funded directly through the National Sciences and Engineering Research Council of Canada).

The David Suzuki Foundation is one of a number of key nongovernmental organizations that seek to advance a sustainability agenda. To this end, the foundation collaborates with scientists and academics, as well as representatives from business and industry, government, and other nongovernmental organizations. Ultimately, the foundation adopts an integrative and pragmatic approach to environmental protection, supporting a clean, competitive economy that does not undermine the ecological services upon which it ultimately depends.

The foundation regularly critiques Canadian environmental policies and programs, and puts forward innovative solutions to promote greater eco-efficiency, full-cost accounting, and closed-loop manufacturing. The foundation operates five interrelated program areas: protecting human health, conserving our oceans, promoting global conservation, building a sustainable economy, and solving global warming.

The David Suzuki Foundation works toward evaluating impacts, mitigating risks, and positing creative solutions to the impending challenges of climate change. Above all, substantial reductions in greenhouse gases require a fundamental shift in the ways in which energy is produced and consumed. The foundation has advocated strongly for Canada to meet its international commitment to adhere to the United Nations Kyoto Protocol on greenhouse gas reductions. The foundation has actively published on climate change since 1997, and in 2002 jointly commissioned *The Bottom Line on Kyoto: Economic Benefits of Canadian Action*, and *Kyoto and Beyond: The Low Emission Path to Innovation and Efficiency*. The foundation challenges global warming skeptics, and seeks to shed light on their underlying motives by drawing explicit attention to their funding.

The foundation encourages organizers of large public gatherings, including conferences, sports events, concerts, festivals, celebrations, and conventions, to be carbon neutral by mitigating and offsetting greenhouse gas emissions. Climate-friendly practices (such as waste minimization and energy and water conservation) can be consciously integrated into virtually every aspect of an event, from the choice of venue, to policies around registration, transportation, food and beverage services, and procurement. Remaining emissions can be offset, rendering the event effectively carbon neutral. In so doing, event organizers demonstrate environmental leadership, with a view to inspiring others to take comparable steps. Multiple benefits ensue, including reduced costs, improved public image, and mitigated emissions. The foundation also encourages people to fly less, and to opt, instead, to connect virtually (through videoconferencing or webcasting), and to vacation close to home.

The foundation's Nature Challenge has spurred some 341,142 individuals to critically examine their lifestyle choices around food, transportation, and energy use. Participants opt to: reduce home energy use by 10 percent (for example, by installing low-flow showerheads and faucets); buy an energy efficient home and appliances, and a fuel-efficient vehicle; eat locally-grown, seasonal, organic foods that are low on the food chain; walk, bike, carpool, or take public transit; and live in close proximity to work or school. All of these actions are framed as simple solutions to help fight global warming. David R. Boyd's *Sustainability within a Generation* explores at length the foundation's vision for transforming human-environment relations. This document examines root causes for Canada's unsustainable ways (that is, an economy that relies almost exclusively on consumption of energy and natural resources), and identifies critical goals and necessary policy shifts toward a more prosperous, just, and sustainable future.

SEE ALSO: Canada; Canadian Association for Renewable Energies; International Institute for Sustainable Development (IISD).

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Deforestation

THERE ARE VARIOUS definitions of deforestation. The United Nations Food and Agriculture Organization (FAO) defines deforestation as:

> A non-temporary change of land use from forest to other land use or depletion of forest crown cover to less than 10 percent. Clear cuts (even with stump removal) if shortly followed by reforestation for forestry purposes are not considered deforestation.

According to the FAO there were 3,952 million ha. of forestland in the world in 2005. The most forested countries in the world are the Russian Federation, with 808.79 million hectares (ha), followed by Brazil with 477.70 million ha, and Canada with 310.13 million

Deforestation caused by agriculture, logging, fuelwood use, and cattle ranching releases approximately 1.7 Pg of carbon a year.

ha. According to the FAO, deforestation occurred at a rate of 8.87 million ha (–0.22 percent) a year 1990–2000, and 7.32 million ha (–0.18) a year 2000–05. The country with the highest deforestation rate is Brazil, with 2.68 million ha a year 1990–2000, accelerating to 3.1 million ha a year 2001–05. The second is Indonesia, with 1.87 million ha deforestation a year 1990–2005. The country with the largest gain in forest area is China, with 1.99 million ha a year 1990–2000, and 4.06 million ha a year 2001–05.

The Rainforest Alliance has estimated that, globally, the main causes of tropical deforestation are land clearing for agriculture (64 percent), logging (18 percent), fuelwood collection (10 percent), and cattle ranching (8 percent). However, the amounts vary geographically and temporally. Fuelwood collection is particularly destructive in dry lands or high altitudes because of slow natural regeneration rates, while cattle ranching is estimated to cause up to 60 percent of the forestland clearance in Central and South America. The exact proportions of each cause of deforestation are also difficult to estimate because land might be used for multiple purposes. While forests might be cut for the logs, the land can then be used for agriculture or cattle ranching.

According to H.J. Geist and E.F. Lambin, the underlying causes of deforestation include: the unequal access to land by the rural poor; the high debt of many developing countries; unsustainable farming practices, especially in tropical countries; unsustainable land tenureship rules that give ownership of land to those who clear it; and the demand for cheap beef for the fast food industry, which in Central and South America generates demand for both cattle ranching and soybean production to feed cattle in North America and Europe.

The consequences of deforestation are global and local: including atmospheric pollution, release of CO_2, climate change, disruption of the hydrological cycle, disappearance of wildlife, soil erosions, and landslides. Deforestation, mainly in the tropics, is estimated to release approximately 1.7 petagrams (Pg) of carbon (C) per year (one Pg is one thousand million metric tons). With a small amount of uptake (about 0.1 Pg C) in temperate and boreal areas, deforestation releases around 1.6 Pg of carbon per year. This can be compared to the carbon released by burning fossil fuel, which is currently at about 7 Pg C per year.

While tropical deforestation is an important source of atmospheric CO_2, the Kyoto Protocol only gives carbon credits for the CO_2 that is sequestered by forest plantations, not for the CO_2 that is retained by natural forests. A post-Kyoto protocol is expected to address this problem by giving credits for the carbon retained by natural forests, so as to increase the economic costs of deforestation, according to R. Sedjo.

SEE ALSO: Brazil; China; Forests; Indonesia; Kyoto Mechanisms; Kyoto Protocol.

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Delaware

THE FIRST OF the 13 original states to ratify the Constitution of the United States, Delaware ranks 45th in population among the states in the United States, although it is the fourth most densely-populated state. Delaware's energy consumption reflects the same pattern. Total consumption is among the lowest in the United States, 47th in rank, but per capita energy consumption is disproportionately high. In 2003, the state ranked 17th highest among the 50 states. Delaware's high consumption of energy can be attributed, in large part, to its energy-intensive industries such as chemical production and paper and plastic products. Ground-level ozone concentrations are at dangerous levels throughout the state.

Delaware, according to records of the Environmental Protection Agency, is one of the nation's leaders in releases of mercury, dioxin, polychlorinated biphenyls, and vinyl chloride, all among the most toxic substances released by industry. Among the companies most frequently named as the leading polluters in the United States, more than 50 percent of them now operate, or have operated, in Delaware. The state spent more than $29 million in 2007 cleaning up contaminated sites.

Carbon dioxide emissions from industry has decreased modestly from 1990 to 2004. Industry continues to be the state's leading consumer of energy, at almost 40 percent, which is nearly double that of the transportation sector. Most of that energy comes from fossil fuels. Transportation, saw only a slight decrease in CO_2 emissions from 1990 to 2004. The state has taken some action to reduce emissions more substantially in the future. Delaware has a vehicle inspection and maintenance program that is in compliance with Clean Air Act policies. The state requires the statewide use of reformulated motor gasoline blended with ethanol, one of the few states to do so. The state's mass transit system is ranked the eighth best in the nation.

COASTLINE AND WETLANDS

Rising sea levels and the accompanying problems are major concerns, as every part of Delaware is within 20 mi. (32 km.) or less of the Atlantic Ocean or the Delaware Bay. Sea level is already rising by 12 in. (30 cm.) per century in some parts of the state, and beach erosion is a growing problem along the state's 381 mi. (613 km.) of shoreline. Delaware made early efforts to respond to the problems of global warming. Legislation to protect shore areas was passed as early as the 1970s, and in 2000, a State Climate Action Plan that placed the state in line with the Kyoto Protocol called for a 7 percent decrease in greenhouse gas emissions from a 1990 baseline. However, amendments weakened coastline protection, and the state has been slow to act upon the recommendations of the Climate Action Plan.

Delaware limits construction on its coastline, and it has spent millions in federal and state funds restoring beaches that have eroded. But shoreline erosion continues, and researchers believe it will only intensify as sea levels rise from global warming. Sand replenishment will become a never-ending and increasingly expensive project. Delaware Bay, the large semi-enclosed inlet of the Atlantic Ocean at the mouth of the Delaware River, is a major spawning ground for horseshoe crabs and the site of the second largest concentration of migratory shorebirds in the western hemisphere, with approximately 1.5 million shorebirds passing through the bay area each spring. The area also supports a number of endangered and threatened species including the bald eagle, the peregrine falcon, and the short-eared owl. Changes to habitat wrought by global warming threaten all these species.

Rises in sea level have already changed the composition of salt marshes and decreased the number of ducks and geese. Between the 1880s and the 1980s, Delaware lost more than 50 percent of its wetlands. The Clean Water Act, combined with the state legislature's measures to protect the wetlands, decreased the rate of loss, but development pressures continue, and rising sea levels could pose an even greater threat to this resource.

GOVERNMENT ACTION

One of the measures that Delaware's 2000 Climate Action Plan called for was a renewable portfolio standard and a strategy to switch to low-carbon fuels. Without this change, the committee felt that the state was unlikely to reach its goal of greenhouse emissions reduction, a goal that required the state to reduce emissions by 15 to 25 percent over what was then a 12-year period in order to meet the 7 percent reduction target based on 1990 figures. In 2003, Delaware, along with Connecticut, Maine, New Hampshire, New Jersey, New York, and Vermont, became one of the original seven states to participate in the Regional Greenhouse Gas Initiative (RGGI), the first cap-and-trade program to control CO_2 emissions in the United States. A primary goal of the collaborative effort is to reduce CO_2 pollution through a mandatory emissions cap on the electric generating companies, the heaviest contributors to pollution.

In summer 2007, Delaware took the state's most decisive steps toward addressing the problems of global warming and climate change. In late June, Governor Ruth Ann Minner signed Senate Bill 18 and created a Sustainable Energy Utility, a state-supervised nonprofit organization. The bill was based on a concept developed, in part, by John Byrne, distinguished professor of public policy, director of the University of Delaware's Center for Energy and Environmental Policy, and a member of the Intergovernmental Panel on Climate Change (IPCC). The plan proposes to cut CO_2 emissions to 2003 levels through conservation and innovative use of renewable energy sources, and save the average Delaware household $1,000 a year in the process.

A month later, Governor Minner signed a bill that increased the state's existing renewable portfolio standard by requiring that 2 percent of the state's electricity supply come from solar photovoltaics by 2019, in addition to 18 percent from other renewable sources by the same date. The other sources may include wind, ocean tidal, ocean thermal, fuel cells powered by renewable fuels, hydroelectric facilities with a maximum capacity of 30 megawatts, sustainable biomass, anaerobic digestion, and landfill gas.

SEE ALSO: Intergovernmental Panel on Climate Change (IPCC); Kyoto Protocol; Sea Level, Rising; University of Delaware.

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Denmark

DENMARK IS A small, flat, highly-industrialized country with a population of 5.4 million (2006 est.). A member of the European Union, it is situated in the northern part of the European continent and is nearly surrounded by the sea. Denmark normally experiences relatively cold summers and warm winters, which places Denmark in the temperate climate zone. The country's greenhouse gas emissions amount to 62.5 million metric tons of CO_2 equivalents (2005 est.). The primary sources of Danish greenhouse gas emissions are energy (51 percent), transportation (27 percent), agriculture (16 percent), and industry (4 percent).

This windmill in Denmark is part of the country's ongoing effort to cut its CO_2 emissions, which fell 7 percent 1990–2005.

Since 1870, the average Danish temperature has risen by 1.8 degrees F (1.0 degree C), and annual precipitation by 4.33 in. (110 mm.). Scientists expect that the climate of Denmark will become warmer, wetter, and windier; changes that will have consequences for agriculture, an important sector in Denmark. Crops will change and farmers will achieve higher yields. On the other hand, there would potentially be a need for increased fertilizer application, as higher rainfall would lead to higher nutrient loss. Increasing the application of fertilizers would have negative implications for the ecological quality of lakes and watercourses.

Predictions are that before 2100, the temperature of seawater surrounding Denmark will rise 5.4–9 degrees F (3–5 degrees C) and the sea level around the Danish coastline will rise approximately 19.7 in. (50 cm.). If this proves true, improved coastal protection will be required. Furthermore, biodiversity will be affected. Some Danish species will disappear, and new species will arrive. Ecosystems, for example the protected Wadden Sea, may be seriously impacted by rising sea levels.

At the end of the 1980s, environmental matters topped the electorate's agenda for the first time. From 2000 until 2006, both the electorate's and politicians' attention had shifted away from environmental matters. However, a new awakening occurred during fall 2006. Suddenly, newspapers reported that the climate change issue had skyrocketed on the electoral agenda.

A public opinion poll showed that 14 percent of the electorate perceived climate change as the most important political problem to solve, and that 12 percent considered the issue as the second most important political problem. Furthermore, 75 percent of the respondents agreed that Denmark should be a front-runner in solving the climate change problem, even if there are substantial costs involved. Another opinion poll, in February 2007, showed that 80 percent of respondents recognized that they had joint responsibility for climate change problems, and 86 percent believed that every Dane had a responsibility to save energy to reduce climate change problems.

Denmark signed the United Nations Kyoto Protocol in 1998, and ratified the agreement in 2002. According to the Kyoto Protocol and the EU Burden Sharing Agreement, Denmark is committed to reducing greenhouse gas emissions by 21 percent during the period from 1990 to 2008–2012. Denmark has succeeded in cutting total greenhouse gas emissions by 7 percent 1990–2005 (calculated according to the IPCC guidelines), despite the fact that emissions from transportation have increased significantly. The reductions have been reached, for instance, by introducing a CO_2 tax in 1992, which, according to an evaluation, has proven that environmental improvements are possible without sacrificing economic welfare.

Furthermore, Denmark has increased the production of renewable energy from offshore windmills, and Denmark has joined the European Union's scheme for climate gas emission trading. Finally, the Danish government emphasized the Kyoto Mechanisms, Joint Implementation and Clean Development Mechanism projects, as cost-effective means to reach the Danish reduction goal. Therefore, resources have been set aside to buy CO_2 credits through these mechanisms. Denmark is hosting the UN climate summit (COP 15) in 2009 in Copenhagen.

SEE ALSO: Agriculture; European Union; Kyoto Mechanisms; Public Awareness; Sea Level, Rising.

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Department of Defense, U.S.

THE U.S. DEPARTMENT of Defense (DOD) is the largest employing organization in the country. It serves in the management and organization the United States Armed Forces and actively works to maintain environmental responsibility while fostering global security. In the United States, the Department of Defense also manages its lands that are federally-owned. As of the mid-1990s, 39,063 sq. mi. (101,173 sq. km.) of U.S. land were owned by the military and, therefore, the Department of Defense.

In an effort to protect the environment, the Department of Defense began cutting back its energy usage in the mid-1980s. Furthermore, it actively reduced the amount of greenhouse gases emitted due to Department activities, in recognition that greenhouse gases have an impact on climate change. The Department of Defense also assisted with research to develop safe alternatives for ozone-depleting chemicals, such as halon. Additionally, by the mid-1990s the DOD had achieved and passed the goal for limited chemical usage amounts as outlined by the Montreal Protocol. The DOD worked with the Environmental Protection Agency (EPA) to reach these goals before the Montreal Protocol's suggested deadline.

In recognition of these extensive efforts to protect the environment, the EPA honored the Department of Defense and Secretary of Defense William S. Cohen, with its Best-of-the-Best Stratospheric Ozone Protection Award. This Award was given at the September 25, 1997, EPA Awards Ceremony. In fact, at the awards ceremony, the EPA Administrator Carol Browner announced that the Department of Defense was the leading world organization in terms of quantity of awards from the EPA, for ozone layer protection. At this ceremony, the Department of Defense and other award recipients were named as "Champions of the World".

In acceptance of the Stratospheric Ozone Protection Award, Secretary Cohen stated that aligning environmental stewardship with national security was a chief priority of the Department of Defense. In fact, out of the 71 awards given at the ceremony, one-fifth went to members of the military community, including military organizations, contractors, and the employees of both. At the awards ceremony, Carol Browner said the following words that outline the EPA's and Department of Defense's stance on global warming; she later stressed that global warming could be fought without economic disaster.

> More than 2,000 of the world's foremost experts on the global environment, internationally recognized scientists, are telling us that there is ample evidence that for the first time in history, pollution from human activities is, in fact, changing the Earth's climate. Modern industrial activity, particularly the burning of fossil fuels, coal, petroleum products, is filling the atmosphere with carbon dioxide and greenhouse gases. These gases trap the sun's heat in the atmosphere and cause the steady, gradual warming of the earth's surface temperature. The average surface temperature is slowly rising, and the scientists tell us that there will be devastating consequences to our environment within the next 100 years. They're predicting more frequent, more intense heat waves; thousands more heat-related deaths; severe droughts; floods will become more common; tropical diseases like malaria will expand their range; agricultural production will suffer; the oceans will rise perhaps by several feet over the next century swamping many coastal areas. This will be our legacy to our children if we do not look for some way to begin reducing our emissions of greenhouse gases.

As of the late 1990s, the Department of Defense was researching new aircraft that would use less fuel, while being more energy-efficient. These aircraft were being researched at many institutes, including the U.S. Army, U.S. Navy, U.S. Air Force, the National Aeronautics and Space Administration (NASA); the Defense Advanced Research Projects Agency (DARPA), and engine companies in the United States.

PIVOTAL AGENDA POINTS

On June 2, 2007, Secretary of Defense Robert M. Gates answered questions at the Shangri-La Security Conference. This conference focused on assisting the development of Asian nations, such as India and the Pacific nations, and connecting them with the rest of Asia. A principal goal of the conference was to foster maritime security in the Asian Pacific. Participating nations came from the Asian Pacific nations as well as Canada, the United Kingdom, and the United States. In an answer to a question regarding the projected key issues in the United States–Asian Pacific (mainly Singapore), relationship for the year 2011, Secretary Gates responded that, in the future, the environment and, particularly, global warming will be pivotal agenda points.

Maritime security and the impacts on it from global climate change are a concern at the Department of Defense.On September 26, 2007, in an article from the American Forces Press Service regarding the increased use of sea transport for trade due to growing shoreline populations around the world, the Department of Defense acknowledged that a Northwest Passage, a maritime route via the northern North American coastline through the Arctic Ocean, had opened. This new passage opened due to climate change.

To advise the U.S. President about current and novel science and technology related to climate change, the Secretary of Defense as well as the Secretary of Commerce alternate in heading a committee known as the

Committee on Climate Change Science and Technology Integration (CCCSTI).

The Department of Defense has had a long history—older in fact than the United States. At the time of the American Revolution in 1775, the group of colonies that would soon become the United States of America established an Army, Navy, and Marine Corps. By 1789, the government recognized the need for a centralized office for these military programs, and thus, established the War Department. The War Department would eventually become the Department of Defense nearly 200 years later.

1790 saw the generation of the Coast Guard, which now acts to maintain homeland security in times of peace. Eight years later, in 1798, a separate Department of the Navy was formed. It was not until the year 1947 that a civilian position was set up by Congress to act as Secretary of Defense, initially intended to serve in the Presidential Cabinet. The War Department became the Department of the Army, and the U.S. Air Force separated from the Army into its own division. The three branches of the new Department of Defense became the Army, Navy and Air Force. In the year 1949, the Department of the Army officially became the official DOD.

SEE ALSO: Canada; Department of Energy, U.S.; Department of State, U.S.; Environmental Protection Agency (EPA); Globalization; Greenhouse Effect; Greenhouse Gases; India; Montreal Protocol; National Aeronautics and Space Administration (NASA); Singapore; United Kingdom.

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Department of Energy, U.S.

THE MISSION OF the U.S. Department of Energy is: "to advance the national, economic, and energy security of the United States; to promote scientific and technological innovation in support of that mission; and to ensure the environmental cleanup of the national nuclear weapons complex." To achieve this mission, the Department of Energy (DOE) has outlined five strategic themes: energy security, nuclear security, scientific discovery and innovation, environmental responsibility, and management excellence.

To the DOE, environmental responsibility most generally means responsibly protecting the environment from the impact of production of nuclear arms. Therefore, a chief role of the Department of Energy within the environmental sector is to clean and decontaminate sites of nuclear power production or use. To advise the U.S. president about current and novel science and technology related to climate change, the secretary of defense as well as the secretary of commerce alternate in heading a committee known as the Committee on Climate Change Science and Technology Integration (CCCSTI), not the secretary of energy. Within the Department of Energy, the Office of Fossil Energy manages plans to reduce carbon emissions.

WATCHDOG OFFICE

The Office of Policy and International Affairs, a part of the Department of Energy, is the watchdog office for climate change. Within this Office, there are six initiatives regarding global warming and climate change. These initiatives are the Carbon Sequestration Leadership Forum, the Clean Energy Initiative, Climate VISION, Greenhouse Gas Reporting Guidelines, the Security and Prosperity Partnership / North American Energy Working Group , and the U.S. Climate Change Technology Program.

The Carbon Sequestration Leadership Forum (CSLF) is composed of a group of nations that produces approximately three quarters of the man-made global carbon dioxide emissions. It was established in 2003. This voluntary membership forum was recognized by the G-8 summit in July 2005 as a key mediator of international communication regarding the climate and climate change. This recognition was in the Gleneagles Plan of Action on *Climate Change,* *Clean Energy and Sustainable Development.* By combining economics, industry, and research, the CSLF works to limit the amount of carbon dioxide release into the atmosphere. It does so in accordance with the United Nations Framework Convention on Climate Change. One plan is to store carbon instead of releasing it; carbon would be stored in the spaces left behind by underground oil fields as they are depleted. Initial research carried out by the DOE has suggested that these deep geologic storage chambers could store carbon produced within the next several centuries. Storage could also take place in geologic formations such as unmineable coal seams, global saline reservoirs, and basalt formations.

WORLD SUMMIT

The Clean Energy Initiative is overseen by the Office of International Energy Market Development, within the Office of Policy and International Affairs. The Initiative was announced by the United States at the September, 2002 World Summit on Sustainable Development, which took place in Johannesburg, South Africa. It was led by the United States, with participation from nations around the globe. There are three partnerships to address the chief headings within the Initiative: the Efficient Energy for Sustainable Development Partnership, the Global Village Energy Partnership, and the Healthy Homes and Communities Partnership.

Climate VISION stands for Voluntary Innovative Sector Initiatives: Opportunities Now. It was established on February 12, 2003, nearly one year after President George W. Bush announced on Valentine's Day of 2002 that he would reduce United States greenhouse gas emissions by 18 percent before the year 2012, without harming the economy. Climate VISION has five chief purposes: to develop methods for reducing greenhouse gas emissions and share these technologies, to develop ways to quantify greenhouse gas emission reduction and sequestration, to develop an infrastructure to promote usage of emission reduction technologies in the commercial sector, to develop a means by which energy consumers can reduce their carbon footprints, and to acknowledge voluntary public or private participation in emissions reduction.

A key partnership in the Climate VISION program is called the APP, for the Asia-Pacific Partnership between nations of this global region (Australia, China, India, Japan, and the Republic of Korea) along with Canada and the United States. The APP works to ensure that as these Asian nations develop, they will incorporate clean, environmentally-safe technologies into their public and private industries.

Greenhouse Gas Reporting Guidelines were updated in early 2007 and made accessible to the public on April 2, 2007. The complete name of the document is *The General Guidelines for the Voluntary Reporting of Greenhouse Gases (1605(b)).* These guidelines are under the auspices of the DOE and are part of the Code of Federal Regulations.

The Security and Prosperity Partnership (SPP) /North American Energy Working Group (SPP/NAEWG) is a partnership between the secretaries of energy of Mexico and the United States and the minister of natural resources of Canada. This partnership was first established in early 2001. The SPP was established by the presidents of Mexico and the United States and the prime minister of Canada on March 23, 2005. It works to promote environmental responsibility in policies, as well as protecting the food supplies of North America and preventing the spread of disease. There are three foci of the NAEWG: market facilitation, clean energy, and technology. Within each focus are initiatives and priorities that any country can propose, but all three must approve.

CLIMATE CHANGE TECHNOLOGY

The U.S. Climate Change Technology Program (CCTP) mission is: "to stimulate and strengthen the scientific and technological enterprise of the United States, through improved coordination of multiagency federal climate change technology programs and investments and, in partnership with others, provide global leadership to accelerate the development of new and advanced technologies that would attain its vision." It was established by President George W. Bush.

In September 2007, the secretary of the Department of Energy appointed a new position for a director of a new Office of Indian Energy Policy and Programs. This new office and director were given the responsibility of assisting Native Americans in learning about, establishing, and maintaining efficient energy sources.

Along these lines, the office was set to manage a $2 million grant for promoting renewable energy sources that would be used by 15 pre-selected Native American nations, including Alaskan villages. Of these 15 groups, nine will begin to establish renewable energy sources, while the other six will research the feasibility of such a project on their lands.

The Department of Energy's Solar Energy Technology Program recognizes that burning of fossil fuels releases carbon dioxide and other greenhouse gases that contribute to global warming. This program, part of the Office of Energy Efficiency and Renewable Energy, therefore, works to make clean solar energy available to regions that previously relied on fossil fuels.

Specifically, the program champions photovoltaic (PV) energy converters that transform solar energy into electricity via superconductors. The program also investigates the themes of concentrating solar power to run turbines that would generate electricity, solar heating whereby solar energy is used to heat water or building spaces, and solar lighting which integrates directed natural sunlight into building lighting schemes.

A major initiative of the Office of Energy Efficiency and Renewable Energy is the Solar America Initiative, which aims to bring photovoltaic energy technology up to par with current fossil fuel technologies, so that it will be cost-competitive by the year 2015.

SEE ALSO: Australia; Bush (George W.) Administration; Canada; Carbon Dioxide; Carbon Emissions; Carbon Sequestration; Carbon Sinks; China; Department of Defense, U.S.; Department of State, U.S.; Energy; Energy, Renewable; Energy Efficiency; Framework Convention on Climate Change; Greenhouse Gases; India; Japan; Korea, South; Mexico; United Nations.

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Department of State, U.S.

THE AREAS OF responsibility of the Department of State are the United States' foreign policy. Also, how foreign policy may impact U.S. security. Therefore, its interests in global warming and climate change are only to the degree that these phenomena may affect international policy or national security.

According to a June 2007 Report to Congress, called *The Senator Paul Simon Water for the Poor Act 2005 (P. L. 109-121)*, "Climate variability is a measure of the degree to which rainfall and temperature vary across seasonal, annual, interannual and even interdecadal time periods compared with a long-term regional climate mean. Climate change refers to long-term, sustained changes in the climate mean itself." This document states that United States' interests in climate change is strategic because climate change affects water levels, cleanliness, and its availability to poorer nations. The long-term impact of inadequate water in these nations could affect United States' interests, because this could negatively impact their public health which could create unstable governments.

President Bill Clinton strongly supported environmental responsibility. His administration created a new Department of State position to watchdog international environmental conditions, the Undersecretary for Global Affairs. In this way, the foreign policy of the U.S. became concerned with the environment and its stewardship. The position of Undersecretary for Global Affairs was first given to Timothy E. Wirth, a former green senator from Colorado. Wirth served in this position from 1993 until 1997. Following with this environmentalist spirit, Secretary of State Warren Minor Christopher issued a statement on February 14, 1996, stating that U.S. foreign policy would, from that point on, keep the environment and its care in focus, and that Department of State officials must consider this focus when designing international policies or meetings. Like Wirth, Christopher served in his position between the years 1993 and 1997.

A chief concern of President George W. Bush, along with the Department of State, is the reduction of the U.S. dependence on foreign oil. As a fortuitous side effect, through the investigation of other routes of energy generation, science and technology lead towards energy sources that are cleaner and more environmentally responsible than the burning of fossil fuels. In May 2007, President Bush pledged to have a plan by the end of the year 2008, which would encompass an international effort to reduce climate change, with efforts to begin in the year 2012. Countries involved would be major developed and developing countries; in other words, those countries that produce and emit the greatest quantities of greenhouse gases. The United Nations would also be included in this process. To this end, a meeting took place in September 2007 between leaders of the invited nations: Australia, Brazil, Canada, China, India, Indonesia, Japan, Mexico, Russia, South Africa, and South Korea, as well as the United States, the United Nations, and the European Union.

REDUCED EMISSIONS

President Bush stated that the United States will reduce its emissions of greenhouse gases in relation to the size of its economy. Therefore, greenhouse gas intensity was defined as greenhouse gas emissions per unit of economic activity; overall greenhouse gas intensity was to be reduced by 18 percent by the year 2017.

As a member of the Asia–Pacific Partnership on Clean Development and Climate (APP), along with Australia, Canada, China, India, Japan, and South Korea, the United States works to ensure that as these Asian Pacific nations develop, they will incorporate environmentally-responsible technologies into their economies and infrastructures.

The APP is a significant team of nations because it represents approximately one half of the world's population and the same percentage of its economy. The APP has eight task forces: Aluminum, Buildings and Appliances, Cement, Cleaner Fossil Energy, Coal Mining, Power Generation and Transmission, Renewable Energy and Distributed Generation, and Steel.

In 2008, in recognition of the 2007–09 International Polar Year, Under Secretary of State Paula Dobriansky traveled to the dedication ceremony for the Amundsen–Scott Station, a new scientific research unit at the South Pole on Antarctica. The station is run by the United States Antarctic Program (USAP), and is the third of its kind at the South Pole since the first station opened in 1956. Research conducted at the Amundsen–Scott Station will be used to analyze climate change, the ozone layer, glacial dynamics, and the universe at large. Antarctica was established as a protected area for peace and science. in the year 1959, by the Antarctic Treaty. The activities of the United States in Antarctica are managed by the United States Department of State in conjunction with the National Science Foundation.

The U.S. Department of State was established on July 27, 1789, as the Department of Foreign Affairs. It was created by the Senate and the House of Representatives in order to assist the president in maintaining international relations, and for purpose of national security. In September of the same year, the name was changed to the Department of State. It is also commonly referred to as the State Department. Today, the State Department is located in the Harry Truman Building in Washington, D.C., and in 2007 ran on an annual budget of approximately $35 billion.

SEE ALSO: Antarctic Circumpolar Current; Antarctic Ice Sheets; Antarctic Meteorology Research Center; Australia; Brazil; Bush (George W.) Administration; Canada; China; Climate Change, Effects; Clinton Administration; Department of Defense, U.S.; Department of Energy, U.S.; European Union; Glaciers, Retreating; Glaciology; Greenhouse Gases; India; Indonesia; Japan; Korea, South; Mexico; National Science Foundation; Policy, International; Policy, U.S.; Russia; South Africa; United Nations.

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Desertification

IN THE UNITED Nation's Convention to Combat Desertification (UNCCD), desertification is defined as "land degradation in arid, semi-arid and dry subhumid areas resulting from various factors, including climatic variations and human activities." This land degradation is defined as a:

> reduction or loss in arid, semi-arid and dry subhumid areas, of the biological or economic productivity and complexity of rain-fed cropland, irrigated cropland, or range, pasture, forest and woodlands resulting from land uses or from a process or combination of processes including processes arising from human activities and habitation patterns, such as soil erosion caused by wind and/or water, deterioration of the physical, chemical and biological or economic properties of soil, and long-term loss of natural vegetation.

In a more complex understanding, desertification also involves land-use change in pastoral and agricultural dryland systems, due to environmental pressures.

Many assessments have been conducted on desertification, each as varied as the indicators that they have been based upon. The most recent one is the Land Degradation Assessment in Drylands (LADA assessment) of the Food and Agriculture Organization of the United Nations (FAO). In the World Atlas of Desertification, based on the Global Assessment of Human-induced Soil Degradation (GLASOD) Assessment on human-induced soil degradation: drylands are characterized as the zones having a ratio of average annual precipitation to potential evapotranspiration (P/ETp) between 0.005 and 0.65, which includes semiarid and arid areas. Hyper-arid zones are not part of the United Nations Convention to Combat Desertification (UNCCD) desertification definition because they are presumed to be so dry that human degradation is severely limited unless irrigation is practiced.

Arable land resources of north Africa and west Asia are being pressured by overgrazing, combined with an extension of the cropped area, and by salinization caused by dam and irrigation systems such as in the Nile Delta. Dryland degradation is widespread in sub-Saharan Africa, northern China, Australia, northeastern Brazil, the Carribean islands; many other dryland areas have experienced damage from deforestation and overgrazing in the drylands. Also, in Europe, degradation is significant in the southern Mediterranean zone.

The complexity of definitions make mapping desertification difficult, but according to 2003 data from the UNCCD and WDA, 70 percent of all cultivated drylands are affected by desertification, and 17 percent are already desertified. 24 billion tons of topsoil is lost every year to desertification, which affects the livelihoods of 250 million people. Only 22 percent of global drylands have degraded soils, this figure increases to 70 percent when vegetation degradation is added. The dryland subtype that is most degraded is the arid subtype, whereas in regions with smaller overall dryland area, the semiarid drylands (the Americas), or the dry subhumid ones (Europe), are the most degraded, respectively. However, within these data it is also difficult to distinguish between states and processes. Africa is particularly vulnerable, with around 60 percent of its total area covered by desert or drylands. The United Nations Environment Programme (UNEP) notes that the extent of desertification is increasing worldwide: "desertification currently affects approximately 25 to 30 percent of the world's land surface area. About 1.2 billion people in at least 100 states are at risk."

LINK TO CLIMATE CHANGE

Climate-simulation models indicate substantial future increases in soil erosion. Desertification will be exacerbated by reductions in average annual rainfall and increased evapotranspiration, especially in soils that have low levels of biological activity, organic matter, and aggregate stability. Desertification and climate can form a "feedback loop," with the loss of vegetation caused by desertification reducing carbon sinks and increasing emissions from biodegrading plants.

Soil degradation begins with removal of vegetation. Unprotected, dry soil surfaces are readily eroded by rain and wind, leaving infertile lower soil layers that bake in the sun and become an unproductive hardpan. Sand dunes may form where the blown surface material accumulates. Water is a defining constraint of the drylands. Drought avoidance and coping strategies are imperative, such as choosing drought-tolerant crops, low plant densities, water conservation, and water harvesting. While water shortage is a constant concern, much of the water that is available is not efficiently used. In the Sahel, degraded soils often exhibit impeded water infiltration, so much is lost as runoff.

Given the uncertainty in the models, some models still project other outcomes, such as the regreening of the Sahel zone. Nevertheless, a loss of vegetative productivity can lead to long-term declines in agricultural yields, livestock yields, plant standing biomass and plant biodiversity, changes that reduce the ability of the land to support people. While before, even in adverse areas people in drylands were able to cope with the cycles of droughts without depleting soils, now, with the extension of droughts due to climate change, these systems became vulnerable to breakdown, often sparking an exodus of rural people to urban areas. Breaking the strong connection of people to the land produces profound changes in social structure, cultural identity, and political stability.

Desertification also impacts remote areas, and has silted-up rivers and retreated lake surfaces far away from its origin. Since the early 1950s, 670,000 ha. of arable land and 2.35 million ha. of rangeland, steppe, and grassland were invaded by shifting sands. Dust storms created as a result of destroyed vegetative cover led to air quality problem, and acid, rain elsewhere.

SEE ALSO: Agriculture; Deforestation; Deserts; Rain; Rainfall Patterns.

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Desert Research Institute

THE DESERT RESEARCH INSTITUTE (DRI) is the nonprofit research arm of the Nevada System of Higher Education (NSHE), with primary research campuses in Las Vegas and Reno and additional campuses in Boulder City, Nevada, and Steamboat Springs, Colorado. The DRI combines the academic world and entrepreneurialism, and faculty members are responsible for securing resources for their salaries. DRI faculty members do not receive state support, nor are their positions tenure-track. The DRI employs more than 500 faculty, support staff, and students who are engaged in one of approximately 300 projects producing about $50 million in total annual revenue. The DRI has an extensive list of private, public, and academic partners and ranks as one of the top 50 recipients of grants in Nevada.

Atmospheric Sciences, Earth and Ecosystem Sciences, and Hydrologic Sciences comprise the principal divisions of the DRI, and the four interdisciplinary centers include those for Advanced Visualization, Computation, and Modeling; Arid Lands Environmental Management; Watersheds and Environmental Sustainability; and Environmental Remediation and Monitoring. The DRI is committed to the effective oversight and management of Nevada's resources, balancing the development of the resources of Nevada with the protection of its environment and meeting the needs for economic expansion and science-based educational programs.

The DRI's educational programs offer environmental programs, including ecology, atmospheric sciences, hydrology, fundamental health and sciences, as well as environmental literature, agriculture, mining, and engineering. The Desert Research Libraries at Las Vegas and Reno maintain collections and services to support the DRI scientific community and other scholars. Resources include archival materials, aerial photographs, the DRI reports, maps, posters, and safety videotapes. One of the academic programs with which the DRI is affiliated is the Academy for the Environment, established in 2004, at the University of Nevada, Reno (UNR), as a multidisciplinary institute aimed at developing, enhancing, and coordinating environmental teaching, research, and service at the university. The faculty of the DRI are integral through teaching in the atmospheric sciences, ecology, evolution and conservation biology, environmental sciences and health, and hydrologic sciences graduate programs.

The DRI, the University of Nevada, Reno (UNR), Sierra Nevada College in California, and the University of California, Davis (UC Davis), have formed a unique partnership offering intensive courses on the environment and sustainability, at the Tahoe Center for Environmental Sciences (TCES). The Storm Peak Laboratory (SPL), constructed during the summer of 1995 and operated by the Atmospheric Sciences Center of the Desert Research Institute, provides an opportunity for students ranging from middle school through graduate school to participate in basic and applied science. The DRI faculty members teach a course in Atmospheric Sciences at the University of Nevada that includes two weeks of field research at the Storm Peak Laboratory. Students gain experience in proposals and project planning.

Students from kindergarten through senior high school have benefited from curriculum development sponsored by the DRI. During summer workshops, kindergarten–12th grade science teachers designed portable instruction modules to be circulated continuously to teachers throughout Nevada for the Desert Research Institute's Science Box Traveling Kits Program. Instructional science topics were based on Nevada's state guidelines for required science education. In 1999, a grant allowed teachers from Arizona, California, Idaho, Oregon, and Utah to participate in the workshop program and return to their states to advocate for similar Science Box programs.

Dr. Joseph R. McConnell, a snow hydrologist from the DRI, received a grant from the National Aeronautics and Space Administration to analyze whether forces other than global warming could be responsible for changes in snowfall and melting in Greenland. McConnell and his colleagues will examine extracted ice cores to determine if recent patterns in Greenland correspond to natural cycles in North Atlantic weather. The study is significant because extreme melting in Greenland has impacts reaching far beyond its own boundaries. Among other priorities of the DRI is research focused on the preservation of Lake Tahoe, Lake Walker, and Lake Mead. Additionally, DRI research efforts have included the investigation of air quality conditions at Ground Zero in the aftermath of 9/11, and working in partnership in west Africa to bring potable water resources to rural villages. Future work includes studying remote sensing to predict environmental change and assist in resource planning.

SEE ALSO: Nevada; University of California.

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Deserts

DESERTS ARE AN environmental extreme, characterized by low rainfall that is highly variable intra-annually and interannually, with a coverage of about 27.7 $Mkm.^2$, equivalent to 35 percent of the earth's surface and, thus, representing one of the largest terrestrial biomes. They occur mainly within latitudes between 5–35 degrees north of the equator and are characterized by very high aridity, very little vegetation cover and large surfaces of exposed bare soil, and high adaptations of plants and animals for survival during long droughts. According to bio-ecological definitions, the world's deserts represent all ecoregions of the world that harbor desert vegetation, identified by the xerophilous life-forms and the general desert-adapted physiognomy of the dominant plants.

Desert climate is characterized by precipitation of less than 9.84 in. (250 mm.) with very high variability, high diurnal variations of temperature, and strong solar radiation. Desert air is very dry; incoming solar and outgoing terrestrial radiation are intense, with large daily temperature fluctuations; and potential evaporation is high. Extreme desert systems already experience wide fluctuations in rainfall and are adapted to coping with sequences of extreme conditions.

Deserts can be hot or cold. Among the hot deserts are ones with two rain seasons (Sonora desert, Karoo); with one rainy season (Northern Sahara, Mohave Desert, Middle-Asian deserts); deserts with summer rain (Southern Sahara, inner Namib, Atacama); deserts with few rains at any season (Central Australia); coastal deserts without rains, but with fog (North Chilean coastal deserts, outer Namib); and deserts without any rain or vegetation (Central Sahara). The Sahara in north Africa and the Namib desert in southwest Africa are classified as the hottest deserts in the world, with average monthly temperatures above 86 degrees F (30 degrees C) during the warmest months and extremes above 122 degrees F (50 degrees C). The diurnal temperature range often is large; winter nights in the Namib Desert sometimes are as cold as minus 14 degrees F (10 degrees C) or lower.

Aridity is the most prominent indicator, commonly measured by the Aridity Index, an estimator for the ratio between mean annual precipitation and mean annual potential evapotranspiration, which is less than -40 for arid deserts and -20 for semi-deserts. Aridity is highest in the Saharan and Chilean-Peruvian deserts, followed by the Arabian, East African, Gobi, Australian, and South African deserts, and lower in the Thar and North American deserts. This high aridity, as well as typical pulse-type variations in desert environments, are caused by global atmospheric and oceanic phenomena, such as the position of the jet streams, the movement of polar-front boundaries, the intensity of the summer monsoon, El Niño Southern Oscillation events, and even longer-term ocean cycles, such as the Pacific Decadal Oscillation.

CLIMATE CHANGE

Driven by these large-scale forces, the intensity and frequency of rain pulses at a local scale may vary substantially with time, and future projections indicate an increasing likelihood of even more episodic climate events and inter-annual variability in deserts. Continental deserts could experience more severe, persistent droughts. In the Americas, temperate deserts are projected to expand substantially under doubled CO_2 climate scenarios. About one third of the Sahel was projected to aridify with warming of 2.7–3.6 degrees F (1.5– 2 degrees C) by about 2050, with a general equatorward shift of vegetation zones. Alternative climate scenarios show less pronounced changes, even shifts to wetter climates in the Sahel zone and movement of vegetation zones, accordingly. The potentially positive impact of rising atmospheric CO_2 remains a significant uncertainty, which also could offset current projections, especially because it is likely to increase plant productivity, leading to contrasting scenarios.

Deserts also play an important role in the regulation of climate, air quality, and atmosphere composition of remote areas through wind-blown desert dust; also the desert albedo influences rainfall and biogeochemistry of other terrestrial and marine ecosystems, in this way increasing vulnerability of remote regions to climate change. The 4th Intergovernmental Panel on Climate Change (IPCC) assessment projects increased dust flux rates, which may increase aridity and suppress rainfall outside deserts, with opposite effects under wetting scenarios, associated with a decline of atmospheric burden by soil aerosols of 20–60 percent. Changes of rainfall in deserts are projected to be in the range of 0.2 mm. day-1.

EROSION

Typical desert soils are aridisols, characterized by little weathering of the maternal rocks and low organic matter in the surface layer, formed under the typical influences of desert conditions by strong winds, scattered but torrential rains, and high temperatures. The materials in these soils are often cemented together forming water-impervious hardpans, sometimes containing salts or gypsum. The low soil cover exposes deserts to more wind erosion than any other environment, and to water erosion, as well, if slopes are steep and rain does fall. Desert landscapes come in two categories: shield deserts and mountain-and-basin deserts.

Very low biomass cover is very likely to make some desert dunes susceptible to aeolian erosion, and, with regional warming of between 4.5–6.3 degrees F, (2.5–3.5 degrees C) most dune fields could be reactivated by 2100. About 10–20 percent of deserts are ecologically degraded by an imbalance between demand and supply for ecosystem goods and services. Because of the extremely slow rate of biological activity in deserts, these ecosystems take decades, if not centuries, to recover from even slight damage. Moreover, because traditional livelihoods in deserts require large areas, they are particularly vulnerable to political and environmental changes. Irreversible damages have been caused in previously good agricultural grounds in deserts by large-scale modern developments, such as dam construction for water and energy supplies.

BIODIVERSITY

Previous, present, and future climate regimes structure desert ecosystems in a way that requires a physical and behavioral adaptation to the patch dynamics of primary production, water, and nutrient cycling in space and time. During pulses of bounty, the fragile seedlings of desert plants can germinate, establish, and prepare for long droughts, burying their roots deep into the desert soils and, to a large extent, it is this heterogeneity of pulses that drives the high biodiversity of desert ecosystems. Many organisms in the deserts already are near their tolerance limits. Desert biodiversity is likely to be vulnerable to climate change, especially in biodiversity "hotspots," such as in the succulent Karoo biome of South Africa, where 2,800 plant species face potential extinction as bioclimatically suitable habitat is reduced by 80 percent with a global warming of 2.7–4.9 degrees F (1.5–2.7 degrees C).

Deserts support about 10 people per sq. km. Humans in deserts undergo considerable dehydration, and therefore, have to cope with the dry environment for their survival with a panoply of behavioral, cultural, and technological adaptations. Traditionally, desert-dwellers were of three types: hunter-gatherers, pastoralists, and farmers, whose livelihoods are adapted to the spatial and temporal patchiness of their environment. The movements of pastoralists, for instance, mimic the variability and unpredictability of the landscape and range reserves. Desert agriculture occurs mostly around oases and desert rivers, which often provide silt and nutrients through flooding cycles.

Finally, the specific aesthetic features and atmospheres of deserts, their silence, wideness, beauty, bareness, and emptiness has always created an intimate, spiritual relationship between humans and the desert landscape, leading to the creation of all three monotheistic religions in desert regions. They still remain places of spiritual inspiration and meditation today.

The Namib Desert can range from 14 to above 122 degrees F; such desert variations can be connected to global phenomena.

SEE ALSO: Agriculture; Deforestation; Desertification; Rain; Rainfall Patterns.

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Detection of Climate Changes

BECAUSE THE ATMOSPHERIC system is dynamic, variations in temperature and precipitation regimes have occurred throughout the Earth's history. Glaciations and deglaciations, for example, show how changeable climate can be. Detecting climate changes shows that climate differs significantly from some previous episode. Detection differs from attribution, which denotes the causes of those changes. While daily fluctuations in weather happen as a consequence of a chaotic atmosphere; climate fluctuations, based on smoothed aggregations of weather events, represent significant shifts in the longer-term averages. To discern these shifts, numerous techniques and methods are employed.

Climate changes, which occur at a variety of temporal scales, are assessed using both directly-observed and proxy data. Directly-observed information refers to meteorological and climate-related variables that have been directly evaluated, such as temperature measured by a thermometer, or cloud tops captured by satellite imagery. Directly-observed data have been used to chart recent increases in air temperature and carbon dioxide (CO_2), concentration, as evidenced by Charles Keeling's famous graph of climbing CO_2 concentrations at the Mauna Loa Observatory.

Proxy data are non-meteorological data, from which climate information is inferred; they serve as a satnd-in for such climate evidence when direct observations are not always available. Examples of proxy data include ice cores, lake sediments, and historical harvest records. Among the information gleaned from proxies are temperature, moisture, sea level, and chemical composition of the atmosphere. These facilitate the reconstruction of past climates.

Although directly-observed data may be preferable, the instrumental record is often too short for all but the most recent evaluations of climate changes. For example, the longest continuous temperature record shows monthly mean temperature only since 1659 (for central England); daily records for the same location extend only to 1772. Many other records are less than 100 years old. Temperature records also require filtering because of biases that may be present in the readings. The effects of urbanization, instrument upgrades, and location changes can result in false changes. Newer technologies, such as satellites, yield even shorter records. However, much climate change research assesses variability at temporal scales up to millions of years, rendering proxy evidence a necessity.

PROXY DATA

Proxy or substitute data extend climate change knowledge beyond the instrumental record, although there is a decreasing resolution and confidence with increasing time. Because climate variability has been identified at various temporal scales, the resolutions of the various proxies differ. Removing the climate signal and reconstructing past climates from them requires the proxy to be related to the climate. Therefore, some link between the two needs to be established; for example, by experimentation or construction of models.

Written historical records, such as harvest yields or military records, as well as diaries and phenological records, have been used to derive information. Temporal resolutions vary, from daily to annual. Farmers' diaries often discuss the weather. Grain harvests, for example, have been linked to precipitation. Dates of cherry blossomings in Japan can provide temperature trends. Historical records may be biased toward significant weather events (such as blizzards), so care must be taken when interpreting them.

TREE RINGS AND POLLEN

The study of tree rings, known as dendrochronology, can yield annual information on climate conditions for the past millennium or so. Every year, many tree species increase the diameter of their trunks by developing concentric rings formed by a layer of wood cells underneath the bark. While each ring corresponds to one year of growth, the spacing between successive rings is usually not uniform. This unevenness is due to differences in annual growth patterns, signifying climatic changes that have either encouraged or suppressed tree growth. Different tree species are sensitive to moisture and/or temperature changes. These environmental conditions can be inferred from the spacing and thickness of the tree rings. Relatively thick rings with a large spacing between successive rings indicate a more optimal growth setting, whereas narrower, tightly-spaced rings point toward climatic stress conditions (such as drought). Dendrochronology is limited to regions that continually support tree growth.

Another form of proxy data, derived from vegetation, comes from pollen and spores produced by plants. Wind can transport pollen grains to nearby water features, where they settle to the bottom and are preserved in sediment layers. Sediment cores extracted from lake beds are analyzed for the amount and type of preserved pollen found in successive sediment layers. Because pollen grains have unique features, plant types can readily be identified and, through techniques such as radiocarbon dating, indicate the time of deposition. Plant growth and distribution is sensitive to environmental conditions, providing an indicator of temperature and moisture trends on time-scales from centuries to millennia.

SEA-FLOOR SEDIMENTS AND ICE CORES

As with lake sediments, the layers or stratigraphy of oceanic deposits and corals can give important clues to paleoclimates. Sea-floor sediments are primarily an accumulation of calcium carbonate- ($CaCO_3$) based shells from organisms that once lived near the ocean surface. These organisms are often sensitive to changes in temperature and salinity, proliferating under optimal conditions and declining in unfavorable conditions.

Because the ocean surface is closely connected to sea-level climate conditions, the amount and type of shells found in the ocean core layers correlates well with atmospheric conditions when the organism died. Coral are small marine organisms that are also made of calcium carbonate, recording oceanic temperature conditions through their growth patterns. Like tree rings, coral thrive under certain conditions; coral are thicker during warmer, and thinner during colder, ocean episodes.

The calcium carbonate shells from ocean cores and coral are also source material for oxygen isotope analysis. This technique examines the ratio between two different isotopes of oxygen that are recorded in the skeletal remains of marine life. Ocean water contains two forms of oxygen molecules, the more common form with an atomic weight of 16 (^{16}O) and the atypical variety with an atomic weight of 18 (^{18}O). Water containing the lighter oxygen (^{16}O) isotope evaporates more readily than its heavier counterpart. This means that during periods of extensive glaciation, the amount of ^{18}O relative to ^{16}O in ocean water increases as more of the lighter oxygen isotope is precipitated out as snow, becoming concentrated in glacial ice. Conversely, the $^{18}O/^{16}O$ ratio decreases during warmer interglacial episodes, when surface runoff returns the ^{16}O previously stored in the cryosphere. Hence, oxygen isotope analysis is also useful for examining the precipitation layers of ice cores.

Taken from glaciated mountaintops and ice sheets, ice cores provide information on past climates in a variety of ways. Oxygen isotope analysis and the depth of snow accumulation in successive layers can give clues on temperature and moisture conditions. Major volcanic eruptions or meteorite impacts are often recorded as a significant layer of dust between ice layers; these episodes adversely impact surface insolation and global temperatures. Ice cores can also provide information on the past chemical composition of the atmosphere from small air bubbles trapped within. Depending on the length, ice cores enable reconstruction of past climates going back thousands of years.

SEE ALSO: Climate Forcing; Climatic Data, Atmospheric Observations; Climatic Data, Ice Observations; Climatic Data, Nature of the Data; Climatic Data, Proxy Records; Climatic Data, Sea Floor Records; Climatic Data, Tree Ring Records; Keeling, Charles David.

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Developing Countries

IN NUNAVUT, CANADA, Inuit hunting is at risk as the ice thins. For many developing countries the danger is from rising sea levels that submerge coastal land or, in the case of some small and low-lying Pacific islands, the country itself. These people have contributed the least to global warming, but they are the most at risk; and the risk is increasing. Seven of the 10 deadliest natural disasters of the past 20 years occurred between 2000 and 2006. Since July 2007, the European Commission has spend £24.5 million aiding victims of disasters in Colombia, the Caribbean, Peru, Kenya, India, Bangladesh, Nepal, North Korea, and the Sudan. The link between climate change and the intensity and frequency of natural disasters is now, finally, recognized.

As well as thinning Arctic ice and rising sea levels, global warming will also bring on heat waves that kill the elderly and sick. It will exacerbate asthma and other respiratory diseases, and heart problems, as body systems work harder to keep cool. And it will bring drought that reduces agricultural output and endangers water and food supplies. The heat will hit the developing world harder than it will the developed world. By 2020, between 75 and 250 million Africans will be without adequate water and sufficient food because crop output will drop about 50 percent. About 130 million Asians may also face food shortages.

A World Health Organization report says that climate change already kills at least 150,000 a year, and that the number will double by 2030. Global warming will increase infectious disease, particularly in tropical areas where increased temperature translates to increased mosquitoes and, thus, increased malaria, dengue, and other insect-borne diseases. Disease also affects the developed world, but richer countries can adjust to increased heat, and thus, reduce heat-stress related illnesses, by using new housing construction and air conditioning technology. Developing countries lack not only the technology, but also the financial resources and the public-health infrastructure.

AGRICULTURE

Global warming, if unchecked, will have, at least, moderate impacts on world agricultural output by late in the 21st. century, but these moderate impacts are more likely to occur in the developed world. The most severe damage will start earliest, and it will hit the areas that can least afford it. Shortfalls in food will also probably create regional conflicts as nations compete for resources.

The developing countries will suffer first because many of them are located in lower latitudes, where temperature thresholds are already close to being reached. Slight rises in temperature can mean loss of already-scarce water and decreased agricultural capacity. These nations have the least economic flexibility, and greatest dependence on agriculture, particularly the subsistence type.

According to William R. Cline, of the Center for Global Development, and Peterson Institute for International Economics, climate change will decrease agricultural productivity 3–16 percent by 2080, but it will cut developing world output by 9–21 percent. Developing countries will lose an average of 9 percent, with Africa losing 17 percent, Latin America 13 percent, south Asia 30 percent, and 20 percent in Pakistan. Without carbon fertilization the percentages will be more severe. China stands to gain 7 percent in the carbon fertilization scenario. India's loss is almost incomprehensible, and could reach 30 percent.

China could have regional losses of 15 percent and a national drop or gain, the range being plus 7 to minus 7 percent. Developed countries in some cases can see increases of 8 percent from warming. Because developing countries are normally closer to the equator, they are closer to the thresholds where increases in warming will cut output, rather than increase output. Cline's numbers do not factor in the increased likelihood of pests, droughts, and floods. Cline notes that technology will allow continuing improvement in yields through the end of the century, but that demand will continue to rise, as well.

Pressures on agriculture are four. To meet population growth, agricultural production must almost double. As incomes rise, the demand for more meat will increase, requiring more food per capita. Increases in yields have been slowing for 20 years and probably will continue slowing. Ethanol will take up to a third of agricultural land from food production.

Developed countries such as the United States, Japan, western Europe, and Australia have moved beyond economic dependence on weather-dependent outputs. Agriculture, fishing, and forestry are less than 3 percent of U.S. gross domestic product. The United States might pay higher prices and lose its agricultural exports, but the Third World will suffer the most. The solution is for the Third World to industrialize, develop as rapidly as possible to free itself of climate dependency.

THE DEVELOPED WORLD'S CONTRIBUTION TO GLOBAL WARMING

Developed nations are responsible for about 80 percent of the current atmospheric carbon dioxide (CO_2). The United States alone has emitted 50.7 billion tons of carbon since 1950. China, with 4.6 times the population, has emitted 15.7 billion tons. India, with 3.5 times the population, has emitted 4.2 billion tons. More than 60 percent of the current industrial CO_2 emissions still come from developed countries, which have about 20 percent of the world's population.

Industrialized nations have caused environmental damage that penalizes developing countries and their poor. It is unfair to expect the developing world to stop trying to provide basic consumption and development needs for the poor, while the developed nations continue to emit greenhouse gases to preserve their luxurious lifestyles. Per capita carbon emissions in the United States are 20 times India's, 12 times Brazil's, and seven times China's. And a portion of the developing world's emissions are due to outsourcing by wealthy nations.

The International Energy Agency (IEA) predicted that in Organisation for Economic Co-operation and Development (OECD) countries, emissions would rise from 11.02 tons per person in 2004 to 11.98 tons in 2030. Emissions for non-OECD nations would rise from 2.45 to 3.55 tons. The developing world may have large overall totals, but it is far behind in per capita pollution. The problem is mostly the responsibility of the developed, industrialized, and motorized OECD nations, and the United States. They have a history of industrialization that dates back to the 18th or 19th century, and their coal-fired industrialization-generated greenhouse gases have not yet dissipated.

EQUITY

Climate change is already having an impact on small island nations. Some of these nations, and other small and poor countries around the world, have been left out of the global warming discussions although the impacts of global warming—and of the solutions that come from the international negotiations—expected to be greater on them than on the developed nations. Equity dictates that these nations attempting to reach the take-off to sustainable development be brought into discussions that affect such things as emissions allowances and other restrictions on economic development.

The issue of equity is usually left out when the developed world and oil producers get together. Their emphasis is on economic effectiveness. Understandably, the United States, consuming 20 percent of the world's resources with 4 percent of its population, and the Organization of the Petroleum Exporting Countries (OPEC) nations, worry about the economic consequences of altering the bases for their economies and way of life. When refusing to sign on to the Kyoto Protocol, the United States claimed that India and China had to endure cuts, too, to keep the economic playing-field level.

Those calling for equity note that the developed world has not provided meaningful assistance to make the transition to clean development. They hold that sustainable development is hampered by the diversion of substantial resources to debt and poverty, that developing countries such as India and China had already made significant cuts in emissions, and that environmental movements in developed countries have frequently pressured dirty industries to relocate to the Third World but provide profits and benefits to the developed world.

In opinion polls, the majority view is that developing countries should limit greenhouse emissions, but should not have to reduce emissions. The majority also back implementation of the Kyoto Protocol, whether or not the developing nations cooperate. Some developed nations back the developing nations in their position that cuts should not be mandatory because emissions per capita are already much lower. In June 2004, a Program on International Policy Attitudes (PIPA) poll found a strong majority wanting limits, but not reductions; the same view held in an earlier PIPA poll in 1998. Other polls have comparable results. Notably, polls show that respondents want the United States to cut emissions, regardless of what others do.

DEVELOPING WORLD SOLUTIONS

Developing countries are becoming more responsible on their own. Even as they develop rapidly, China, Brazil, Mexico, and India are cutting total emissions beyond the levels demanded by the developed world under the Kyoto Protocol. Emissions are still increasing, but the rate is slowing. In late 2005, Reuters reported that a state-owned energy firm in

China committed $2.48 billion over 5 years to alternative energy projects including biomass and garbage treatment. Chinese tariff policy favors non–fossil fuel energy sources. China has a target of 20 percent of energy from renewable sources by 2020, but is currently 70 percent dependent on coal for electricity. The United Kingdom has a goal of 10 percent for energy from renewable sources.

The Pew Center reported, in 2002, that some of the developing nations (Brazil, China, India, Mexico, South Africa, and Turkey) have cut greenhouse emissions by 19 percent, or 300 million tons a year. Additional cuts may reach another 300 million tons by 2010. They used market and energy reforms, energy efficiency, alternative fuels to reduce imports and improve living standards in remote locations, slowed population growth, cut deforestation, and switched away from coal to natural gas and other cleaner fuels.

DEVELOPED WORLD RESPONSES

The United Nations Framework Convention on Climate Change (1992) obligates the developing nations to use clean and sustainable technology, but it also obligates the developed world to assist the developing world in its transition to cleaner technologies. The framework established the principle of common but differentiated, responsibilities. This principle recognizes that developed countries have historically, and currently, create the largest amount of greenhouse gases. Per capita emissions are relatively low in developing countries, but the share will grow as these countries industrialize to satisfy the needs of their people. The convention obligates the rich to help. Christian Aid reports that the developed world owes the developing world $600 billion in compensation for the impacts of climate change. The $600 billion is more than triple the developing countries' debt.

Not all developed nations accept this responsibility. The United States repeatedly protested during the Kyoto Protocol that the agreement did not set the same level of reduction for developing nations as it does for developed ones. The U.S. Senate is on record as refusing to sign any treaty that does not require developing nations to cut their emissions. The counter argument, of course, is that the developing nations have not contributed nearly as much, and should not be expected to reduce equally.

Some developed world leaders attribute global warming, at least to some extent, to overpopulation. That position puts the blame on developing nations with large populations, such as China and India. President George W. Bush is on record repeatedly as refusing to accept limits unless the developing countries do too. Prime ministers Tony Blair and John Howard agree. Critics say that it appears these three leaders would have the world believe that China and India are responsible for runaway climate change and have to be party to any agreement before anything can happen. The developed world fears the impact of large populations developing rapidly; strong economic growth fuels demand for energy and materiel—and demand may exceed supply of resources. But the developed world agreed long ago that development was permissible, even with massive amounts of pollutants. China and India are now being asked to take a different approach, a clean and sustainable way that the old developed countries did not try. This is one view of "common but differentiated responsibilities."

The developing countries produce slightly over a third of greenhouse gases. Their per capita emissions, one fifth those of the developed world, will increase as they develop consumerism, and, by 2100, the developing world will create two to three times the emissions of the developed world. The U.S. government has used this prospect as a rationale for rejecting any agreement, including the Kyoto Protocol, that does not put limits on the developing world. That may be moot because negotiations are taking place on a new agreement that, first, shows the developed world is serious (for instance, Britain has promised to reduce CO_2 emissions by 60 percent), and, second, supports adoption of new technology by the developing world. If this happens, the developing world should skip the dirty-energy phase of industrialization and move directly to clean coal and hybrid cars, for instance. International carbon trading should provide the economic incentive for developed world businesses to help developing industries.

Because of climate change, six years after the adoption of the United Nations Millennium Development Goals, reaching those goals was less than likely. Global warming has finally become most of the world's number one concern. Global warming will have impacts on food, energy, transportation, and make access to healthcare, education, and social services more difficult. The impacts will be greatest in fragile environments, such as mountains and coastal areas.

Africa will be most at risk because African economies depend so heavily on agriculture and natural resources. Drought and flood are major disasters that put life and livelihood at immediate risk. Global warming's unpredictable weather will exacerbate already severe African problems with food, security, and poverty. Africans had great expectations from the first climate summit to take place south of the Sahara, the 12th Conference of Parties (COP 12) of the United Nations Framework Convention on Climate Change (UNFCCC) in Nairobi, Kenya.

THE UNFCCC

Unfortunately, the developed nations persist in seeing climate change and sustainable development as separate issues. The developed nations think globally: a ton of CO_2 is a ton of CO_2 regardless of where it comes from. The developing nations are adapting on a local level, and, sometimes, their local development needs create unwanted CO_2. Also, negative global impacts come from sources other than climate change. Flood and drought occur independently of global warming, although, climate change exacerbates the arbitrariness of weather. The developing nations need development plans that are climate-proof, and the best way to get results is to fight the two problems simultaneously.

Under the UNFCCC, developing nations began creating National Adaptation Programs of Action (NAPA) by 2006, and eight had finished by that time. The plans include such things as Malawi's reforestation as a means of reducing floods, and Benin's project to make people in the rural northwest more capable of adjusting to water scarcity, a high risk in that area. Implementation of the plans, naturally, will require large sums of money. The World Bank estimates an annual cost of $10–$40 billion. The UNFCCC has established a Special Climate Change Fund (SCCF) and a Least Developed Countries Fund (LDCF.) Both the SCCF and LDCF are funded by voluntary contributions from the developed countries. The Kyoto Protocol calls for a third source, an Adaptation Fund, that funds tangible adaptation projects in developing countries. Financing is through a tax on the trade on emission certificates. By the end of 2012, the fund should have $270–$600 million to spend. Disagreement arose at Nairobi over who would manage the fund, with developed country representatives wanting an agency with a global agenda.

The European Commission (EC) proposed a global alliance between the European Union (EU) and developing nations. The solutions include incorporation of new technology and improved communication with the Least Developed Countries (LDC) and the Small Island Developing States (SIDS.) The EU's Spring Council 2007 offered proposals for the next climate change agreement in 2012, when the Kyoto Protocol expires. This council also committed the EU to major cuts in emissions. The Global Climate Change Alliance (GCCA) offers assistance in reducing deforestation-generated emissions, getting developing countries more involved in the global carbon market, helping in preparation for natural disasters, and making climate change part of poverty reduction and development plans. The GCCA acknowledges that development has to be climate proof. The GCCA has funding of £50 million for 2008–10. The EC also appealed to EU states to spend more of their development assistance on helping developed nations cope with climate change.

SEE ALSO: China; Diseases; Economics, Cost of Affecting Climate Change; Economics, Impact From Climate Change; Environmental Development Action in the Third World; Framework Convention on Climate Change; Global Warming; India; Kyoto Protocol; United States.

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Diseases

DISEASE IS THE pathological process that presents a characteristic group of symptoms and that establishes the condition as an abnormal entity different from either the normal or other pathological body states. Disease is related to the concept of health, which is broadly defined as a state of dynamic balance, in which an individual or group's capacity to cope with the circumstances of living is at an optimal level. The freedom from disease or the risk of contracting one is only part of the modern concept of health, which involves complete physical, mental, and social well-being. The causes of human disease are varied and result from a combination of environmental, genetic, lifestyle, and socioeconomic factors acting over the lifetime of an individual.

This range of factors and interactions that shape human health have led to a questioning of the classic mechanical model of disease that has dominated the scientific approach guiding research on human health. The mechanical model of disease, as the name implies, only views the organism as a simple machine, instead of a complex system interacting with its environment. In this complex process for preserving health or combating disease, a person or population's environment can shape the behaviors associated with disease.

A changing environment can be a factor in the initiation or spread of disease. Recent research demonstrates the importance of socioeconomic factors in producing disease, and the recognition that these socioeconomic factors, in combination with physical environments (light, temperature, seasonality, and pollution) and biological phenomena, such as pathogens, need to be understood in a holistic way.

The concept of a complex process is key to understanding disease for people inhabiting changing environments, marginal environments, and extreme environments, such as Alaska. Environmental health focuses on the interrelation between human disease and the health of other species in an ecosystem. Contaminated water and air, endocrine disrupters, and even biological terrorism pose important stressors in which human systems have become agents of change that affect rural and natural landscapes, including the movement of organisms and materials. Environmental well-being refers to the ability of the environment to support all life, including human economic and social systems. The efficiency and sustainability of environmental services, the cycling of materials, and the maintenance of organismal balance are needed to reduce the incidence of disease.

Diseases affect homeostasis, which is the feedback that maintains a living organism's body function within limits essential for the body to continue functioning properly, despite external and internal stresses that would move the system away from balance. Diseases that exist in a population for a long time, where they are maintained at a low level, are called endemic. An epidemic occurs when there is a marked increase in the incidence of disease within a region. When an epidemic spreads around the world it becomes a pandemic. For example, the 1918 pandemic is believed to have been related to 30 million deaths. Climate change is expected to increase the spread of disease, especially biologically-transmitted pathogens.

Chronic diseases such as Alzheimer's, emphysema, heart disease, acquired immune deficiency syndrome (AIDS), and cancer are diseases that have a slow onset and last for extended periods of time. Diseases can also be classified by type, such as infectious, developmental, nutritional, radiation, and chemical. Many diseases, such as neoplastic diseases like cancer, involve both genetic components and environmental factors leading to increases in susceptibility. Thermal, chemical, and radiation damage mainly results from a damaging excess of kinetic energy or ionization of molecules in tissues leading to cell death. Free radicals react with molecules in the cell and change their structure, affecting their ability to function. This is the basis for Pauling's molecular theory of disease. Chemical exposure can stimulate or depress metabolic functions, such as homeostasis, by interfering with enzymes or receptors. Some chemicals produce effects that are characterized as a systemic disease. This disease process affects all of the body's organ systems. Most environmental pollutants, such as mercury, lead, cadmium, arsenic, and persistent organic pollutants are systemic toxins. Systemic pollutants, because they are ingested, inhaled, or absorbed, will be more widely distributed during climate change by floods, fires, and winds.

Most public health problems involve diseases caused by pathogens; but environmental molecules, either natural (metals, metal-containing compounds, or plant secondary products) or anthropogenic (pesticides, pharmaceuticals, or industrial waste) can lead to adverse effects on public health. However, some responses are considered to be adaptive and not disease states, such as the induction of a detoxification enzyme.

Human health is also affected by nutrition, contact with allergens and pathogens, and exposure to contaminants in air, water, and foods. Population density, age distribution, mobility, and other demographic variables, as well as the genetic composition, and cultural and behavioral attributes of individuals, influence the incidence of disease. Thus, understanding the relationships between human health and the environment is critical, particularly given the potential for alteration of ecosystems by socio-economic activity, rapid global change, and climate variability. The World Health Organization monitors disease on a global scale.

GLOBAL WARMING AND CLIMATE CHANGE

While high blood pressure in a population can impose a health risk and poor nutrition increases susceptibility to disease, global warming and climate change, alter the temperature, water cycle, and pathogen distributio, posing direct threats to human health. According to the United Nations Intergovernmental Panel on Climate Change, certain regions and populations are more vulnerable than others to increases in disease. As climate changes, regions with high endemicity of malaria, or regions affected by El Niño–linked epidemics may expand. Climate changes will put stress on food and water systems, leading to environmental diseases. Similarly, areas under socioeconomic stress, poor land-use and resource practices, or underdeveloped health infrastructure will have problems combating increases in disease. Chemical hazards related to resource development, such as coal use in the environment, produce a diversity of diseases, ranging from asthma to birth defects and cancer.

Climate change will not only affect exposure to disease vectors and pollutants, but also lower human resistance to disease. Drought is associated with poor hygiene and increases in diarrhea, scabies, and conjunctivitis. Fire smoke carries metals, such as mercury, and fine particles that exacerbate cardiac and respiratory problems, such as asthma and chronic obstructive pulmonary disease. Volatile organic compounds and particulate matter formation can increase at higher temperatures. Once pollutants are formed, climate and environmental change, such as temperature inversions, can increase exposure to toxicants.

Flooding increases waterborne diseases by contaminating drinking water. In marine ecosystems, bacteria such as the vibrio species proliferate in warmer waters. Temperature also increases the incidence of vector-borne diseases. Both malaria and arboviruses are mosquito-borne diseases. Rodent-borne hantavirus infections increase in relation to El Niño's heavy rainfall. Changes in climate will affect food productivity and lead to malnutrition, which may increase disease rates. Inadequate diets also occur in developed nations, as fast food and contaminated food represents an increasing percentage of the diet. Also, fast-food processing and transportation can remove nutritional value from the foods, often increasing the sugar and fat content.

A disease of dietary insufficiency in children known as kwashiorkor needs to be monitored as climate changes. Dietary factors are major components of heart disease and cancer. Increased saturated or trans fat intake may be correlated with increased risks of colon and prostate cancer. Obesity has been linked to endometrial cancer. Cancer is still rare in children, but some types are increasing, such as glioma, a form of brain cancer that has increased by 40 percent in children over the last 40 years. Also, children tend to be more susceptible to environmental toxins because of high relative exposure (with more food intake, lower body weight, and higher internal dose); they have higher rates of cell proliferation and an immature detoxification and cell repair system.

Children of subsistence families are at increased risk from climate change and the global concept of food production as a commodity.

SEE ALSO: Anthropogenic Forcing; Coal; Developing Countries; Drought; Ecosystems; Emissions, Baseline; Floods; Food Production; Pollution, Land; Seasonal Cycle; Wind-Driven Circulation; World Health Organization (WHO).

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Djibouti

LOCATED IN NORTHEAST Africa, with land borders with Eritrea, Ethiopia, and Somalia, Djibouti was formerly known as French Somaliland, and later as the Territory of Afars and Issas. It has a land area of 8,958 sq. mi. (23,200 sq. km.), with a population of 496,374 (2006 est.), and a population density of 88 people per sq. mi. (34 people per sq. km.). With extremely poor soil, less than 1 percent of the country is arable land, with another 9 percent being used for meadows and pasture, mostly to graze cattle, sheep, and goats.

The electricity for the country is produced entirely from fossil fuels, and all the carbon dioxide emissions come from liquid fuels. As a result, even with the low standard of living and the undeveloped nature of the country, it recorded 0.6 metric tons of carbon dioxide per capita each year 1990–97, with the amount falling slowly to 0.48 metric tons in 2003. This marked decline is far more than that achieved by most other countries in sub-Saharan Africa, in spite of the country still having a poor system of public transportation, with plans for a railway from Djibouti to Addis Ababa, first discussed as early as 1894, never resulting in any construction work.

The government of President Hassan Gouled Aptidon took part in the UN Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, with the Vienna Convention being ratified in 1999. Under President Ismail Omar Guelleh, Djibouti accepted the Kyoto Protocol to the UN Framework Convention on Climate Change on March 12, 2002, and which took effect on February 16, 2005.

SEE ALSO: Eritrea; Ethiopia; Somalia.

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Doldrums

DOLDRUMS ARE TECHNICALLY known as the intertropical convergence zone (ITCZ), the intertropical front, the monsoon trough, or the equatorial convergence zone, the doldrums are a belt of low pressure surrounding the earth at the equator. It is formed by the vertical ascent of warm, moist air from the latitudes above and below the equator. The air is drawn into the ITCZ by the action of the Hadley cell, a macroscale atmospheric feature that is part of the Earth's heat and moisture distribution system. It is transported aloft by the convective activity of thunderstorms.

The position of the ITCZ varies throughout the year. Over land, it moves back and forth across the equator following the Sun's zenith. Over the oceans, where the ITCZ is better defined, the seasonal cycle is more subtle, as convection is limited by the relative stability of ocean temperatures. Occasionally, a double ITCZ forms, with one located north and another south of the equator. When this occurs, a narrow ridge of high pressure forms between the two convergence zones, one of which is usually stronger than the other.

The location of the ITCZ can have dramatic effects on rainfall in equatorial locations, resulting in wet and dry seasons in the tropics, rather than the cold and warm seasons characteristic of higher latitudes. Regions in the ITCZ receive precipitation more than 200 days per year. Within the ITCZ surface winds are slight, unlike the zones north and south of the equator where the tradewinds blow. For this reason, sailors named this belt of calm the doldrums due to the stagnation they found their sailing ships in after days of no wind, high heat, and humidity.

The ITCZ's role in the formation of tropical storms depends upon the low-level vorticity as one of its six requirements, and the ITCZ trough fills this role as it is a zone of wind change and speed, otherwise known as horizontal wind shear. As the ITCZ migrates more than 500 km. from the equator during the respective hemisphere's summer season, increasing Coriolis force makes the formation of tropical storms within this zone more possible. In the north Atlantic and the northeastern Pacific oceans, tropical waves move along the axis of the ITCZ causing an increase in thunderstorm activity, and under weak vertical wind shear, these clusters of thunderstorms can become tropical hurricanes.

GLOBAL WARMING

The effects of global warming on the ITCZ could be significant. Given that surface winds over the ocean tend to follow ocean currents, changes in the circulation of ocean currents brought about by global warming will also have a direct influence on the ITCZ, resulting in an intensification of precipitation in the ITCZ, according to S. Nawrath and A. Levermann. A simulation model of global warming (using a general circulation model, or GCM, with enhanced carbon dioxide, or CO_2), indicates an increase in the ITCZ strength and hydrological cycle that accompany global warming, according to U. Cubasch, et al.

A key feature for nearly all GCM simulations of the climate under an enhanced CO_2 is that increases of tropospheric water vapor along with a stronger ITCZ and hydrological cycle are required for any substantial global warming, as described by J.T. Houghton, et al., but once they do occur, these conditions create the potential for the development of more powerful storms, according to K.A. Emanuel. The stronger the ITCZ becomes, the more favorable are conditions for the development of major hurricanes in the central Atlantic. In general, global warming will result in an exaggeration of preexisting conditions, whereby wet areas become wetter and dry areas become drier.

SEE ALSO: Equatorial Countercurrent; Equatorial Undercurrent; Hurricanes and Typhoons; Monsoons.

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Dominica

THIS CARIBBEAN ISLAND of Dominica, formerly a British colony, has a land area of 290 sq. mi. (751 sq. km.), with a population of 71,727 (2006 est.), and a population density of 272 people per sq. mi. (105 people per sq. km.). Some 9 percent of the land area is arable, with another 3 percent available for use as meadows or pasture. Unlike many other Caribbean islands, Dominica does not rely heavily on tourism, although some 70,000 people do visit the country each year. One major environmental problem for Dominica is that hurricanes hit the island at regular intervals. Although much of the land area of Dominica is higher than many of its low-lying neighbors, the rising sea temperature is threatening the marine life around the island, as well as the coral reefs at Scotts Head Drop and the Pinnacle. Some divers have already noticed the start of coral bleaching, and the ministry of tourism has been worried that this might eventually result in a downturn in the number of tourists that do visit the island.

Traditionally, Dominica has had a low carbon dioxide emission level per capita, with 0.8 metric tons per person in 1990, although this has progressively risen, and was 1.8 metric tons per person in 2003, with Dominica ranking 121st in carbon dioxide emissions, almost entirely from using liquid fuels. The country's agricultural industry has traditionally relied on the heavy use of chemical pesticides and fertilizers, which cause other environmental problems.

With the rising sea levels, there are worries that the flooding of parts of Dominica, that might result, could lead to the spread of malaria and dengue fever, and also damage the water-bottling industry that has become an important part of the local economy. This has led to moves introduced by the Ministry of Agriculture and the Environment in Roseau, the country's capital, to reduce the use of chemicals in agriculture. The Dominican government of Eugenia Charles took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, and in April–May 1994, Dominica was represented at the Global Conference on the Sustainable Development of Small Island Developing States held in Barbados. The government of Roosevelt Skeritt accepted the Kyoto Protocol to the UN Framework Convention on Climate Change on January 25, 2005, which went into effect on April 25, 2005.

SEE ALSO: Alliance of Small Island States (AOSIS); Hurricanes and Typhoons; Oceanic Changes; Sea Level, Rising; Tourism.

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Dominican Republic

LOCATED IN THE Caribbean, the Dominican Republic occupies the eastern part of the island of Hispaniola, the other part the Republic of Haiti. It has a land area of 18,810 sq. mi. (48,442 sq. km.), with a population of 9,183,984 (2007 est.), and a population density of 474 people per sq. mi. (182 people per sq. km.). The capital, Santo Domingo, makes up for about a quarter of the population of the country, which remains extremely poor, with a Gross Domestic Product per capita of $2,776 per year.

In the Dominican Republic, sugar cane crops are being repurposed to make ethanol to blend with gasoline.

About 21 percent of the land is arable, with a further 43 percent used for meadow or pasture. Historically, the mainstay of the economy has been sugar, with sugar cane now being used to make ethanol to blend with gasoline to reduce greenhouse gas emissions. The carbon dioxide emission per capita for the country has been relatively low, at 1.4 metric tons in 1990, but rose steadily to 2.5 metric tons by 2003. Most of this came from the use of liquid fuels (94 percent), with the remainder from the manufacture of cement (5 percent), and the use of solid fuels (1 percent).

The largest amount of the electricity generated is used for general household consumption, for air conditioning units in houses and businesses, and also for the influx of tourists. There has also been a rise in the number of people who own their own cars, and no longer use the *gua-gua* (buses). Forests cover 13 percent of the country. There is extensive logging by farmers and developers, even though commercial tree cutting has been outlawed since 1967.

To try to combat climate change, the government of Joaquín Balaguer took part in the United Nations Framework Convention on Climate Change, signed in Rio de Janeiro in May 1992, and ratified the Vienna Convention in the following year. The government of Hipólito Mejía accepted the Kyoto Protocol to the UN Framework Convention on Climate Change on

February 12, 2002, which want into effect on February 16, 2005. This, however, has not prevented the destruction of most of the coral reefs off the north shore of the country, which have been badly damaged by hurricanes and by anchors from fishing boats that have heavily overfished that region.

SEE ALSO: Alternative Energy, Ethanol; Deforestation; Haiti; Oceanic Changes; Tourism.

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Doris Duke Charitable Foundation

THE MISSION OF the Doris Duke Charitable Foundation (DDC) is to improve the quality of people's lives through grants supporting the performing arts, environmental conservation, medical research, and the prevention of child maltreatment, and through preservation of the cultural and environmental legacy of Doris Duke's properties. Established in 1996, the foundation supports four national grantmaking programs. It also oversees three properties that were owned by Doris Duke in Hillsborough, New Jersey; Honolulu, Hawaii; and Newport, Rhode Island. The foundation is headquartered in New York and is governed by a 10-member board of trustees. The foundation has a specific program on environment that targets the challenges brought about by global warming and climate change.

The DDC's activities are guided by the will of Doris Duke, who endowed the foundation with financial assets that totaled approximately $1.8 billion as of December 31, 2006. The foundation regularly evaluates and modifies its allocation of resources from the endowment to support the programs and properties. Born in New York in 1912, Doris Duke was the only child of James Buchanan Duke, a founder of the American Tobacco Company and Duke Energy Company, and a benefactor of Duke University in his native North Carolina. During an adventurous lifetime lived in the spotlight of media attention, Doris Duke did a great deal of philanthropic work, especially in the areas of medical research, childcare, and environmental preservation. When she died in 1993, at the age of 80, Duke left virtually all her fortune to the DDC. Duke's butler, Bernard Lafferty, was left in charge of the foundation by the heiress, but a lawsuit soon provoked his discharge.

The foundation awarded its first grants in 1997. As of December 31, 2006, the foundation has approved approximately 696 grants totaling approximately $479 million to nonprofit organizations throughout the United States. Grants are awarded in four program areas. The Arts Program supports performing artists by producing their works for public performances. The Medical Research Program supports clinical research to prevent and cure diseases. The Child Abuse Prevention Program promotes the healthy development of children by protecting them from abuse and neglect. The scheme which is most directly related to global warming and climate change is the Environment Program.

Doris Duke was a lifelong environmentalist and had a particular interest in conservation. In her will, she expressed her interest in "the preservation of wildlife, both flora and fauna" and in supporting "ecological endeavors." These became the two main points in the mission of the DDC's Environment Program. The scheme works to reach its aims through two strategic initiatives. Habitat Conservation seeks to preserve essential habitats identified in state wildlife action plans through grants that identify priority habitats for conservation, protect priority habitats, and build conservation knowledge. The DDC regards the wildlife conservation strategies submitted in 2005 by the 50 U.S. states to remain eligible for funding through the U.S. Department of the Interior's State Wildlife Grants Program as a blueprint for protecting the most important areas for our nation's wildlife. Habitat Conservation, thus supports state efforts to develop and implement wildlife action plans that identify priority lands for habitat conservation. It encourages the protection of priority areas identified in state wildlife action plans, the development of new sources of conservation funding, and the integration of state wildlife action plans into local, regional, and national planning efforts. The program also has a series of training, research, and education initiatives that advance the Environment Program's mission.

The second function of the DDC is directly related to climate change. It seeks to help build a clean-energy economy through grants that design optimal pricing policies for greenhouse gases, identify and promote policies that accelerate the development of clean-energy technologies, and suggest ways to adapt to climate change. The DDC recognizes that:

> climate is changing at a rate that jeopardizes our environmental, economic and social welfare, and the choices we make now about how we generate and use energy will either lock us into decades of unmanageable carbon emissions or set the stage for a sustainable future. The Climate Change Initiative focuses on building a clean-energy economy that works for people and the planet.

By devising optimal domestic and international pricing policies for greenhouse gases, especially carbon dioxide, the DDC intends to make existing and new clean-energy technologies competitive in the marketplace. Grants in this strategy fund academic institutions and nongovernmental organizations working at the state, national, and international levels to design optimal greenhouse gas pricing policies. These will encourage the limitation of emissions.

The second strategy of the Climate Change scheme, to promote the development of clean-energy technologies, encourages the development of policies that will make the existing technologies (such as wind and solar power) available to the market more quickly, particularly technologies dealing with energy efficiency, renewable energy, and low-emission uses of coal. This strategy also endorses policies leading to the development of tomorrow's clean-energy technologies.

The third strategy of the Climate Change scheme is intended to suggest ways in which we can adapt to climate change. Initiatives in this area try to assess the likely effects of climate change and identify adjustments that can be made to reduce the impact of those effects on people and the environment. The DDC considers this strategy important as, regardless of whether actions are taken now to reduce greenhouse gas emissions, gases already in the atmosphere will continue to push temperatures higher. This phenomenon will have uncertain impacts on agriculture, forest and freshwater resources, wildlife, and public health.

The DDC regards its Climate Change project as an important part of its work and one consistent with the mandate of Doris Duke's will. It has committed to the formulation of clean-energy policies that can encourage the building of long-term infrastructures. The Climate Change initiative was launched in 2007 for a five-year period, with a budget of $100 million.

SEE ALSO: Alternative Energy, Overview; Climate Change, Effects; Conservation; Economics, Cost of Affecting Climate Change.

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Drift Ice

IN THE WORLD'S polar regions, ice that floats on the water's surface is termed drift ice. Drift ice is named for its tendency to be carried by wind and currents. Drift ice that is forced into a single mass is called pack ice. The two major ice pack regions in the world, accounting for the majority of the ocean drift ice, are the Arctic and Antarctic ice packs. Increasing water and air temperatures are causing this ice to melt. The extent of this ice depletion by climate change is unknown. Further, the impact of these changes on ice-dependent species, in the long-term, is not clear.

Drift ice plays a critical role in climate and ecosystem habitats. The ice originates from the freezing of seawater and can be of varying size and shape. The extent of regions that are covered in potential drift ice (sea ice) during the past 30 years has significantly decreased in the Arctic. However, researchers suggest that while some Antarctic areas are decreasing in ice cover, others are actually on the increase. While the

Some of the polar regions' most sensitive macrofauna, including birds, seals, penguins, and polar bears, are dependent on drift ice as platforms for rest and hunting, and as sources of food.

future of drift ice is uncertain, climate models predict a continual decrease in the Arctic regions and a comparable decrease in the Antarctic regions.

The annual fluctuation in Arctic ice ranges from 4.35–9.32 million sq. mi. (7–15 million sq. km.), from the end of summer melt to its peak at the end of winter, respectively. The sea and drift ice area surrounding the Antarctic continent, similarly, range from 1.86–11.18 million sq. mi. (3–18 million sq. km.) during the same seasonal fluctuation. Seasonal ice can range in thickness from 3.28–6.56 ft. (1–2 m.), compared to the typically much thicker permanent ice that does not melt during the summer. The area of ice that does not melt during the summer is gradually decreasing.

Drift ice contributes significantly to the albedo of the Earth's surface, or its reflectivity. High albedo reflects more of the Sun's energy, keeping the Earth cooler, whereas low albedo, particularly with decreasing ice, permits absorption of the Sun's energy by the oceans, which hold the heat and, ultimately, warm the Earth. Snow-covered drift ice contributes even more significantly to a high albedo, but is becoming rare during the summer melt season, when solar energy is greatest.

The contribution of drift ice to the livelihood of humans and animals is significant. Drift ice is a keystone contributor to local and regional food webs. Any changes in ice densities impact tiny microorganisms, including algae and zooplankton, which are dependent on the ice for nutrients and shelter. Ice algae are the primary producers in ice-associated food webs. As primary producers, they are critical to the survival of all higher-level organisms. Ice habitats are critical for the juvenile life stages of many microorganisms, such as zooplankton, which are dependent on these algal and bacterial populations for survival. Fish seek shelter under the drift ice and feast on the abundant zooplankton. Some of the polar regions' most sensitive macrofauna, including birds, seals, penguins, and polar bears, are dependent on this floating ice as platforms for rest, hunting, and a source of food; many feed on the microorganisms and fish found just under the drift ice.

Indigenous Arctic peoples are dependent on drift ice and sea ice for subsistence hunting of whales, seals, and fish. Decreases in, and thinning of, drift ice with climate change and warming trends reduce the time annually that these peoples have to hunt. The macrofauna spend less time in areas that are readily accessible to the hunters, decreasing the opportunity for a successful hunt and the feeding their families. These decreases in drift ice may also be beneficial to humans, however, with the opening of channels for new sea routes and potential future economic benefits. Ease of navigation through these areas may increase trade between indigenous peoples.

From a global climate perspective, melting of drift ice is likely to have a significant impact on ocean circulation patterns. Ocean circulation is driven by water density differences (thermohaline circulation). Ocean surface waters freeze, and as they freeze, salt from that water is transferred to the water below, thereby increasing its salinity (drift ice has very low salt content). This causes the surrounding surface waters of the oceans where ice forms to increase in salinity. The drift ice is moved by winds and currents to far-reaching locales, contributing "freshwater" ice melt to these areas. With increased melting of the drift ice, freshwater inputs to coastal areas are increasing, potentially causing submersion and flooding of these coastal zones.

Scientists predict that as the ice thins, seawater circulation patterns will change, potentially impacting the ocean circulation patterns of the entire planet. Biodiversity of microorganisms dependent on the drift ice for habitat and resources will decrease. If the oceans change from primarily ice-covered to primarily open waters, the productivity (phytoplankton) of the regions will increase dramatically, altering the oxygen and nutrients available for other organisms, and shift the food web structure, as ice-algae would no longer serve as the primary producers. Regional macrofauna may be forced to move to new regions, if drift ice is no longer present, or their populations will be significantly diminished. The potential impact of climate change and warming on the distribution of drift ice (as the foundation of sea ice) is a major focus of the 2007–08 International Polar Year research programs.

SEE ALSO: Antarctic Circumpolar Current; Antarctic Ice Sheets; Arctic Ocean; Radiation, Ultraviolet; Salinity; Sea Ice; Sea Water, Composition of.

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Drought

DROUGHTS OCCUR WHEN the rainfall in an area falls below its normal pattern for an extended period of time. If the drought occurs in a region where crops are usually not irrigated, then farmers suffer crop losses that may range from mild to severe. If the drought is extreme, the crop losses may be total, because the plants wither and die without water. The weather, which is the current atmospheric conditions locally or regionally, can develop into a pattern that seems to be stuck. In such conditions, floods or drought may occur. Meteorologists who make long-range weather predictions cannot predict droughts. However, scientists and others who study climatic conditions produced by weather patterns in an area or region over long periods of time have found that there are times in which drier weather than normal occurs and when wetter weather than normal occurs.

By studying the growth patterns of tree rings, seasons of significant growth in wet years can be seen in comparison with years in which drought occurred and as a consequence the tree grew little. When the pattern of wet and dry year growth is observed in tree ring patterns, it is not unusual to find multi-year periods when trees grew rapidly followed by little growth in multi-year times of drought. Weather over a long time period becomes patterns of the climate flowing in irregular repeated cycles. These may be cycles that occur occasionally every 50 or 100 years, or they may occur somewhat more frequently.

Droughts are caused by a lack of rainfall or snowpack. If water vapor is not in the atmosphere, then rising temperatures causes warm air to rise and, in the case of warm moist air, to condense in the cooler upper atmosphere and to shed its moisture as rain or other forms of precipitation. If rising air or water vapor is not present in combination, then drought results.

Meteorological droughts are due to changes in climatic conditions over vast regions. Conditions that can cause a drought include shifts in the jet stream in the presence of an El Niño, which signals changes in the temperature of vast areas of ocean water that contribute moisture for rainfall or other changes.

Agricultural droughts are usually produced by meteorological droughts. They occur when the average precipitation is insufficient to support agricultural activity at its normal levels. In agricultural droughts, crops die or produce only a small portion of their normal yield. Livestock must be fed with imported food, sold, or turned loose to forage for themselves. Deforestation also affects local conditions that cause or retard rainfall. Many scientists believe that it is still too soon to determine whether the rise of average global temperatures in the last 100 years is sufficient to create global warming conditions that are causing droughts in areas where droughts have historically been rare.

EFFECTS OF DROUGHT

When droughts occur, they can have a number of negative effects. The drought can cause the destruction of plants and animals, and the deaths of vast numbers of human beings. Droughts can be the result of a failure of winter rains and snows. The absence of winter moisture can affect plants, animals, and humans. In many areas, water supplies are dependent upon winter moisture that is stored for use by farmers and cities, and may, if the drought is prolonged, create immense problems for humans. For example, Los Angeles, California, is dependent for much of its water supplies on snowmelt from the snowpack in the high Sierra Mountains in northern California. If there is a winter snow drought, it is a threat, because water supplies have to be managed very carefully and alternative supplies sought.

The failure of the winter snows or rains, the spring rains, or even summer showers to come can also be accompanied by weather patterns that are damaging. Warm winter temperatures may trick plants into blossoming as if the warm seasons of the year have arrived. The sudden return of cold weather can then bring freezing temperatures that damage or kill plants that have emerged from a wintertime dormant state.

Global warming as a likely cause of the destruction of glaciers is of enormous concern to many scientists, the United Nations, and others because their destruction may greatly affect the rivers of India, China, and Southeast Asia. The Himalayan glaciers are the sources for the largest rivers in Asia. The Indus River, especially in its Punjab area, feeds millions. The Ganges and the Brahmaputra are also the sources of water for 500 million Indians. If the Himalayan ice pack were to disappear because of global warming, then the Yellow, Yangtze, Mekong, and Salween rivers would probably disappear or be reduced to only a trickle of their former flow volumes. The effects could be deadly for billions of people.

Droughts are often accompanied by higher than normal temperatures. The higher temperatures cause plants to suffer heat stress. The heat stress from temperatures that may be 10, 20, or more degrees above normally occurring temperatures dry out plants so that not only crops, but also grasses, brushes, trees, and other plants are vulnerable to dehydration. They may become dormant to endure a drought. Diseases may then successfully attack plants that would not have normally been vulnerable.

The longer a drought continues, the drier the vegetation, including dead-fall and the decaying leaf matter on the ground in wooded areas. The possibility of forest fires, or of fires in more open country, begins to grow at an exponential rate. It is not unusual for drought to be accompanied by many forest fires or brush fires.

HISTORICAL EXAMPLES OF DROUGHT

Short-term drought occurred in many places in the world during the 20th century. western Europe, including England, experienced years of drought on a number of occasions, as did parts of the United States. South America, Africa, and Asia have also known years in which drought conditions occurred. In the 1960s, drought appeared in the northeastern United States. Winter snows failed in the western United States 1975–77. In 1976, western Europe suffered a summertime drought. In the late 1960s and in the early 2000s, parts of Africa suffered from drought.

There are regions of the world where drought is normal. Some areas, such as the northeastern area of Brazil or other semi-arid regions, have regularly reoccurring patterns of drought. Drought in some areas of the Amazon basin, in 2005, was recorded as a 100-year drought. Some Brazilian scientists argued that it was due to deforestation that was pushing the Amazon rainforest to a tipping point where it would never recover as a rainforest.

In areas of the Mediterranean, or where a Mediterranean climate occurs (California, Central Chile, South Africa, and south and southwestern Australia) drought in the summertime is normal because there is less than 4 in. (2.54 cm.) of rain that falls during the summer months. The winters in areas with a Mediterranean climate are cooler and wetter than the summers. The rains of the non-summer months cause plants to grow profusely. However, the long dry summers expose the plants to fire hazard. Southern California is well known for brush fires that destroy the vegetation in many thousands of acres. People who have built homes in fire-prone areas may lose them to these wildfires. Plants in such regions are adapted to drought and to depend upon periodic fires for renewals. Fires that occur in drought conditions can be so severe that great expanses of timber and grassland are destroyed. With the cover crops and vegetation removed by fire, hot, dry winds can pick up soil and further damage soil productivity.

One reason for the concern over the loss of glaciers is that they feed rivers like the Indus, which sustains millions of people.

During the 1930s, a period of drought (1931–38), afflicted the states of the Great Plains. The 1920s had been a wetter time. It had also been a time in which farmers used the plowing techniques of the eastern United States. The deeper soil in the east was improved by plowing deep to bring up minerals from under the soil. However, in the drier conditions of the Great Plains, plowing deep broke the water table's contact with surface plants. The conditions were created for the terrible dust storms that occurred in the famous Dust Bowl.

RECENT DROUGHTS

Droughts occur in other parts of the United States with some frequency, but on an irregular schedule. They may be mild and last only a year or two. Other droughts can be prolonged and last for five, six, or more years. They range from mild, to severe, to extreme. During 2007, Georgia, Alabama, and areas of Florida suffered an extreme drought that was unprecedented. Lakes, ponds, and streams ran out of water and became dry. Wells and other sources of water were depleted, causing significant political turmoil.

Besides a meteorological and an agricultural drought, the area was experiencing a hydrological drought. The water resources had not been husbanded with sufficient stewardship to make them last well during the drought. Some areas of the world, such as the Aral Sea, and a lesser extent the Caspian Sea, have experienced hydrological drought because water resources have been used beyond the limits of precipitation needed to restore them to normal levels in wet years.

Political disputes, in 2007, over the distribution of water by the U.S. Army Corps of Engineers from Lake Lanier in north Georgia into the Chattahoochee River involved many parties. The politics of drought, in this case, involved not only the federal government, but also the governments of the states of Alabama, Florida, and Georgia, as well as many of their cities and counties. In addition, power companies that use riparian waters in the generation of electricity were involved in the controversies that the drought evoked.

The drought also brought ecologists, state environmentalists, and others concerned about the survival of plants and animals into conflict with businesses and developers. Species of mussels in the lower Chattahoochee could become extinct if water levels drop too severely. They are a harbinger species, like canaries in coalmines in earlier times, which were used to detect the presence of dangerous quantities of gas that threatened life. Their loss could be much more important than just the loss of an inedible species that plays a role in cleansing impurities from river water, aiding the survival of fish species.

The drought in the southeastern United States in 2007 is believed to be connected with global warming. It may just be a cyclical shift in the positioning of normal summertime high-pressure air masses usually centered westward over Bermuda. Most scientists believe that the drought conditions in the United States may be the result of global warming, but in order to state that climate has changed, long periods of weather activity must occur, be recorded, and then examined for permanent changes in patterns.

In other parts of the world, droughts have caused famines resulting in the deaths of those who live a subsistence life in arid lands at the edge of deserts. The people of Mongolia, of the Sahel, which is the arid transition zone between the Sahara Desert and the savannah lands to the south, of the southwestern United States and northwestern Mexico, Australia, the Middle East and Central Asia, and other places have long lived with recurring periods of drought.

Historians have concluded that periods of drought also stimulate mass movements of people. When drought occurred in Mongolia, the weakest tribes were driven out to rampage westward across the steppes and became civilization-changing forces. It is likely that severe droughts caused by global warming will cause movements of peoples and will also contribute to political instability in many parts of the world. The instability may also lead to wars and the deaths of many people, just as the lack of water during droughts has often caused deaths from heat, famine, and consequent diseases.

Conflicts in the late 20th century and the early 21st century in the Horn of Africa and in the Darfur region of Sudan are directly related to prolonged drought conditions that exacerbated conflicts between tribes and peoples. Other conflicts are also connected to competition for scarce resources that are directly related to water shortages caused by droughts. Drought conflicts can bring nomads into a struggle with farmers of marginal lands. The farmers, or the nomads, if defeated, may well overrun their neighbors, causing disruptions among peoples who were not as severely affected by a drought. Drought is normal in many parts of the world, but it may be that global warming is contributing to an increase in droughts, or a shifting of the locations of droughts. Regardless, with the great increases in world population during the 20th century, it is prudent to create drought mitigation and survival plans.

SEE ALSO: Agriculture; Climatic Data, Atmospheric Observations; Desertification; Deserts; Food Production; Rain; Rainfall Patterns; Weather.

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Dynamical Feedbacks

A DYNAMICAL FEEDBACK is a relationship within a system in which the effects caused by one part of the system on another part eventually come back to affect the first part. The easiest such relationship to envision might be a tug of war, in which each side has to pull harder, causing the other side to pull harder, causing the first side to pull harder still. In the study of global warming and climate change, these feedbacks are especially critical.

In a more general sense, a feedback is a relationship found in most complex systems: the output of that system is returned to the input. Negative feedback reduces that output (cancels out some of the effect), while positive feedback increases it. In climate change, as in many complex systems, both negative and positive feedbacks exist; just as with credits and debits in a bank account, the net effect is determined by the strength and magnitude of those multiple gains and losses.

Where global warming is concerned, positive feedbacks are easy to identify: they are all relationships where global warming encourages a trend, which itself contributes to further warming. An oft-cited hypothetical from Earth science classes is the use of chlorofluorocarbon-emitting air conditioning: as summers get hotter, such air conditioners run longer, releasing more CFCs into the air contributing further to the greenhouse effect,and the next summer is hotter still. There are plenty of observable expamples of dynamical feedback. In recent years, there have been more forest fires than usual. Global warming and dry weather contribute to this. In turn, the fires impact the climate, not only through deforestation, but by releasing large amounts of carbon dioxide.

Similarly, warmer temperatures have meant the thawing of permafrost, in the high-latitude soil that has been below the freezing point for at least two years (and often much longer). In western Siberia, areas of permafrost peat bogs that have remained frozen for thousands of years—since the last ice age—have begun to thaw, releasing considerable amounts of methane, which will worsen the greenhouse effect. Methane hydrate—ice containing dissolved methane—exists in enormous deposits on the cold ocean floor, and warming sufficient to melt it would release a great deal of methane all at once—at, it is believed, a much faster rate than has been seen in the past, even from industrial pollution. Methane is a greenhouse gas with an effect on global warming five times that of carbon dioxide.

The carbon cycle, too, can work as a positive dynamical feedback for global warming. As anthropogenic causes increase the total amount of carbon passing through the carbon cycle, more of it remains free in the atmosphere, as the carbon load exceeds what the other phases of the cycle can take in. Various models have found that global warming increases the amount of anthropogenic carbon dioxide remaining in the atmosphere, which, in turn, accelerates global warming; the models disagree only on the extent to which this happens.

The ice-albedo feedback is another clear example. As temperatures near the Earth's polar regions increase, more and more ice melts—either permanently or for the summer—leaving land and water in its place. Ice is a highly reflective surface, that reflects more sunlight back into space does than land or water—and the difference in reflectivity is relevantly high. Over time, as the polar ice retreats, more Sunlight is retained by the Earth's surface, and with it, more heat. Though popular discussion of the polar ice caps melting with regards to global warming focuses on rising sea levels, many models implicate the ice-albedo feedback in their predictions of future catastrophe and major climate change.

Perhaps the greatest feedback is the evaporative feedback. Just like carbon dioxide and methane, water vapor is a greenhouse gas. Higher temperatures lead to greater evaporation of the Earth's surface water. At the same time, the amount of moisture the air can hold increases exponentially with the temperature—as anyone has noticed in a southern summer, the hotter it is, the more humidity or the more water vapor can be held in the air. So globally, as temperatures rise, not only is more water vapor produced, but less of it is forced to condense or precipitate, and the absolute water vapor content of the atmosphere increases—and with it, the temperature rises again.

SEE ALSO: Antarctic Ice Sheets; Biogeochemical Feedbacks; Climate Feedbacks; Evaporation Feedbacks; Ice Albedo Feedback.

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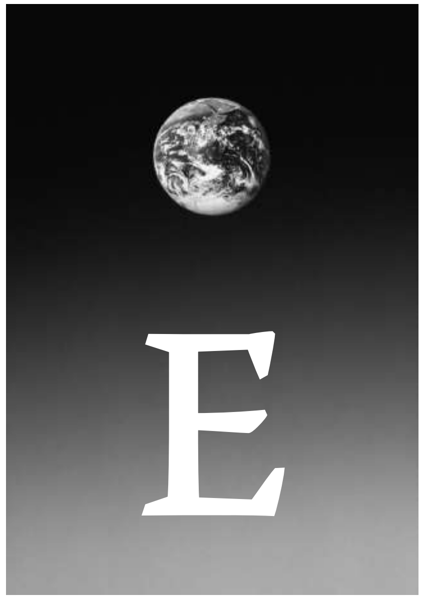


Earth's Climate History

CLIMATE IS NOT a static set of weather conditions, constant over eons; rather it varies, sometimes in dramatic ways, over time. The hot climate of the newly-formed Earth gave way to glaciers in a little more than a billion years, an immense time by human reckoning, but not nearly so long by geological standards. Earth's climate has alternated many times between hot and cold periods of varying magnitudes. Radiation from the Sun, the ocean currents, rainfall, wind, continental drift, the concentration of greenhouse gases in the atmosphere, volcanic activity, radioactivity in the Earth's core, the eccentricity of Earth's orbit around the sun, the tilt of Earth's axis, and photosynthesis all affect climate. Climate has not one, but, rather, myriad causes. Disentangling these causes is not easy, but it is necessary to understanding why climate changes over time. The current climate is warming. The culprit, carbon dioxide, has been increasing in the atmosphere, driving up temperature, and prompting speculation over Earth's future climate.

The interlocking scientific theories of the 19th century—Darwinism and uniformitarianism—implied that climate changed little, and then only gradually. uniformitarianism held that the climactic conditions prevailing today are very similar to the conditions that prevailed centuries and even eons ago. Charles Darwin matched his theory of evolution to the dictates of uniformitarianism. Darwin posited that species evolve gradually in response to slow and small changes in the environment. Climate might change, but neither abruptly nor by a large magnitude. In contrast, the advocates of catastrophism asserted that Earth has been racked by sudden changes. Modern geology has retained the kernel of catastrophism. The climate has changed quickly by geological standards, and by large swings in temperature and precipitation.

EARTH'S EARLY CLIMATE

Earth is roughly 4.5 billion years old. Its early climate was the hottest in the planet's long history. Temperatures were hot enough to liquefy rock, a circumstance that accounts for the absence of rock from the early geological record. The mass of radioactive elements in Earth's core was the maximum at the origin of Earth. The radioactive elements generated heat and pressure as they decayed, pushing molten rock toward Earth's surface. Volcanoes were active, bringing molten rock to the surface, where it liberated its heat. Volcanoes spewed carbon dioxide (CO_2) into the atmosphere, causing the greenhouse effect. Sunlight passed through the atmosphere and struck Earth, which absorbed some sunlight as heat and radiated the rest into space as infrared radiation. Rather than disappearing into space, the infrared radiation was absorbed by CO_2, heating the atmosphere. The amount of CO_2 in the atmosphere of the newly-formed Earth was 1,000 times higher than it is today, more than making up for the fact that the young Sun burned with only 70 percent the luminosity of its mature, current phase. At its origin, Earth received only as much sunlight as Mars receives today. The young Earth was too hot for water to liquefy. Instead, the atmosphere held all of Earth's water as vapor. Like CO_2, water vapor traps heat in the atmosphere, intensifying the greenhouse effect.

As the mass of radioactive elements in Earth's core diminished, the climate cooled, and the first rock formed roughly 3.8 billion years ago. The cooling of the atmosphere liquefied water vapor, which fell to Earth as rain. The deluge was greater than any rainfall since, filling Earth to a depth of 2 mi. (3.2 km.) and forming the primordial ocean. The origin of life around 3.5 billion years ago enhanced the cooling of the climate, for among the first life were single celled photosynthetic algae. Like modern plants, these algae consumed CO_2 and exuded oxygen. The reduction of CO_2 in the atmosphere weakened the greenhouse effect. Rainfall also diminished the amount of CO_2 in the atmosphere. CO_2 dissolves in rainwater to form carbonic acid, a process that removes carbon dioxide from the atmosphere. With the reduction in CO_2, temperatures dropped below freezing, causing the planet's first ice age roughly 3 million years ago.

The retreat of the glaciers one million years later inaugurated a long period of warm climate. The sun, burning steadily brighter, bathed Earth in its heat. Warm inland seas covered Earth, moderating the climate. Ocean currents circled the globe, spreading warm water from the equator to the poles. The warm climate persisted until 800 million years ago, when a series of ice ages and interglacials alternated the climate between cold and warm cycles.

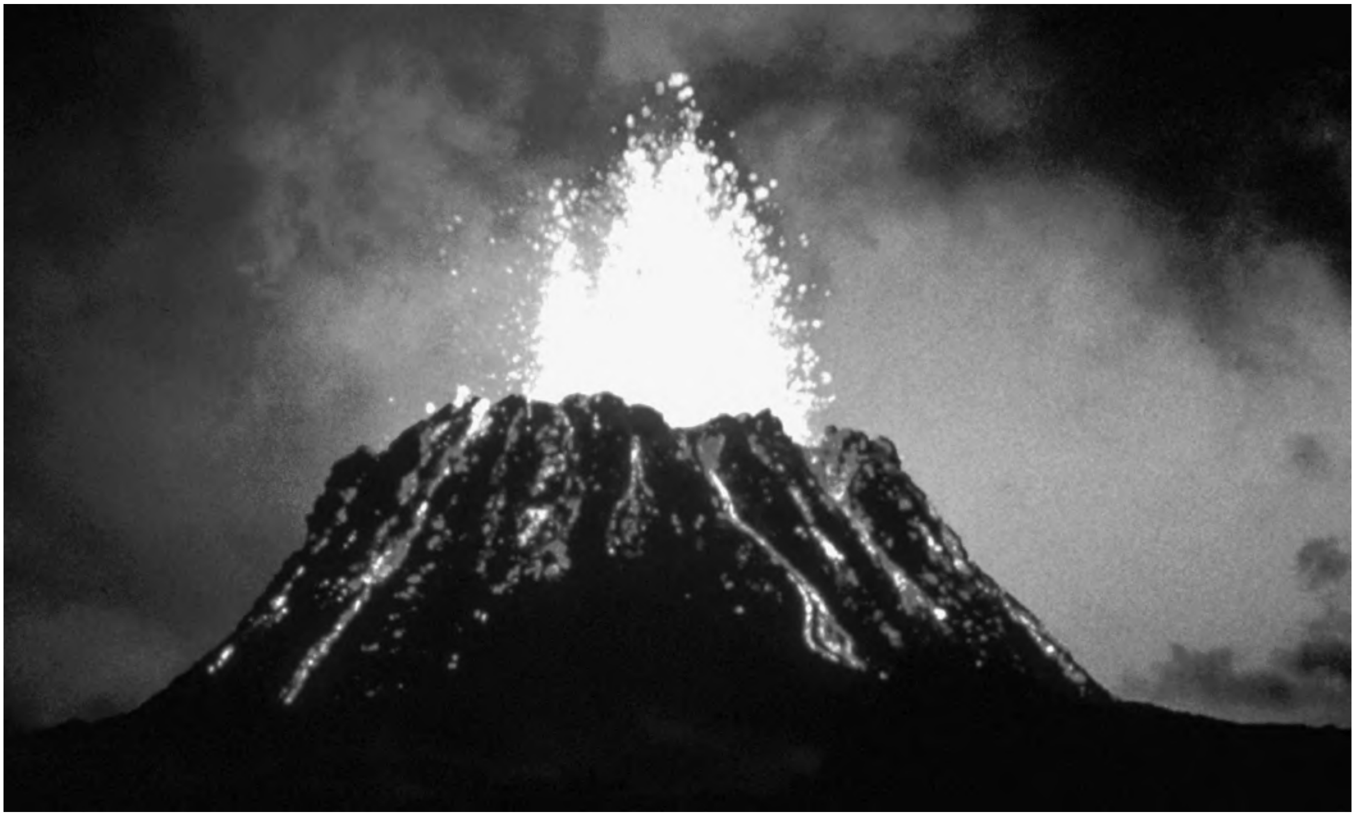
The multiple changes in climate may have an astronomical cause, in addition to terrestrial ones. Earth's orbit around the Sun is not constant, but changes its geometry. The orbit traces an ellipse that puts Earth far from the Sun at its greatest distance and near the Sun at its shortest distance. Because Earth's distance from the Sun varies, the amount of heat that Earth receives from the Sun fluctuates. Under these circumstances, Earth's climate alternates between hot and cold extremes, accounting for the advance and retreat of glaciers. At other times, Earth's orbit is nearly circular. Earth, at roughly a constant distance from the Sun, receives nearly the same amount of heat from it. Under these conditions, Earth's climate is uniformly warm, as it was during the Cretaceous Era.

EARTH WARMED

During the last Ice Age, glaciers covered the ocean as well as the land, killing photosynthetic algae that lived in the ocean. With algae in small numbers, they were able to remove only a fraction of CO_2 from the atmosphere. With no check on its accumulation, CO_2 increased in the atmosphere, causing the greenhouse effect. The greenhouse effect ended the Late Proterozoic Ice Age roughly 550 million years ago, inaugurating a new warm period. The lush plant growth of the Carboniferous Era (350–280 million years ago) confirms that the climate was warm and that CO_2, essential for plant growth, was abundant. Around 230 million years ago, the continents gathered into a single landmass called Pangea. Being near the equator, Pangea's climate was tropical. Even warmer was the Cretaceous Era (135–65 million years ago). Temperatures soared 20 degrees F (11 degrees C) warmer than in the current era. Forests covered Antarctica. Ocean currents again carried warm water to the poles. The transit of warm water to the poles caused polar water to be only 40 degrees F (4 degrees C) cooler than equatorial waters. The difference today is 75 degrees F (24 degrees C). The water at the bottom of the ocean, now near freezing, was then 25 degrees F (14 degrees C) warmer. Coral reef, which requires warm water to survive, grew 1,000 mi. (1,609 km.) closer to the poles than it does today. Antarctica was warm enough to support the growth of forests.

EARTH COOLED

The end of the Cretaceous suddenly reversed the climate. The consensus among scientists holds that an enormous meteor impacted Earth 65 million years ago. The meteor ejected a gigantic cloud of debris and dust and ignited widespread fires, which pumped ash into the atmosphere. The debris, dust, and ash blocked out much of the Sun's light, chilling the climate. So severe was the reversal in climate that the dinosaurs and a large number of marine species, unable to cope with the new conditions, perished.



Roughly 4.5 billion years ago, active volcanoes spewed carbon dioxide into the atmosphere, causing the greenhouse effect. Earth's early climate was so hot that all water vaporized, trapping heat in the atmosphere and intensifying the greenhouse effect.

The sudden reversal in climate has had a lasting, if erratic, effect on Earth. During the past 55 million years, temperatures have declined 20 degrees F (11 degrees C). Around 35 million years ago, the climate grew cold enough for glaciers to form on Antarctica. Yet, by 4 million years ago, the glaciers had melted and forests had returned to Antarctica. The forests were transitory: within one million years glaciers had once more spread across Antarctica and had begun to grow in the northern hemisphere.

The warmth of the Cretaceous returned briefly 130,000 years ago, when the climate was again warmer than it is today. The water from melting glaciers flowed to the oceans, raising the sea level 60 ft. (18 m.) higher than it is today. Approximately 30,000 years later, the climate cooled yet again, and glaciers once more spread across the continents, plunging Earth into its most recent Ice Age. Between 16,000 and 10,000 years ago, the glaciers in retreat, temperatures rose nearly 15 degrees F (8 degrees C). Toward the end of this era, and extending to 6,000 years ago, rain was plentiful. Africa had no deserts. Rather, Lake Chad, swollen with rain, was 10 times its current size. Salt Lake, in what is today Utah, was likewise several times larger than it is today. Variations in temperature were greater than they are today, because the tilt of Earth's axis was extreme. If Earth did not tilt on its axis, there would be no seasons, because the northern and southern hemispheres would receive the same amount of sunlight year round. However, Earth tilts on its axis 23.5 degrees. As a consequence, the northern and southern hemispheres receive differing amounts of sunlight during the course of a year, accounting for the seasons. The greater the tilt, the greater the amount of sunlight falls in summer, and the greater the darkness in winter. About 10,000 years ago, Earth tilted on its axis 25 degrees. The northern and southern hemispheres received 7 percent more sunlight in summer than they do today, and 15 percent more sunlight in summer than in winter. By contrast, the differential in sunlight between summer and winter is only 8 percent today.

Temperatures peaked 7,000 years ago at 2–3 degrees F (1–1.5 degrees C) above current temperatures. The climate remained warm and wet another 3,000 years. There was then no desert in the American Southwest, which received enough rainfall to sustain the growth of trees. Between 6,000 and 4,000 years ago temperatures rose 5 degrees F (2.7 degrees C) , melting parts of the glaciers that remained in Antarctica and Greenland. The water from these glaciers flowed to the ocean, raising sea level 300 ft (91 m.). The end of the rainy epoch 4,000 years ago turned the climate arid. Rainfall in the American Midwest fell 25 percent, even as July temperatures peaked 4 degrees F (2 degrees C) above current July temperatures. Deserts formed in the American Southwest, Africa, Asia and Australia. Along the Atlantic coast of North America, the climate remained warm and humid.

EARLY HUMAN RESPONSE TO CLIMATE CHANGE

Originating in Africa with a body adapted to warm weather, humans thrived in the moderate climate of antiquity. Inventing agriculture at the end of the most recent Ice Age, humans settled in the warm latitudes that sustained the growth of crops. At the margins, however, the climate was inhospitable. The Near East had long been arid. Around 4,000 years ago the Akkadians relied on rainfall, scant as it was, to irrigate their crops. When the rains failed, their civilization collapsed. Drought likewise extinguished the Mayan civilization of southern Mexico and Guatemala 1,200 years ago. In Europe, however, the Medieval Warm Period between 1,000 and 1,300 C.E. rewarded peasants with bountiful crops. They seldom went hungry, and landlords grew rich on the proportion of the harvest that they commandeered from the land. The favorable climate allowed Europeans to finance the crusades and the building of cathedrals.

Yet after 1300, the climate turned against Europeans. In only a generation, summers went from warm to cold and wet, and crops rotted in the fields. Having enjoyed a surplus of food, peasants were now on the verge of starvation. They clashed with landlords over who had a right to what little harvest there was. Malnutrition left Europeans vulnerable to disease, and the Black Death killed between one third and half the population. Climate had conspired with disease to inflict misery on a scale that is difficult to imagine. The cold climate intensified between 1645 and 1715 when the Sun, shedding one percent less sunlight than it does today, chilled Earth, cooling it 2 degrees F (1 degree C) . The diminution of sunlight corresponded with the low number of sunspots during these years. Sunspots are a measure of how much heat the Sun radiates into space and indicate, in this instance, that a small diminution in the sun's activity suffices to cool Earth. The eruption of Mount Laki, a volcano on Iceland, in 1783 spread volcanic ash and debris across the Northern Hemisphere, blocking out sunlight and cooling Earth. The eruption of Mount Tambora in Indonesia had a similar effect. By 1816, temperature had fallen 7 degrees F (3.8 degrees C) in New England and 5 degrees F (2.7 degrees C) in Europe. History records 1816 as the year that had no summer.

Although temperatures, with some fluctuation, have declined during the past 55 million years, they are beginning to rise again because of the greenhouse effect. Since 1750, the amount of methane, a greenhouse gas in the atmosphere, has risen 2.5 times. Fortunately, methane does not persist in the atmosphere, but breaks down in a few years. More worrisome is the amount of CO_2, which since 1750 has risen 31 percent. Unlike methane, CO_2 does not deteriorate, and has the potential to remain in the atmosphere for centuries. Since 1900, temperatures have increased 1.3 degrees F (0.7 degrees C) and the sea level has risen 6 in. (15 cm.) from the melting of glaciers in Greenland and Antarctica. Since 1973, the polar icecaps have shrunk six percent. The snow is melting from Mount Kilimanjaro in Africa and the Himalayan Mountains in Asia. Adding to the Greenhouse Effect is an increase in the number of sunspots since 1985. The increase in temperatures may intensify the climate, causing hurricanes in the Caribbean and Gulf Coast, and droughts in Africa and North America.

Curiously, temperatures and the amount of CO_2 in the atmosphere were higher 130,000 years ago than they are today; yet, the earlier warm climate was followed by an ice age. Therefore, scientists may not be able to predict if the current temperatures will spiral upward or will end in yet another ice age. Unsure of the future, humans are increasingly aware that their activity affects the climate. The burning of fossil fuels at a prodigious rate pollutes the atmosphere with more CO_2, threatening to raise temperatures still further. In the developed world, progressives talk about renewable energy, but despite their rhetoric, countries continue to pump CO_2 into an already crowded atmosphere. In Central and South America, people are chopping down the rainforest, removing the trees and plants that would have consumed some fraction of the CO_2. Earth, and with it the climate, may be in crisis.

SEE ALSO: Climate; Climatic Data, Historical Records; Ice Ages; Greenhouse Effect.

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Earthshine

THE *WORLD BOOK* defines albedo as "the ratio of light reflected to light received by a planet or other heavenly body." Earthshine arises from sunlight reflected from the Earth to the dark of the moon and back to the nighttime Earth. The albedo is due to the Earth's cloud cover and the diversity of landscapes. Leonardo da Vinci (1452–1519) first explained Earthshine in the 15th century. A simple technique was developed to measure the amount of sunlight that bounces off the Earth's surface and is subsequently reflected by the moon. Earthshine is faintly visible to the naked eye on the darker side of the crescent moon as an ashen glow. For many phases of the moon, Earthshine is easily visible by the naked eye.

André-Louis Danjon (1890–1967) performed the first rigorous Earthshine measurements in 1926. He captured 200 data points over a period of five years with his cat's eye photometer, and using a technique he pioneered called the Danjon scale. Danjon found it was important to take the measurements well after and well before a full moon or a new moon. Having an even area of bright and dim light when observing the moon's surface is needed to gain an accurate reading of Earthshine. After then, few measurements were taken, until NASA funded Project Earthshine in the 1990s to obtain albedo numbers. A value of 0.297 was obtained from the study. The research team used a 6-in. refractor telescope housed at California's Big Bear Solar Observatory. Earth's albedo decreased 2.5 percent during a period of five years. Satellite measurement of solar irradiance reported a variation of no more than .1 percent during an entire 11-year solar cycle. Some experts believe this deviation is too small to change climate or leave a terrestrial footprint of the solar activity cycle. Thus, Earth's reflectivity may be what is magnified in an indirect role of the Sun in climate change. If this ability to reflect light is degraded, by even as little as 1 percent, global warming could be accelerated.

Earthshine measurements using low-power Earthbound telescopes are practical since they are cost-effective, easy to conduct, and immediately cover a large portion of the Earth's surface. Satellite determinations of the albedo, however, are costly and require precise calibration to obtain good results. In addition to capturing measurements when there is a clearly-defined moon crescent, it is important to average a large number of data points. This is to remove the effects of a single measurement location where a nighttime measurement would see more light reflected by a large landmass on the opposite side of the planet, or where less light would be reflected by an ocean. This process of averaging provides a more accurate reading of a changing albedo. Modern techniques enable a measurement accuracy of 2 percent for each reading, which is equivalent to measuring Earth's emission temperature to within 0.8 of a degree C.

Earth's cloud cover dominates the "shininess" feature of the planet. Clouds reflect around 50 percent of incoming sunlight. Snow and ice reflect even more sunlight, usually from 50–90 percent. The melting of polar ice and disappearance of Greenland's ice cover leaves more water, which reflects only 8 percent of sunlight, and uncovers more land, which is also a poor reflector of sunlight, usually with a reflectivity of 10–25 percent. The darker the surface, the lower the albedo, and the more solar energy absorbed. The dark side of the moon usually refers to the side of the moon that the human eye cannot see from Earth, even with the aid of a telescope. In the controversial world of climate change and the use of Earthshine as a tool to gauge global warming, the dark side of the moon now refers to the dim side of the moon in its crescent configuration. The moon's surface provides astronomers and climatologists another means for measuring both sunshine and Earthshine, and to assess the global warming phenomenon.

SEE ALSO: Albedo; Climatic Data, Atmospheric Observations; Measurement and Assessment; Sunlight.

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East Timor

FORMERLY A PORTUGUESE colony, East Timor (or Timor Leste) occupies the eastern half of the island of Timor, along with the enclave of Oecussi, on the northwest coast of the island. It has a land area of 5,743 sq. mi. (15,007 sq. km.), with a population of 947,000 (2005 est.), and a population density of 166 people per sq. mi. (64 people per sq. km.). Forests, with a small timber industry, cover much of the country. Much of the arable land is used for subsistence farms and small coffee plantations, and coconut, cloves, and cocoa are also grown commercially. Because of the undeveloped nature of the country, and the low standard of living, the rates of carbon dioxide emissions are extremely low, measured at 0.2 metric tons per person in 2002 and 2003.

During a visit to the island around 1901, an Australian chemist, traveling to find new pharmaceutical products, spotted deposits of oil, but attempts to locate oil on land during the 1930s never found any substantial supplies. However, during the 1980s, vast oilfields were found offshore in the Timor Sea between East Timor and Australia. Jointly developed by Australia and Indonesia, East Timor lay claim to these fields after its independence in 1999. The oilfields are now jointly owned by East Timor and Australia. As a result, East Timor has become a petroleum exporter, contributing to climate change and global warming. The major effect of global warming on East Timor is likely to be increased damage to coastal areas, including Dili, the capital. Some problems with agricultural production may also begin as the temperatures rise, making it harder to grow some crops that normally grow in more temperate climates.

SEE ALSO: Agriculture; Oil, Production of; Sea Level, Rising.

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Ecological Footprint

THE ECOLOGICAL FOOTPRINT is a metaphor for ecological impact, regardless of where that impact occurs. The ecological footprint is also an ecological accounting tool, a measure of the environmental impact of consumption and subsequent waste discharge. Consumption items are divided into food, shelter, transportation, and consumer goods and services. The consumption impact is measured by converting impact variables into the single unit of land, measured in hectares or acres. This includes land appropriated by fossil energy use, the built environment, gardens, cropland, pasture, managed forest, and land of limited availability, including untouched forests and non-productive areas, such as deserts and icecaps. The major strength of the ecological footprint as a way of measuring the sustainability of cities is that it enables a picture of the flow of materials into and out of the city.

Bill Rees and his students, particularly Mathis Wackernagel, developed the concept of Ecological Footprints (EFs) as a way of ascertaining sustainability at the University of British Columbia in Vancouver, Canada. Most analyses of sustainability, whether radical or mainstream, recognize that major concentrations of human consumption generate impacts far beyond a nation or a city's formal boundaries. Prior to the invention of the concept of EFs, very few policy, lobby group, or academic analyses successfully moved beyond highlighting these external impacts as issues that needed to be addressed. Ecological footprint analysis managed to put forward a way of both measuring and vividly demonstrating how ecological impacts extend far beyond the official area of cities or countries.

The EF approach is similar to the idea of "ghost acres" developed by the Swedish academic Georg Borgstrom in 1965. The focus of Borgstrom's work was adequate nutrition for a growing population. The ghost acres were comprised of fish acreage and trade acreage. Jim MacNeill and colleagues extended the concept in the lead-up to the Earth Summit in Rio de Janeiro in 1992. The metaphor of ghost acres for food production was extended to include other consumption concerns, and repackaged as "shadow ecologies." More recently, William Catton discussed the idea of "phantom land." This concept refers to how humans currently use the ecological productivity of ecosystems that no longer exist. For example, nature cannot replace fossil fuels such as coal and oil at the rate that humans are diminishing the stock of nonrenewable resources. The goal of ecological footprints is to document "overshoot," which refers to the excess global demand over global supply, of nature's resources for human use.

Since the original EF methodology was developed, a number of different approaches have emerged. At the Footprints Forum in Siena, Italy, in June 2006, an international standard for footprinting was introduced to ensure consistency. This standard was divided into application standards and communication standards. Standard number 15 attempts to clarify the relationship between EFs and sustainability; that ecological footprinting is a necessary criterion for sustainability, but it is not an absolute indicator of sustainability. This point is crucial because the EF is a tool that may be used to inform choices and policy development, but it is not a predictive tool, nor can it be a surrogate for environmental policy.

Although the national scale is used as a benchmark in the 2006 Footprint Standards, the EF approach can be used at a variety of scales that have been labeled sub-national. These include cities, regions, states, counties, and organizations. In the case of a city, the approach can be used to calculate the equivalent amount of land consumed for a city to function. This equivalent amount of land is influenced by changes in both population and per capita material consumption.

Critiques have been made about the ecological footprint concept. These include questioning the desirability of converting everything into a single unit, called land. Although the goal may be deciding how best to limit the footprint. However, reducing the size of the ecological footprint does not equate to reducing environmental impacts if the uniqueness of nature, the cultural values associated with particular sites, and so on, are lost in this quantification process.

There is also the problem of boundary definition for comparing ecological footprint scores. It is easy to achieve a smaller EF where the boundary around a city is drawn wide enough to include agricultural land. There have been studies of many cities around the world using similar methodologies, which make it possible to compare the results and arrive at some logical, but erroneous, conclusions. Areas with a high population and with little or no agricultural land within their borders will inevitably generate a higher EF, unless there is a huge difference in the material consumption between areas.

The high ecological footprint for many places is primarily due to the use of "energy land." This land is calculated as the amount of land and water required as carbon sinks to sequester the greenhouse gas emissions generated by human activities, including energy production, agriculture, and transport. This carbon component now comprises about half the total EF. It has increased approximately nine fold since 1961 because of reliance on fossil fuels.

Critics of the ecological footprint methodology question the assumption that land is used only for single functions, or that land uses only meet one particular ecological service. While footprint advocates claim that the ecological footprint tends to underestimate humanity's demands on the available resources of the planet, critics claim that one implication of ignoring the potential of land to be used for multiple purposes simultaneously is to bias the ecological footprint upwards.

The concept of the ecological footprint as a way of measuring sustainability and as a catalyst for positive changes has become increasingly popular in environmental policy and environmental planning work. While it can be applied at a variety of scales, the concept has been very important in encouraging urban planners and environmental managers to look beyond the traditional scales of planning and environmental management to consider the regional and international environmental impacts of urban activities.

SEE ALSO: Carbon Sinks; Energy Efficiency; Food Production; Resources; Sustainability; Technology; Transportation.

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Economics, Cost of Affecting Climate Change

THE MAJOR PROBLEM with determining the economics of affecting climate change is the number of variables involved and the inability, even using advanced modeling theories, to accurately project these variables for more than a few years. Projecting the economic costs of doing nothing to combat climate change, or the costs of attempting to do something, are hampered not only by understanding the effects of the climate change on national, regional, and global economies, but also by the infinite variables that must be incorporated into the economic models. These variables are contingent on the infinite variables incorporated into the currently evolving and competing climate change models.

MODELING DIFFICULTIES

Even if the climate change model of the United Nations Environment Programme (UNEP)/World Meteorological Organization (WMO) Intergovernmental Panel on Climate Change (IPCC) is the accepted model, the IPCC model itself is evolving at such a rapid rate that any economic projections based on it are outdated in no more than five years. The 2001 IPCC data used to create most current climate change models and to extrapolate economic projections was already out of date before the spring 2008 IPCC report updated the data and created a model synthesized from the competing models. As the data and modeling of climate change evolves, the economic projections based on them evolve, making the economic projections less reliable because their assumptions and infinite variables are built on the changing assumptions and variables of climate change models that are themselves evolving.

Variables include policy and regulatory shifts, population growth and densities, the pace and type of climate changes, agricultural and forestry losses, changes in governments, changes in regional alliances, wars, damage from catastrophic storms, the impact of climate change on human health, technological change, utility costs, changes in energy use and generation, savings from efficiency improvements, and water shortages. Modeling these variables is made even more daunting by the need to project the range of potential changes in these quantifications and then amalgamate them into a coherent economic model that itself rests on the range of projected quantifications of the evolving climate change models. Additionally, any projection becomes outdated if massive policy changes are introduced. If, for example the four major greenhouse gas (GHG) emitters, the United States, China, Russia, and India, adopted the Kyoto Protocol, the costs of adoption, estimated at $350 billion (2001–10) if Kyoto was universally accepted, would have to be integrated into future economic projections. These future economic projections would then have be readjusted once the climate change models were remodeled integrating the universal acceptance of Kyoto or another policy shift

Another challenge in projecting the economic impact of climate change or in affecting climate change is that there is no standard format for making these projections. Some of the studies use annual projections, some five-year projections, some decade projections, some 100-year projections, and some 200-year projections. The longer the projections, the more assumptions must be made to create the projections, making the projections more subject to variances in the original projection and, thus, less reliable. This difficulty is seen in the competing projections of impact and mitigation based on the 2001 IPCC data and correlative climate change models.

CURRENT ECONOMIC MODELS

The median projection based on the 2001 IPCC data is that inaction will reduce global Gross Domestic Product (GDP) by 5 percent annually, resulting in an annual global loss of $3.341 quadrillion using a rounded World Bank 2006 global GDP projection of $67 quadrillion (in 2006 values). Assuming that emissions can be stabilized by 2025, the projected annual reduction in the global GDP due to climate change will be one percent annually, resulting in an annual global loss of $670 trillion (in 2006 values) using the World Bank 2006 GDP projection of $67 quadrillion. This study asserts that the costs escalate radically if the cost of feedback loops is integrated; that is, changes in one variable can lead to changes in another variable, such as the melting of the permafrost releasing more carbon dioxide into the air. This study assumes a net social cost of carbon dioxide of $85/ton, but other studies assert that the cost is less, perhaps as little as $2.50/ton. This study also does not offset the mitigation savings ($2.68 trillion annually) with the cost of mitigation.

Chris Hope's University of Cambridge PAGE (Policy Analysis of the Greenhouse Effect) model estimates the cumulative cost of climate change approximates a much smaller estimate of $74 trillion (in 2000 prices from the then value of the Euro) by 2200, and asserts that if mitigation efforts are begun immediately that the estimate would be reduced to less than half that amount. These projections vary from those of the IPCC report partly because different economic and climate change models and modeling assumptions, the inclusion of different variables in the models, and different means of calculating the variables that are in common.

Claudia Kemfert's World Integrated Assessment General Equilibrium Model (WIAGEM) from the German Institute for Economic Research estimates the cost of inaction to be $20 trillion annually by 2100, approximately 6–8 percent of the projected 2100 GDP. This estimate assumes the implementation of climate change mitigation policies limiting the increase in the average global temperature to 3.6 degrees F (2 degrees C). WIAGEM estimates the annual cost of mitigation to be $3 trillion annually. The WIAGEM cost estimate rises to $32 trillion annually if no mitigation is undertaken. The WIAGEM estimates assert that the net loss of abating the rise the average global temperature by only 3.6 degrees F (2 degrees C) until 2100 results in a net savings of $9 trillion annually. The WIAGEM study asserts that if mitigation does not begin until 2025 that this underestimate the costs of climate change by 2100, and correlatively the sooner, the more widely, and the more actively that mitigation is pursued, the more this figure overestimates over project the cost. The IPCC Third Assessment Report (TAR) *Climate Change 2001* projects annual mitigation costs of $78–$141 billion. Other studies assert that at present values, the cost of mitigation exceed $2.5 trillion annually, in agreement with the WIAGEM study.

ASSUMPTIONS OF CURRENT ECONOMIC MODELS

All of these studies make assumptions about future data. For example, each study makes assumptions on the future costs of money. The IPCC TAR assumes certain economic offsets, through tradable emissions permits, and makes additional assumptions within projected ranges for monies generated or saved through taxing structures, incentive sector tax cuts rewarding greater fuel efficiencies or encouraging alternative forms of energy, incentive sector tax increases reducing carbon fuel consumption, the costs of labor, market conditions, the value of technological innovation, and recycling methods. Assumptions are also made about the rate of regulatory and policy changes and the impact of these changes. For example, different studies make different reduction projections of carbon intense energy by assuming different lengths of possible life extensions of existing nuclear power generation plants, different lengths of time to get new nuclear plants producing energy, and different lengths of service for the new and refurbished nuclear plants.

Assumptions are also made concerning the net return on new technology created to meet all of the new policies and regulations aimed at mitigation. For example, it is assumed that money, jobs, and new businesses will be generated by researching and creating alternative forms of energy, hybrid cars and their support systems, new power plants using energies such as wind or geothermal, and other, as yet unforeseen, technologies. Conversely, however, the expenditures for these new technologies will draw monies from other existing sectors costing loss of jobs, revenue, and taxes that could offset the economic advantages of the new technologies. The WIAGEM study projections are made assuming some value to technological change and assuming no value to technological change.

Though it is difficult or even impossible to quantify the real monetary costs of affecting climate change, climate change will have great impact on society, population densities (out migration and in migration), agriculture, infrastructure, manufacturing, and intergovernmental relations. These effects will bear more intensely on the poor than those wealthy enough to adapt and prosper from climate change. The cost of doing nothing is high. This can be seen in the cost of catastrophic natural disasters that pale in comparison to the potential catastrophes that even the most conservative climate change models project. The total cost of catastrophic storm damage in the United States 1980–2005 is estimated to be in excess of $560 billion, with Hurricane Katrina alone causing between $150–$200 billion in economic damage. Worldwide natural catastrophes cost another $220 billion.

SEE ALSO: Climate; Climate Change, Effects; Climate Cycles; Climate Models; Computer Models; Economics, Impact From Climate Change; Historical Development of Climate Models; Impacts of Global Warming.

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Economics, Impact From Climate Change

THE ECONOMIC IMPACTS of climate change are the net costs or benefits from such climatic change on the global economy relative to a prior world with constant climate. Economic impacts are usually measured relative to a pre-industrial average climate (1750–1850). Climate change will directly and indirectly affect people's lives, the physical environment, as well as the economic growth of developing and developed countries. The economically most significant physical changes brought on by climate change are shifted temperature, rainfall, and radiation patterns, because these factors serve as inputs to production and affect human well-being directly or indirectly through socioeconomic and ecological systems. The largest effects are likely to occur through impacts on the global water balance, the food production system, human health, land, and ecosystems. In addition to gradual changes in the geographic distribution of temperature and rainfall, extreme and catastrophic events occurring with greater frequency are expected to cause much damage. Economic impacts of climate change are also predicted to differ greatly between developing and developed countries.

MODELING THE ECONOMICS OF CLIMATE CHANGE

Translating changes in future climate into economic impacts measured in monetary terms is a challenging task for a number of reasons. First, in order to understand how climate will affect the global and regional economies, a solid understanding of how the economically relevant dimensions of climate are going to vary at these spatial scales is required. Global climate models (GCMs) provide predictions of the main variables of interest, rainfall and temperature, at increasingly finer temporal and spatial resolution. However, there is much uncertainty remaining over the predicted spatial and temporal distribution of climate across GCMs and emission scenarios. In economic impact evaluation, this uncertainty is amplified by the uncertainty about how individuals, firms, and governments respond to the changing climate directly, and are affected by it indirectly through its impacts on ecosystems.

The economy is a complex system, whose response to a changing climate must be studied using models because, unlike physical scientists, economists lack the opportunity to conduct controlled experiments on this system. Agents in this complex system will sometimes respond in offsetting directions to climate changes. Individuals, for example, respond to incrementally hotter summers and milder winters by cooling more during the hot months and heating less during the cold months, resulting in increased energy consumption in the summers and decreased energy consumption in the winters. Further, responses to the changing climate may be gradual and small or abrupt and sizable. For example, farmers may respond to slightly drier and hotter growing seasons by planting and harvesting earlier in the season. If, however, summers become significantly drier and hotter, farmers may switch crops and/or install irrigation equipment. More households may purchase air conditioners or run existing ones not only during the day, but also during the night. Such adaptions make it extremely difficult to predict impacts on humans and the economy as a whole, because individuals respond to exogenous changes in often-unpredictable ways.

One aspect that is especially difficult to predict is the investment in successful research and development of new technologies. The energy intensity of most industrialized economies has dropped significantly since World War II. This is partially due to improved energy efficiency of capital, but also due to a structural shift of these economies away from manufacturing toward the production of services. Much of manufacturing, which is thought to be more carbon intensive, has shifted to the developing world. Predicting the future path of energy efficiency and structural composition of the worlds' larger economies is a difficult task. This is especially true for technological innovation, which often progresses in discrete leaps that are virtually impossible to predict.

The timespan used to assess the economic impacts of climate change is much longer than that for many other environmental problems, due to the long atmospheric lifespan of many greenhouse gases. While there is evidence of climate change impacts at the beginning of 21st century, many of the potentially larger effects are expected to occur after mid-century. In order to evaluate the potential costs of climate change, economists discount its future costs and benefits. Discounting essentially recognizes that a dollar today is worth more than a future dollar, because investments are productive and, therefore, resources today are more valuable than resources tomorrow. This implies that if there are two equally damaging outcomes 10 years apart, the second bad outcome would be judged to have lower current dollar damages. There is a much debate over the practice of discounting and the choice of discount rate. Some advocate a discount rate of zero. The choice of discounting method and discount rate has a significant impact on the calculated damages valued in present-day currency.

There are several classes of models used to simulate the economic damages from climate change. Statistical/econometric models are used to estimate the benefits/damages from climate change on, for example, agricultural yields and net profits at the farm or county level using historical data. The estimated relationship between yields or net profits and climate based on observed data is then coupled with GCM output to provide estimates of future yields and farm profits. The advantage of the econometric approach is that it uses actual observed data, which reflects individuals' responses to already-observed changes in climate. The disadvantage of this approach is that these studies deal with specific sectors at the country or a lower level of spatial aggregation. Therefore, many studies are required to obtain global estimates of impacts. Finally, these models are sensitive to estimation technique and the choice of variables used to explain variation in yields/net profits. Several econometric studies have been conducted to estimate the impact of climate change on agriculture, mortality, energy demand, water demand, ecosystem damage, and stream flows.

One alternative to modeling the potential damages from climate change is the use of large-scale simulation models. This computer-based modeling approach represents the different sectors of the global or national economy individually, and assumes specific climate sensitivities for the relevant sectors. As in reality, the economic sectors are interlinked; thus, climate-change induced damages, for example, in the agricultural sector may affect labor markets, which may affect wages in the agricultural (and potentially, other) sectors. Some of these simulation models have built in the fact that economic growth is directly linked to the amount of greenhouse gases emitted into the atmosphere.

Through this feedback loop, climate change impacts in the model depend on emissions, which are dependent on the state of the economy. The advantage of these simulation models is their ability to represent spillover effects across sectors and the feedback between the economy and the climate system. The disadvantage of these complicated computer models is the need to make a assumptions concerning how individual sectors of the economy are linked, as well as how they respond to changes in climate. Results from econometric studies are often used to inform these simulation models, yet the necessary number of parameters needed in these simulation models is much greater than what our current knowledge from econometric models. The simulation models do have the crucial advantage of simulating the impacts of different policy tools on emissions, as well as on the economy as a whole.

DIRECT EFFECTS OF CLIMATE CHANGE

The direct effects of climate change that are best understood are the impacts of temperature, the hydrological cycle, and sea-level rise. The increase in globally-averaged temperatures by mid-century will potentially boost production in temperate climates by expanding arable land, lengthening growing seasons, and increasing yields. Negative impacts are likely to affect the world's poorest countries, where plants are already suffering from temperature and water stress. Due to their geography, low incomes, and importance of the agricultural sector, developing countries are more exposed economically to the risks from climate change.

Sub-Saharan Africa stands out as an already famine-stricken region, with the potential of putting an additional 10 million people at famine risk, increasing stress on already fragile political and economic systems. Some shortfalls during periods of famine could be met by imports, assuming functioning markets (not always be a valid assumption). Parts of South Asia responsible for a major share of global rice production are expected to experience drier, warmer climates, although these effects are expected to be significant only after 2050.

Rising sea levels increase the risk of coastal flooding. The largest flood risk and saltwater intrusion potential is in south and Southeast Asia. Vegetable production, aquaculture below sea-level, and coastal fisheries are going to be most severely affected. The effects from rising sea levels are amplified by increased anticipated short periods of extreme rainfall, as well as on and offshore storm episodes. Rising sea levels will negatively impact food security in south Asia, coastal zones in Africa, as well as island-states worldwide. Major affected food production centers in delta regions are found in Vietnam, Bangladesh, India, and Thailand. In some areas, coastal land can be replaced by converting upland areas with increased temperatures to agricultural land, although population movement towards urban centers at coasts and in delta regions may result in large negative impacts for the small farm production sector. Saltwater intrusion may further negatively impact irrigation systems in coastal areas. Rising sea levels may displace as many as 200 million people by mid-century. By the end of the century, 20 percent of Bangladesh could be flooded, if sea levels were to rise by 39 in. (100 cm.).

INDIRECT EFFECTS OF CLIMATE CHANGE

A major indirect effect of climate change on agriculture will be the lower availability of irrigation water.

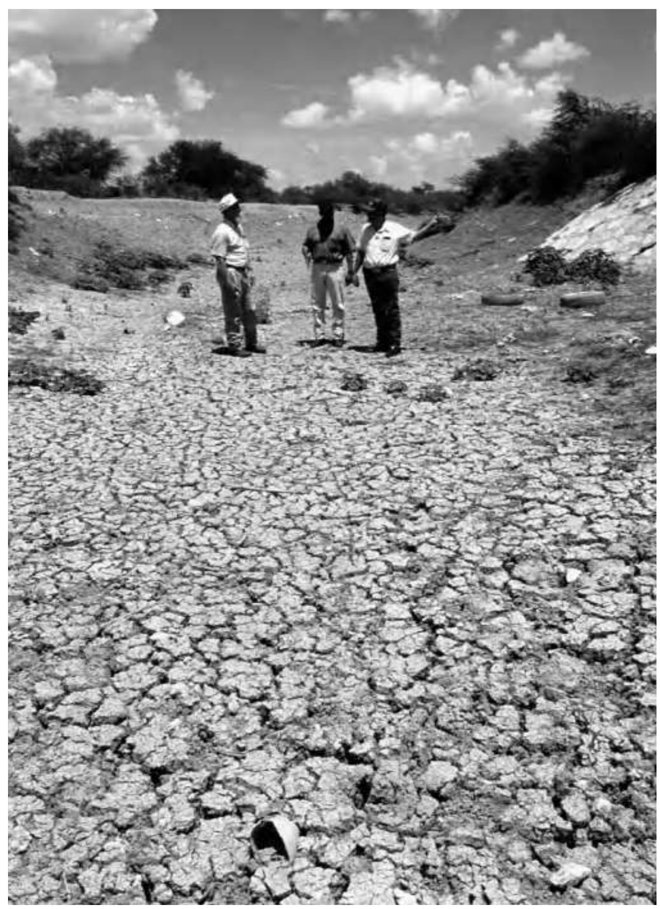
The main mechanisms through which climate change has an impact on irrigation water are less runoff and groundwater recharge, combined with increased rates of extraction in many parts of the world. The main geographic areas of concern are India, which in the recent past has seen a slowdown in the growth rate of rice yields, southern and North Africa, some of Latin America, and parts of Europe. Droughts and the lack of water may spark or reignite political and military conflict between countries whose water systems are interdependent. The indirect impacts of decreased rainfall and the increased frequency of droughts will drive up wildfire risk and, even in the short-term, change the distribution of pests. Decreased frequency of winter frosts will also affect the spatial distribution of pests. Historically, famines were caused by pests, which are becoming an increasing concern. In addition, marine ecosystems, home to the world's fisheries, will be affected though climate-induced acidification of the oceans.

Impacts on human health due to global warming will come directly from increased heat stress and malnutrition. Additionally, vector-borne illnesses such as malaria will become more widespread in areas near the Equator, whereas deaths from extreme cold may decrease at high latitudes. Further, climate change has already and will further impact ecosystems leading to devastating species loss. The loss of these species affects the global economy through their loss as measured by their existence value and their potential uses in the pharmaceutical and ecotourism sector.

MONETARY IMPACTS OF CLIMATE CHANGE

While it is very difficult to reliably estimate the monetary impacts of climate change, one study estimates that climate change may lower India and Southeast Asia's gross domestic product by 9–13 percent by the end of the century, compared to what it would be in the absence of climate change. An estimated 145–220 million more people may have to subsist on less than $2 a day, resulting in 165,000–250,000 additional annual child deaths in south Asia and sub-Saharan Africa attributable just to lower income. Lower farm profits will increase rural poverty rates, preventing farmers from investing in the necessary capital to expand and secure future production.

A few developed economies will benefit from moderate global warming in the short term, yet are at risk under scenarios predicting greater warming toward the end of the century. Canada, Russia, and Scandinavia may see higher crop yields, fewer cold-related deaths, lower heating fuel needs, and an influx of winter tourists, initially. However, warming in these countries is predicted to progress faster, requiring ecosystems to adapt more quickly. Lower latitude high-income countries are more vulnerable to consequences from climate change. Even a 2–3 degree increase in temperatures may lead to significant decreases in water availability in southern Europe and California. Regions relying on snow packs for agricultural water storage are predicted to experience a more volatile water supply throughout the century. Predictions for the world's largest economy, the United States, are a gain or loss in GDP of one percent at moderate increases in global temperatures, with potentially negative consequences at higher temperature increases.



If summers become significantly drier and hotter, farmers may switch crops and/or install irrigation equipment.

A major concern are the economic impacts of extreme events, such as the shutdown of the thermohaline circulation, extreme shifts in regional weather patterns, shifts in El Niño–Southern Oscillation (ENSO), changes to the monsoon, as well as the potential melting or collapse of major ice sheets. It is estimated that costs of extreme weather events could be on the order of 0.5–1 percent of global GDP by 2050, and higher as the globe gets warmer. Even moderate increases in hurricane wind speed of 5–10 percent could double annual economic damages from hurricanes. In addition, costs of flooding in Europe could triple or quadruple, unless flood management actions are taken. Extreme heat events, such as summer 2003, which killed 35,000 people and caused $15 billion in agricultural damages, could be quite common by mid-century. More large-scale shocks could potentially disrupt global financial markets and trading patterns, if they interfered with transport and communications infrastructure.

MITIGATION POLICIES

One unknown that will greatly affect the impacts of climate change on the economy is the degree and type of mitigation policy chosen by the international community. Global government action on climate change began with the Rio Earth Summit in 1992, which resulted in the Kyoto protocol of 1997. Ratifying industrialized countries agreed to cut back their emissions by a collective average of 5 percent of 1990 level emissions. Successor agreements require even more stringent cutbacks to achieve stabilization at roughly double pre-industrial concentrations of CO_2 in the atmosphere. Even though carbon-containing fuels have served as one of the main inputs to the production of goods and services since the Industrial Revolution, decreasing their use does not necessarily imply decreasing the amount of goods and services produced.

The use of substitute fuels with lower life-cycle carbon content, or the more efficient use of existing fuels by improving combustion technology, or switching to hybrid technologies can be encouraged. In order to decrease the amount of carbon emitted into the atmosphere, governments can use command and control regulations, which prescribe the technology used or the total amount of carbon emitted by each source. An alternative would be to employ flexible instruments, which may reach the same emissions reductions, but at a lower cost. Two examples of such flexible instruments are carbon taxes and cap-and-trade systems. Cap-and-trade systems rely on the trading of so-called carbon permits, where the regulator determines the total emissions of carbon by all sources through the number of permits issued. A carbon tax essentially imposes a per unit fee on each ton of carbon emitted. Under certain assumptions, these methods provide reductions at least cost. The choice of policy instruments also has implications for technological innovation. It has been shown that taxes and cap-and-trade programs provide much stronger incentives for technological innovation than command and control strategies such as emissions or technological standards.

SEE ALSO: Climate Models; Computer Models; Economics, Cost of Affecting Climate Change; Global Warming; Policy, International.

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Ecosystems

ECOSYSTEMS ARE DEFINED as communities that involve dynamic interactions among living elements (such as animals, plants, and microorganisms), and the inanimate elements of their environments. All parts of an ecosystem need to work together to maintain the proper balance of the system, and it is necessary for all ecosystems to function in conjunction to maintain balance.

The term ecosystem was first used in 1930 by Roy Clapham (1904–90), an appointee to the Demonstratorship in Botany at England's Oxford University. At the time, Clapham was studying plant ecology under the guidance of Botany Department Chair Arthur Tansley (1871–1955), a pioneer in the field of ecology. Two decades after Clapham and

Tansley first articulated the concept of ecosystems, ecologists began including the study of ecosystems as a distinct field of study within the discipline of ecology. Scientists have since identified eight major ecosystems: the temperate forest, tropical rain forests, deserts, grasslands, the tundra, the taiga, the chaparral, and the ocean.

An ecosystem may be as small as a puddle or pool of water, or as large as the Sahara Desert or the Atlantic Ocean. The ecosystems of the tropical forests provide a classic example of the extent of ecosystems. In these forests, thousands of vegetable and animal species that live in the air and on the ground interact with millions of surrounding organisms. Within each ecosystem, the habitat is a physical element that combines the natural and adaptive conditions of particular species. All ecosystems are dynamic. Changes may be temporary in response to outside events such as forest fires or natural disasters, or they may occur according to established cycles. Commonly occurring factors that affect changing ecosystems are nutrient availability, temperature, light intensity, grazing intensity, and species population density. Six ecosystems are identified as most necessary for supporting life on Earth; agroecosystems, forest ecosystems, freshwater ecosystems, grassland ecosystems, coastal ecosystems, and urban ecosystems. The integral relationship between these ecosystems and human life is demonstrated by the fact, half of the world's jobs are dependent on agriculture, forestry, and fishing. In the poorest sections of the world, 70 percent of all jobs are derived from these industries.

BIOMES AS GROUPS OF ECOSYSTEMS

Biomes, sometimes confused with ecosystems, are in reality composed of a number of similar ecosystems that work together to maintain the critical balance of the environment. The Earth itself is a biome, as are the Great Basin, the High Plains, and the Kalahari Desert. Through global warming and climate change, human behaviors are altering vital ecosystems throughout the world, including those that make up the food chain, the carbon cycle, the nitrogen cycle, and the water cycle. The critical nature of this dilemma is evident in the well-documented loss of species, their habitats, and ecosystems as a result of human pollution and overexploitation of resources. Particular attention is being paid to the ecosystems of Antarctica, the Arctic, the Bering Sea, and the Greater Yellowstone Ecosystem. In the Arctic, scientists have identified two major climate and ecosystem changes during the past 50 years, in part as a response to warming temperatures, that have precipitated a transition from primarily cold Arctic ecosystems of the pre-1970 period to the to sub-Arctic conditions during 1970–2000. The Bering Sea provides the vast opportunities for studying the ecosystems of various bird and marine mammal populations.

In 1992, at the Earth Summit in Rio de Janeiro, member nations negotiated the Convention on Biological Diversity, popularly known as the Biodiversity Treaty. The treaty, which was signed by 196 countries, became international law on December 29, 1993. The treaty formally recognizes the interrelationship between human life and various ecosystems and encourages universal commitment to conserving biological diversity and using all biological resources responsibly. It also calls for equitable sharing of genetic resources among developed and developing countries.

In 2001, 1,300 scientists from 95 nations began working on the Millennium Ecosystem Assessment (MA) under the auspices of the United Nations. The assessment team is charged with identifying the effects of global warming and climate change on various ecosystems and determining ways to employ conservation and sustainable development to check the pace of ecosystem failure and environmental degradation, while improving human well-being. Between 2001 and 2005, the MA published five technical volumes and six summary reports. Scientists involved in the MA have concluded that 60 percent of the 24 ecosystems under investigation are being degraded as a result of human behavior. MA scientists have learned that this degradation is leading to the emergence of new and old diseases, abrupt alternations in water quality, the presence of dead zones in coastal waters, the collapse of fisheries in many sections of the world, and shifts in regional climate. While agreeing that the ecosystems of tropical forests and coral reefs are particularly vulnerable to global warming and climate change, the MA has identified degrading dryland ecosystems as the most significant threat to human health because of these are the areas where poverty is greatest.

SEE ALSO: Arctic Ocean; Carbon Cycle; Climate Change, Effects; Deserts.

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Ecuador

LOCATED ON THE Pacific Coast of South America, Ecuador is located on the equator (from where it takes its name), and has a land area of 98,985 sq. mi. (256,370 sq. km.). It has a population of 13,850,000 (2005 est.), and a population density of 122 people per sq. mi. (47 people per sq. km.). Six percent of the land is arable, 18 percent is used for meadows and pasture, mainly for cattle and sheep, and 40 percent of the country remains forested. Hydropower generates 75 percent of its electricity, with the remainder from fossil fuels. These contribute to a relatively low rate of per capita carbon dioxide emission, 1.6 metric tons per person were generated in 1990, rising slightly to a peak of 2.2 metric tons in 1993, and falling gradually to 1.8 metric tons per person by 2003. Some 84 percent of the carbon dioxide comes from liquid fuels, with 9 percent from gas flaring, and 5 percent from the manufacture of cement. With the heavy use of hydroelectric power, electricity production only accounts for 10 percent of these emissions, with 41 percent made by the transportation sector.

While Ecuador has contributed little to cause global warming and climate change, the country has seen a rise in annual temperature by about 0.18 degrees F (0.1 degrees C) per decade since 1939, with the rate of warming doubling in the last 40 years, and tripling in the last 25 years. The effects of global warming are noticeable on the Galapagos Islands, located in the Pacific Ocean. Temperatures have risen steadily. In March/April 2002, a study showed repeated bleaching of the coral reefs, with disastrous effects on the marine environment.

The Ecuadorian government of Rodrigo Borja Cevallos ratified the Vienna Convention in 1990, and took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992. In October 1997, Yolanda Kakabadse the vice president of the World Bank, and adviser to the Global Environment Facility addressed the Fifth World Bank Conference on Environmentally and Socially Sustainable Development at Washington, D.C. The government of his successor, Jamil Mahuad, signed the Kyoto Protocol to the UN Framework Convention on Climate Change on January 15, 1999; it was ratified on January 13, 2000, and took effect on February 16, 2005.

SEE ALSO: Oceanic Changes; Pacific Ocean.

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Edison Electric Institute

THE EDISON ELECTRIC Institute (EEI) is an association or a trade group representative that seeks to represent people and organizations owning stock in power companies. The stock companies represented by the EEI directly represent 95 percent of the power consumers served by stock companies generating electric power in the United States, which produce about 70 percent of the total power produced in the United States. The other 30 percent is produced by member cooperatives, by the Tennessee Valley Authority, or other government-owned generating facilities, or by privately owned companies. All of the companies that are members of the EEI are American-owned. In addition, 65 international electric companies are affiliate members. The 170 industry suppliers and related organizations are associate members.

The chair, president, and CEO of PNM Resources, Jeff E. Sterba, was chosen as the chairman of the EEI in June 2007. PNM is the parent company for Public Service Co. of New Mexico. In 1998, he was chosen as executive vice president of USEC, a global energy company headquartered in Maryland. In 2000, he returned to PNM as CEO. At the same time, Sterba was chosen to lead the EEI, its member associations chose David M. Ratcliffe and Anthony F. Earley Jr. as first and second vice chairmen, respectively. David Ratcliffe is currently chairman, president, and CEO of Atlanta-based Southern Company, which is a holding company that owns Georgia Power, Alabama Power, Gulf Power, Mississippi Power and other operating power and service companies. Anthony F. Earley Jr. is chairman and CEO of Detroit's DTE Energy.

Serba recognized that he was chosen to lead the EEI in a time of great changes in the power industry, saying in a prepared statement, that the Energy Policy Act of 2005 would be implemented soon. Although its provisions deal with matters that can override environmental concerns and interests, Serba was also aware of great challenges involving climate change and the need for energy efficiency. The EEI was organized in 1933. It works with all of its members, affiliates, and associate members, as an advocate of their interests. This means that the EEI promotes the development and adoption of equitable public policies before legislatures and before regulatory bodies.

Because the EEI is an industry association, it has command of the industry's critical data, reports, problems, and needs. With this information on the industry and its contacts, it can effectively lobby the U.S. Congress, state legislatures, federal and state government agencies, or including opinion leaders. The EEI stock analysts who advise investors may also be called upon to provide information to the news media to counter the claims of opposing consumer groups or environmentalist groups. Lobbying activity of EEI is extensive. It is the advocate for its numerous members, and has lobbied on legislation concerning the use of renewable fuels, energy efficiency, power plant security (especially against the threat of terrorism), and on environmental issues, including climate change.

A subject of particular interest has been its lobbying for the use of power lines as a medium for high-speed internet service and communications. Some internet media providers such at AT&T have lobbied for net neutrality, for all of the providers and users of the internet to be treated the same. In opposition have been some phone companies and cable companies that want to charge for internet traffic. By the end of 2007, the EEI had spent over $5 million to lobby various agencies of the federal government on the subject of climate change. Organizations lobbied included the White House Budget Office, the Environmental Protection Agency, the Energy Department, the Federal Energy Regulatory Commission, and the Federal Communications Commission.

The EEI is a long-term participant in debates over climate change science and its assessments. It has been an active observer to the Framework Convention on Climate Change sessions of the Conference of the Parties and the Subsidiary Body for Scientific and Technological Advice, and the Intergovernmental Panel on Climate Change sessions. The EEI, through its members, is an expert on the power industry and on some aspects of climate change. The EEI has recognized the problem of greenhouse emissions, especially by its industry members, and since at least 1994 has engaged in a number of activities to reduce and eliminate these power plant emissions as a cause of climate change.

SEE ALSO: Energy; Greenhouse Gases; Nongovernmental Organizations (NGOs); Technology.

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Education

GLOBAL WARMING EDUCATION is part of environmental education, and varies from raising awareness of the phenomenon, to a deep civic implication and political engagement, depending on the strategies and the goals that are adopted. Global warming education follows some principles of environmental education, and, more specifically, education of complexity, as proposed by French sociologist Edgar Morin. Morin advocates redefining the relationship to scientific knowledge, to understand sciences as carriers of uncertainties, leading to a particular reading of the world and climate, a reading that is interesting, but not sufficient to join the aims of environmental education regarding global warming.

In order to educate for the environment, combining the scientific analysis of the climate with other disciplinary and cultural analysis, is recommended, according to Gerard Fourez. Global warming education must teach ways to decode the dominant tendencies of Western analyses regarding global warming and their consequences, to minimize the consequences of catastrophic scenarios, and move toward greater social justice and rethink our relationship with nature and others.

ENVIRONMENTAL EDUCATION AND SUSTAINABILITY

The fourth report of the Intergovernmental Panel on Climate Change (IPCC), published in February 2007, confirms the reality of global climate change. Some scientists have pointed to the uncertainties and the inevitable limits of the climatic modeling, and other researchers question the ascendancy of scientist's analyses of the question in the public sphere. They assert that sociopolitical analyses should lead scholars to question the neo-liberal model of society, with its faith in technical progress, as well as the inequitable sharing of the wealth which ensues from it, according to Scott Lash, et al. The consensus of the IPCC experts has strengthened over the years, and concludes that the production of greenhouse gas of human origin is an important cause of global warming.

For more than 30 years, various arguments have fed the debate: scientific, economic, ethical, and sociopolitical. From the 1970s, environmental education became the subject of a succession of international conferences of United Nations Educational, Scientific and Cultural Organization (UNESCO) and the United Nations Environment Programme (UNEP). It began with the United Nations Conference on the Human Environment held in Stockholm in 1972, followed by the Earth Summit in Rio de Janeiro in 1992, and the World Summit on Sustainable Development (WSSD) in Johannesburg in 2002. The shift from environmental education to education for sustainable development is clear in the titles of these conferences.

The defining principles and orientations of environmental education found their inspiration in this type of consensus and the reports that followed, such as Tbilisi's in 1977, following the Intergovernmental Conference on Environmental Education that took place there. Such reports underline the necessity of lifelong learning, which prepares individuals for the analysis of the fundamental problems of a contemporary world in constant evolution. The complexity of the environmental question and the importance of interdisciplinarity require analysis of the environmental questions using social, political, economic, and scientific dimensions, while underlining the necessity of redefining our value system to renew the relationship between nature and human beings.

Since the early 1990s, environmental education has been defined as education for sustainable development: UNESCO launched the International Decade of Education for Sustainable Development in 2005, which will last until 2014. This is contested by many academics. Some see a legitimate proposal to reinforce the institutionalization of environmental education, and recognize some of the principles of deep ecology. Others, notably the team of Lucie Sauvé from Université du Québec à Montréal (UQAM), point out that education for sustainable development is defined in an instrumental way, as being at the service of a development for economic purposes, as the key to solving environmental problems. The idea is above all considered a resource to exploit for economic development. Education seems miles away from the initial critical aims of social transformation that should characterize environmental education, according to many authors of the domain, such as: Joel Spring, Ian Robottom, John Fien, Noel Gough, and Annette Gough. These critical goals should also be considered and provide a direction for global warming education.

A NEW NATURE-HUMAN RELATIONSHIP

A critical environmental education consists of developing, not only among youth, but the population in general, the capacities to analyze educational propositions regarding the environment and dominant environmental discourses to decode hidden ideological orientations, the beliefs and interests that direct them, and which implicitly tend to reproduce the practices that are nevertheless the ones that would be necessary to shift to a different kind of relationship between nature and human beings. The reference to science and technological transfers as the main answer to defining and correcting the problem is insufficient to correct a situation that requires that humans also question the philosophic foundations, sociological, political, and economic dimensions of the regulation of climate. To reproduce the same economic logic is denounced by many as incapable of correcting the shameless exploitation of nature and human beings that are at the heart of the environmental crisis.

Edgar Morin proposes principles and a philosophy for complexity, the consideration of the other, and acknowledgement of uncertainty in the scientific domain. This approach offers a vision of the world rethought concerning connections with nature. These principles provide different educational aims than the principles of education for sustainable development, prescribed in many educational ministerial programs on the international level. Education for sustainable development might reproduce a narrow vision of nature as just a resource for better management of economic development of the world.

Environmental education is different, and strives for different goals, geared to the age of the target audience, the pupil. In many North American school systems, environmental education generally begins with science education, the learning of scientific knowledge and principles, such as biology, chemistry, physics, or ecology. Many teachers rely on the idea that a better understanding of sciences can lead to better protection of the environment. That postulate is of interest, but it is not enough. Environmental education must be institutionalized to reach its aim of social transformation.

STUDENTS AS SOCIAL ACTIVISTS

Environmental education implies a critical pedagogy that gives pupils a role as social actors and considers them to be competent interlocutors, capable of logical argumentation, reasoning, and of being informed about complex questions. This type of environmental education can use interdisciplinary pedagogies, such as those proposed by the Belgian team of Gérard Fourez, and should lead to questioning the principles of the free-market economy and the dominant ways of thinking that are at the origin of the Western relationship to nature. For instance, the exploitation of natural resources for purposes of short-term profit; faith in technical progress, which allows scientific analyses and technical solutions to settle the imbalance that the more developed societies tend to print in the ecological regulations of the planet. For instance, such reasoning legitimizes nuclear energy to renew the modes of energy production and decrease greenhouse gas emissions. This position strengthens the dependence of societies on very expensive and risky technologies, as well creates an international balance of power to the detriment of the countries of the south; rather than promoting an analysis of the foundations of the systems of over-consumption, and decreasing energy and natural resource consumption. A more critical environmental education engages youth in concrete action and civil citizenship, toward another vision of the world, in a quest for more social justice.

Some approaches to science education also suggest engaging pupils as young citizens in community projects to assist in restoring ecosystems. It is the case, most notably, in the works of researcher Wolff-Michael Roth. Thus, pupils learn scientific notions while learning about the analysis of history and the local culture, and about their impact on the studied ecosystems from various disciplinary specialists (for instance, a biologist and a water quality technician). Science education and environmental education are then anchored in a sociocultural and critical analysis, aimed toward concrete actions and political pressure. The students, having analyzed the quality of water, explain their results to the group

Global warming education should teach general principles and scientific knowledge, as well as the limits of science.

and exert political pressure to change the ways people conceive of and consume water.

Global climate change shows up often in the media and political discourse. In a more political context, some politicians support the urgency of taking measures to reduce the production of greenhouse gases. The carbon exchange has become a new player on international economic markets. The Kyoto Protocol, intended as the first step in the international regulation of this issue, is already considered behind to some, in front of the scale of the phenomenon. This topic is part of secondary school curricula in many countries in North America and Europe. Researchers in science and environmental education analyze the pupils' and teachers' conceptions of this issue and plan educational strategies for the study of climate changes in classrooms.

These strategies go from the enrichment of pupils' scientific knowledge to improving the pupils' capacities of debate, critical analysis, and civic action, according to Jonathan Osborne and his colleagues. Frequently, popular magazines on science and nature (such as *Green Teacher*, or *La Recherche*) dedicate special issues on global warming. Magazines and documentary books for youth also address the question and can serve as documentary resources and references in class, but always with developing critical reading by pupils. It is sometimes necessary to consult various sources and to critique the information that is presented, and understand the author's ideological orientations. Some science museums organize exhibitions on this question for the public and schools.

Global warming education can take various forms, from simple awareness of the scale of the phenomenon with young children, and the understanding of some elements of climate regulation, and the presumed impact of consumer habits on the rates of carbon dioxide (CO_2) in the atmosphere (according to the conclusions of scientists), to more critical analysis and citizenship participation with older pupils. The information can be oriented differently according to educational goals. In an interdisciplinary way, this question can also lead to a more critical reflection on the complexity of the problem, including political, economic, or ethical analyses. According to the educational goals, the type of pedagogy selected can vary in the degree of critical analysis of the discourses and practices related to the Western system of society and its globalization, and engage pupils in more or less civic action.

Educators can seek a better understanding of the scientific notions that contribute to define this complex climatic phenomenon: physics, chemistry, climatic zones, functioning of the water and carbon cycles, understanding sources of greenhouse gases and their contribution to the climatic regulation. Understanding climate regulation models can be taught to older students. An interdisciplinary reading of this question should be integrated into such education, which, besides teaching scientific notions, will include analyzing the history of contemporary societies linked with their models of energy production and consumption and their contribution to global warming. Energy consumption of the concerned pupils and that of their teachers, for example, would also be analyzed to compare it to energy consumption and consumer habits in poorer countries.

The importance of the automobile in wealthy societies and its consequences should be documented and analyzed, both by reading technical and sociological data, for awareness, changing habits, and definiting the main aspects of the problem, to recommend concrete attempts of social transformation. In so doing, the pupils feel engaged and capable of changing things in society, even if only at a local level, so they learn to involve themselves actively in the democratic debates by knowing the decision-making authorities to whom they can address their point of view. Global warming education contributes directly to citizenship education, which can lead to the analysis and the commitment of the young people concerning other environmental questions, while enriching their knowledge of the sciences and the society.

It is also important to denounce ambient catastrophism, especially that conveyed by the media. Education should instead cultivate hope and optimism, logical and critical reasoning, and provide knowledge, without shying away from explaining elements of debate within the scientific community and the scale of the challenges to be surmounted. Science education should prepare young people to argue about contemporary social and environmental questions that contain a scientific dimension. The climatic question lends itself well to this type of exercise.

To teach global warming is also to get acquainted with certain research practices and to recognize the complexity and the limits of sciences, to enrich the current image of science that is popularized in school sciences and media, to make it more accurate and open to discussion. If Bryan Wynne's proposals are followed, education will update school sciences and to move them closer to their public. It is a matter of forming future scientists and informed citizens, who have an open and critical attitude when facing the contemporary scientific developments. Thus, global warming education should try to teach pupils and people, in general, certain principles and scientific knowledge, and also the different issues debated on this question. Teachers must remain aware of the limits of current approaches that would only lead to replacing obsolete technology with another, without questioning the overconsumption society model, which remains individual and always competitive.

SEE ALSO: Developing Countries; Economics, Cost of Affecting Climate Change; Energy Efficiency; Global Warming; Sustainability; United Nations Development Programme (UNDP).

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Egypt

DOMINATING NORTHEAST AFRICA, the Republic of Egypt has a land area of 386,660 sq. mi. (1,001,449 sq. km.), with a population of 80,335,036 (2007 est.), and a population density of 192 people per sq. mi. (74 people per sq. km.). Some 7,933,000 people live in Cairo, the capital, the 14th largest city in the world population, with a population density of 91,900 per sq. mi. (35,420 per sq. km.). Alexandria, the second largest city, has a population of 3,917,000 and a population density of 3,575 per sq. mi. (1,378 per sq. km.). Egypt is heavily reliant on the Nile River, and droughts over many centuries have caused severe food shortages in the country. However, there have not been enduring shortages, and the population of has Egypt grown steadily. Temperatures in recent years have been high, however, reaching 105.8 degrees F (41 degrees C) on August 6, 1998, the warmest August day on record.

With many areas of Egypt undeveloped, the rate of per capita carbon dioxide emissions has been low, at 1.4 metric tons per person in 1990, rising to 2.0 metric tons by 2003. The country's electricity production is heavily dependent on fossil fuels, which account for 77 percent of total production, the remaining 23 percent comes from hydropower, much of it from the hydroelectricity plant at Aswan. The development of this hydroelectric plant also led to the creation of Lake Nasser, which allows some 400,000 hectares of cropland to be cultivated throughout the year.

Electricity generation and heat production account for 31 percent of the country's carbon dioxide emissions; 5 percent come from other energy industries, and 28 percent from manufacturing and construction. In Cairo and many other urban areas, considerable traffic congestion has resulted in transportation contributing to 17 percent of the carbon dioxide emissions; liquid fuels contribute to 67 percent of the emissions, 2 percent come from solid fuels, 22 percent from gaseous fuels, and 9 percent from cement manufacturing. Pollution in much of urban Egypt has been bad for many years. There are more than a million automobiles in Cairo, many poorly maintained, which contribute to the world's highest level of lead and suspended solid particles in the world. This accounts for an estimated 10,000 to 25,000 premature deaths per year, and has contributed considerably to the environmental pollution, and to the regions greenhouse gas emissions.

The Mubarak government of Egypt ratified the Vienna Convention in 1988, and took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, which was ratified in 1994. In October 1997, M. El-Ashry from the World Bank addressed the Fifth World Bank Conference on Environmentally and Socially Sustainable Development at Washington, D.C. The Egyptian government signed the Kyoto Protocol to the UN Framework Convention on Climate Change on March 15, 1999, which was ratified on January 12, 2005, and took effect on April 12, 2005.

SEE ALSO: Drought; Oil, Consumption of; Transportation.

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Ekman Layer

THE EKMAN LAYER (EL) is a boundary near-surface layer in the low troposphere and upper ocean, in which the vertical turbulent friction plays a crucial role in the balance of governing forces. Ekman drift is to the right of the wind in the Northern Hemisphere, which causes upwelling along the equator and certain coasts.

As Ekman showed in his classic paper, the basic steady balance within EL (in the ocean where depth can be considered infinite) occurs between vertical friction and the Coriolis force. Such balance leads to the generation of the Ekman spiral of drift current (wind), that is the turning and weakening of the Ekman current (or wind) to the depth (upper boundary of Ekman layer in the atmosphere). The vector of the Ekman current (wind) is rotating clockwise/counterclockwise to the depth (in the atmospheric boundary layer) in the Northern/Southern Hemisphere. The angle between vectors of surface Ekman current and surface wind is equal to 45 degrees, if the coefficient of vertical turbulent exchange (mixing) does not depend on the depth, as was postulated in the classic Ekman theory. In fact, this angle is usually close to 30 degrees, because the coefficient of vertical turbulent mixing decreases to the depth.

In deep ocean, EL thickness (or Ekman scale) is determined as a depth, where the current direction is opposite to the surface one. Speed of drift current at the low boundary of EL is smaller than surface speed by e^{π} times. Thickness of EL in the homogeneous fluid (gas) is controlled by two parameters, namely, turbulent stress (or dynamic velocity depending on the wind speed) at the sea surface and Coriolis parameter. Wind in the mid-latitudes, which speed is about 33 ft. (10 m.) per second, generates the surface drift current of about 12 in. (30 cm.) per second. The corresponding Ekman scale is about 98 ft. (30 m.). In the ocean with intermediate depth (ocean depth and Ekman scale are the same order), the Ekman spiral is modified and rotation of the current vector to the depth decreases. Typical temporal scale of steady Ekman spiral development is equal to local inertial period. For instance, classic Ekman balance in the mid-latitude interior of the upper ocean is established in about one day after the beginning of wind forcing.

There is also bottom EL in the ocean, which should be taken into account in the global circulation models if the ocean's depth is not too large in comparison with the Ekman scale, or for super high-resolved models with typical size of vertical grid in the bottom layer of about 33 ft. (10 m.). Special care should be taken for the case of a shallow sea, where the depth is much smaller than the Ekman scale. In this case, surface and bottom ELs create a unique EL in which turbulence is well developed, while the Coriolis term is small. As a result, the rotation of drift current to the depth is negligible, and directions of surface wind and drift current in the shallow ocean coincide.

From comprehensive analyses by Eric Kraus, Andrey Monin, and Alexander Yaglom, in the stratified fluid (gas), a depth of mixed turbulized layer may be much smaller than EL thickness because turbulent stress is working against buoyancy force. In this case, a profile of velocity within the mixed layer looks like a drift current in the shallow sea. Transport of drift (Ekman) current in the ocean's interior (that is, in deep ocean) does not depend on the coefficient of vertical turbulent exchange. It can be calculated accurately if surface wind stress and latitude are known. For instance, from the assessment of Eric Kraus and Sid Levitus, integral meridional volume transport of drift current across a latitude circle in the world ocean associated with the trade winds reaches about 50 Sverdrups (one Sverdrup = 10^6 cu. m. per second) and it accounts for a significant proportion of meridional overturning circulation within the tropics and at the boundary between the tropics and subtropics.

SEE ALSO: Atmospheric Boundary Layer; Coriolis Force; Currents; Mixed Layer; Ocean Component of Models.

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El Niño and La Niña

THE WATERS ALONG the barren coast of Peru are cold and flow northward during most of the year, but around Christmas time, they are warm and flow southward. The latter current was originally given the name El Niño, Spanish for "the boy." Because of its timing, and because it is associated with refreshing rains, the name also refers to Child Jesus.

Every few years the current is exceptionally intense and persistent, bringing very heavy rains that transform parts of the coastal desert into a garden. At such times the fish (such as anchovies) that usually are abundant in the cold water, disappear temporarily. Today, the term El Niño is reserved for these interannual events which now are perceived as disasters even though they originally were welcomed as blessings. El Niño was originally regarded as a regional phenomenon, confined to the shores of Peru, but is now recognized as part of the changes in oceanic conditions across the entire tropical Pacific Ocean.

Furthermore, El Niño is not a sporadic departure from "normal" conditions, but is one phase of a continual oscillation with a period of 3 to 5 years; the complementary phase is known as La Niña. (This oscillation is evident in a record of sea surface temperature variations in the eastern equatorial Pacific over the past century. The figures show the spatial structures of El Niño and La Niña.)

The fluctuations in oceanic conditions are in response to fluctuations in the trade winds, which are intense during La Niña, weak during El Niño. Why do the winds change?

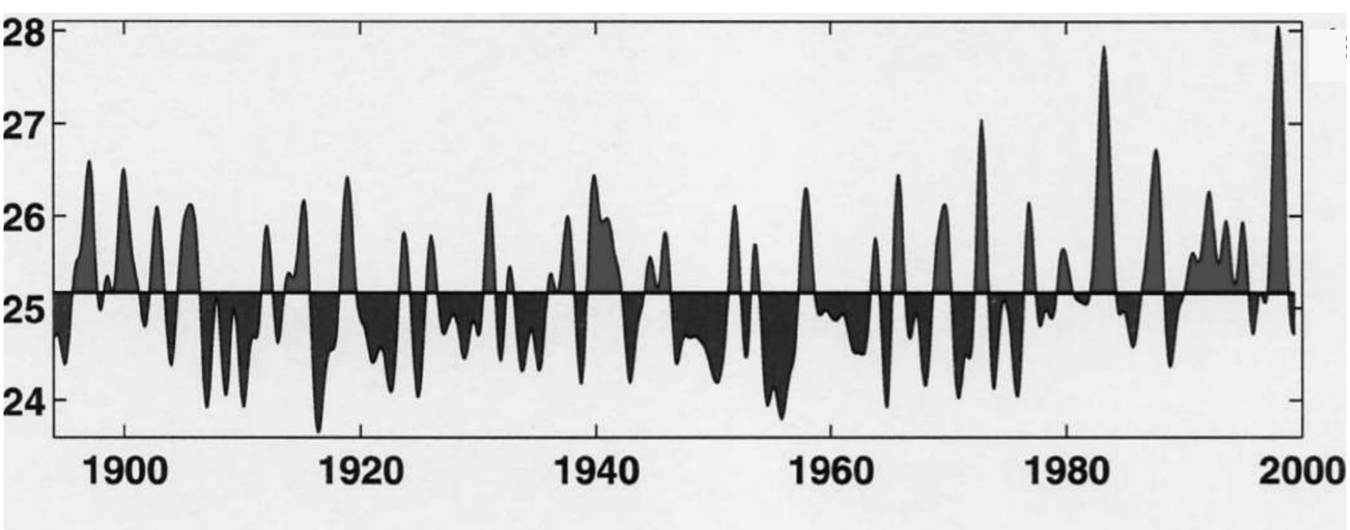
Early in the 20th century, Gilbert Walker's attempts to predict failures of the monsoons in India led to his discovery of the Southern Oscillation, which includes oscillations in the intensity of the trade winds over the tropical Pacific. Those oscillations, it turns out, are the ones that induce El Niño and La Niña. From a meteorological perspective, the changes in the wind patterns are a consequence of the changes in the sea surface temperature patterns associated with El Niño and La Niña.

This circular argument—sea surface temperature changes are both the cause and the consequence of changes in the winds—implies that interactions between the ocean and atmosphere are at the heart of the matter. Those interactions are unstable, capable of amplifying small, random disturbances, such as a burst of strong winds, into a major climate fluctuation.

To ask why El Niño (or La Niña) occurs is as meaningless as asking why a pendulum swings. It is more interesting to inquire about the factors that determine the period of the oscillations—the width of the ocean basin is an important one—and to explore the predictability of El Niño.

THE NIMBLE ATMOSPHERE

Forecasters take into account that the interactions between the ocean and atmosphere are not symmetrical: the nimble atmosphere swiftly responds to changes in sea surface temperature, but the sluggish ocean adjusts slowly to changes in the winds. The ocean has the "memory" of the system and needs to be monitored to anticipate El Niño. The large array of instruments that oceanographers have deployed across the equatorial Pacific enabled them to anticipate the intense El Niño of 1997 several months in advance.



Oscillations in sea surface temperatures (in degrees Centigrade) over the past century, in the eastern equatorial Pacific Ocean (after removal of the seasonal cycle.) El Niño conditions prevailed during the periods in lighter gray above the 25 degree C line, La Niña during the periods in darker gray below the 25 degree C line.

The impact that global warming will have on El Niño is a matter of debate. The properties of El Niño, its intensity and frequency of occurrence, for example, depend on the background state, which includes the time-average intensity of the trade winds, and the spatially averaged depth of the thermocline. The factors that determine those conditions today are poorly understood.

SEE ALSO: Equatorial Countercurrent; Southern Oscillation; Trade Winds; Walker Circulation.

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El Salvador

LOCATED IN CENTRAL America, El Salvador has a land area of 8,124 sq. mi. (21,040 sq. km.), with a population of 6,948,073 (2007 est.), and a population density of 823.6 people per sq. mi. (318.7 people per sq. km.). It is the only country in Central America that does not have a Caribbean coastline. Pacific hurricanes occasionally affect the country, as was the case with Hurricane Mitch in 1998. Some 27 percent of the land is arable (the highest percentage in Central America) much of it in coffee plantations; 29 percent of the land is used for meadows and pasture, with only 5 percent forested.

One of the poorest countries in the region, electricity generation in El Salvador comes largely from fossil fuels (42.3 percent) and hydropower (35.5 percent). The country has a very low rate of carbon dioxide emissions per capita, at 0.5 metric tons in 1990, rising to one metric ton in 1997, and 0.99 metric tons in 2003. Most of the carbon dioxide emissions come from the use of liquid fuels (91 percent), with the remaining 9 percent from the manufacture of cement.

Global warming and climate change are expected to lead to flooding in some low-lying parts of El Salvador, with the threat of more insect-borne diseases such as malaria and dengue fever. The right-wing government of Alfredo Cristiani ratified the Vienna Convention in 1992, and took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, and the government of his successor, Armando Calderón Sol, signed the Kyoto Protocol to the UN Framework Convention on Climate Change on June 8, 1998. The Kyoto Protocol was ratified on November 30, 1998, and took effect on February 16, 2005.

SEE ALSO: Diseases; Floods; Hurricanes and Typhoons.

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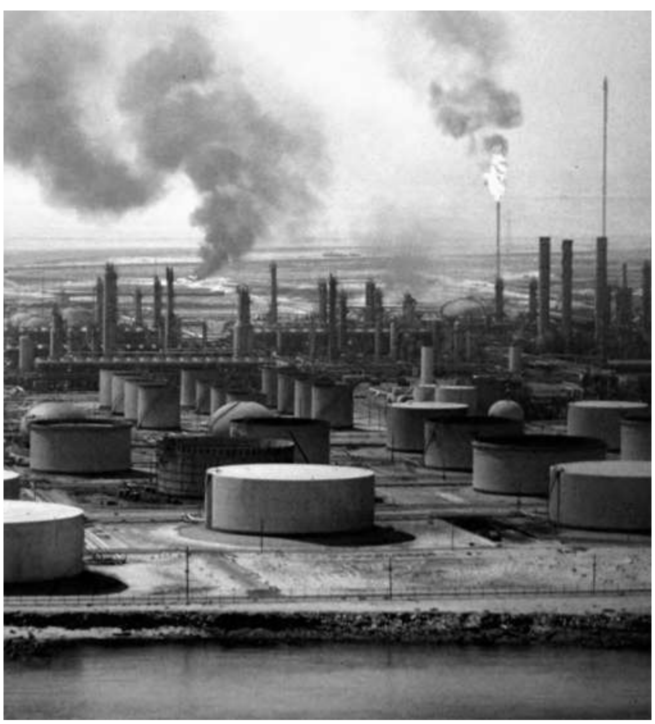
Emissions, Baseline

THE EMISSION BASELINE represents the starting point or reference level from which increases and decreases in emissions are measured. The intergovernmental action through which national governments have coordinated their response to the threat of human-induced climate change is based on the United Nations Framework Convention on Climate Change (UNFCCC), adopted in 1992, and its Kyoto Protocol, negotiated since December 1997. In 2001, the so-called Marrakech Accords marked the shift from negotiation of an intergovernmental framework to cope with climate to a phase of implementation. Setting a baseline for greenhouse gases emissions is part of this shift towards implementation.

Under the terms of the UNFCCC, all signatory countries have common, but differentiated, responsibility to reduce their greenhouse emissions. Yet, only the Annex I Parties were subject to a specific commitment to adopt policies and measures with the aim of returning their emissions of CO_2 and other greenhouse gases to 1990 levels by 2000. This was not a legally-binding emissions target; the commitment of Annex I Parties was simply to aim to return their emissions to 1990 levels by 2000, not necessarily to achieve that goal. In addition, the approach of the UNFCCC, stressing as it does the common, but differentiated, responsibility among the signatories, takes into account national diversity in addressing climate change. The UNFCCC calls for special consideration for least-developed countries (LDC) and economies in transition (EIT) and has granted them a certain degree of flexibility in implementing its targets. Several EITs have taken advantage of this flexibility by choosing a baseline earlier than 1990, prior to the economic collapse that led to dramatic cuts in their emissions.

During the first Conference of parties, the signatories launched the AIJ (Activities Implemented Jointly) phase whereby parties could implement emission mitigation projects in the territories of other Parties, including developing countries, but without gaining credit for the emissions reduced. Many of the projects during the AIJ pilot phase were concerned with the establishment of baselines and their results have contributed to negotiations on the rules for the project-based flexibility mechanisms under the Kyoto Protocol, such as the Clean Development Mechanism and joint implementation with EITs. Unlike the AIJ phase, these mechanisms allow crediting.



An emission baseline represents the starting point from which increases and decreases in emissions are measured.

The negotiations among the parties of the UNFCCC led to the adoption of the Kyoto Protocol. Article 3.1 of the document sets a collective emission reduction target for all Annex I Parties of at least 5 per cent by 2008–2012, from the baseline 1990. In the same vein of differentiated responsibility that also characterized the Framework, the Protocol divides this collective target among the Annex I Parties, giving each of them an individual commitment listed in Annex B. Each Annex I Party chose its individual emission targets in Kyoto. The Protocol's targets deal with the six main greenhouse gases: CO_2, methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6). Article 3.8 allows parties to use a baseline of 1995 for the latter three gases, in recognition of their increased use since 1990. Article 4 of the Protocol contains the so-called bubble provisions. According to this article, the European Union (EU) is permitted to redistribute its 8 per cent reduction target as it wishes among its member states. An important difference between the targets of the UNFCCC and those of the Protocol is that the Protocol's ones are legally-binding. The Protocol clearly states that Annex I Parties "shall ensure" that they do not exceed their targets, indicating obligation to achieve the targets, not just attempting to meet them.

During the negotiations, ambitious emission reductions were proposed, such as minus 15 per cent by 2010 by the EU and –20 per cent by 2005 by The Alliance of Small Island States (AOSIS). Yet, in the end, more modest targets were adopted. These do not represent a sufficient measure to stabilize the concentration of greenhouse gases in the atmosphere at a safe level. Yet, the Kyoto Protocol's legally-binding emission baselines represent a landmark reversal of the persistent upward trend in emissions. In most of the industrialized world, this trend has been developing since the industrial revolution. The emissions of many industrialized countries continued to rise since the adoption of the UNFCCC and meeting their own Kyoto Protocol targets will require them to make considerable efforts. The targets of the Russian Federation and Ukraine to simply stabilize emissions at 1990 levels are widely considered as extremely generous, since their emissions declined dramatically in the early 1990s: by over 35 per cent from 1990 to 1998 in the case of the Russian Federation

SEE ALSO: Emissions, Cement Industry; Emissions, Trading; Kyoto Protocol; Montreal Protocol.

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Emissions, Cement Industry

HYDRAULIC CEMENT IS the binding and strength-contributing agent in concrete and most mortars. The cement is hydraulic because it sets and develops strength through the hydration (chemical combination with water) of its component minerals or compounds. Among hydraulic cements, the most common are Portland cement and similar cements having Portland cement as a base.

Concrete is a very common construction material and is a proportioned mix of fine and course aggregates (such as sand and gravel or crushed stone), hydraulic cement (only about 10–12 percent by volume, or about 11–14 percent by weight), and sufficient water to fully hydrate the cement.

In 2006, hydraulic cement was manufactured in about 150 countries and world output was about 2.5 billion metric tons (Gt) per year, enough for about 20 Gt per year of concrete (including mortar) or about 3 tons of concrete per year per person on the planet. The most important environmental issue with respect to global warming stems from cement rather than concrete manufacture: nearly one ton of carbon dioxide (CO_2) is emitted for every ton of Portland cement made. Although generally well below the total CO_2 emissions from fossil fuel-fired power plants and motor vehicles, the cement industry is overall the world's largest single industrial source of CO_2 emissions.

Portland cement is made by finely intergrinding Portland cement clinker (about 95 percent by weight) with about 5 percent calcium sulfate (mainly as the mineral gypsum). The CO_2 emissions come from the clinker's manufacture. The chemical composition of clinker is fairly uniform worldwide, and averages about 65 percent calcium oxide (CaO), 22 percent silicon dioxide, 6 percent aluminum oxide, 3 percent iron oxide, and 4 percent other oxides. These oxides are derived by the high-temperature breakdown in a kiln of a variety of (mostly geologic) raw materials. The clinker is then formed by chemically recombining these oxides into certain hydraulically reactive compounds (mainly calcium silicates).

The dominant CaO component of clinker is chiefly derived from limestone, an abundant rock made up primarily of the mineral calcite (calcium carbonate, or $CaCO_3$). In the kiln, the calcite is broken down by the calcination reaction: $CaCO_3$ + heat CaO + CO_2. Calcite is 56 percent CaO; thus, it takes 1.16 tons of calcite per ton of clinker of 65 percent CaO content, assuming no other source of CaO.

This amount of calcite yields 0.51 tons of CO_2; this emissions factor is commonly boosted to 0.52 tons to account for some loss of calcined raw materials in exhaust dust from the kiln, and the possible presence of small amounts of other carbonate minerals in the raw materials.

Although calcination occurs at temperatures 1,292–1,832 degrees F (700–1,000 degrees C) below those needed for the subsequent formation of the hydraulic calcium silicates in clinker 2,562–2,642 degrees F (about 1,350–1,450 degrees C), it is calcination that consumes much the largest share of the total heat energy requirements.

Depending on the kiln technology and factors such as heat loss through the kiln shell, about 3–7 GJ of heat energy is required per ton of clinker manufactured. This enormous amount of heat is supplied by burning large quantities of fuels (typically coal and/or petroleum coke), which also releases CO_2, typically about

0.43–0.48 tons of CO_2 per ton of clinker, depending on the fuel's overall carbon content.

Thus, counting calcination and combustion, total CO_2 emissions are about 0.95–1.0 tons per ton of clinker, or about 0.90–0.95 tons per ton of Portland cement. Based on typical issues affecting the accuracy of clinker and cement production data, estimates of CO_2 output using the foregoing emissions factors accurate to about plus or minus 5 percent. Other fairly high-volume emissions from cement plants (such as kiln dust, sulfur oxides, and non-N_2O nitrogen oxides) are not significant to the issue of global warming.

There are four main strategies to reduce CO_2 emissions from cement manufacturing. The first involves reducing overall fuel (heat) consumption by upgrading the kiln technology (for example, conversion or replacement of wet kilns with preheater-precalciner dry kilns). The second involves switching among fossil fuels and/or incorporating a proportion of waste fuels; the latter reduce primary fossil fuel consumption, commonly have lower carbon contents, and may offer carbon emissions credits. The third strategy is to source some of the requisite CaO from non-carbonate materials such as iron and steel slags, or coal combustion ashes; these not only do not directly involve calcination emissions, but also require far less heat in the kiln to process.

The fourth strategy is to encourage the use of blended cements rather than straight Portland cement. Blended cements are integral mixes of Portland cement and pozzolans. Pozzolans are siliceous materials that have little initial cementitious character, but which become hydraulically cementitious when reacted with calcium hydroxide (such as that released through the hydration of Portland cement). Although the first three strategies can reduce plant-level CO_2 emissions, the main emphasis (of four strategies) is to reduce the emissions per ton of cement produced by keeping the kilns working at full capacity (their most efficient condition), to make more cement using less raw material and fuel.

SEE ALSO: Carbon Dioxide; Carbon Emissions; Industrialization.

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Emissions, Trading

EMISSIONS TRADING IS a method of controlling harmful carbon emission by creating a system of economic incentives for reduction. Since the creation of the Kyoto Protocol in 1997, where all signatory nations agreed to implement caps on the six major greenhouse gasses and reduce emissions to 1990 levels by 2012, emissions trading has become one of the most popular tools in controlling industrial pollution. Critics argue that it does little to get to the root causes of that pollution and, ultimately, has a negligible impact on global carbon emissions. The process is relatively simple: a regulatory authority sets a limit, or cap on the amount of emissions a company can produce in a year. The company is given a certain number of credits per metric ton of emissions. If that company comes in under the cap, they can keep unused credits and sell or trade them on the open market; if they exceed the cap, they are required to purchase credits from another company with lower emissions.

The most popular form of this system is called cap-and-trade, where a limit is set with an eye toward overall reduction of emissions. Under baseline and credit programs, there is no cap, but companies are required to stay under a baseline level set at a given year. Project-based, or offset credits are programs that reward emitters for implementing changes that reduce emissions well below the regulatory caps.

The largest experiment in emissions trading is the European Union Emission Trading Scheme (EU ETS). All 27 EU member nations are part of the scheme, and participation is mandatory. Each nation is allocated an amount of carbon tonnage relative to their total industrial output: for example, heavily-industrialized Germany was given an initial cap of 499 metric tons (mt) of carbon emissions, while tiny Malta was allocated 2.9 mt. Individual companies, which are required to report their emissions with the EU ETS, are then allocated credits. Phase I was launched in January 2005. Early reviews are mixed, with many believing that the caps established by the European Union were too lenient and have not resulted in a lowering of emissions.

The United States has utilized cap-and-trade to a limited extent, most notably in the reduction of sulfur dioxide (SO_2) emissions, the main pollutant in acid rain. This program, begun under the Clean Air Act of 1990, proved so successful that the European Union used the American model when setting up the ETS. However, the United States is not a signatory to the Kyoto Protocol, and does not have a single, unified program like the ETS. Individual states and regions are creating their own cap-and-trade programs, some of which are showing early success.

Supporters of carbon-emissions trading argue that this is a prime example of free-market environmentalism that creates a politically and economically viable way to control pollution. Rather than forcing industries to implement often-costly changes in infrastructure, it reduces overall carbon emission, while giving each industry time to develop cleaner alternatives. It also creates a new and potentially lucrative market in carbon-credit trading; giving value to something that was previously just waste. During the EU ETS's first year, 362 million tons of CO_2 were traded for €7.2 billion on this new carbon market. Cap-and-trade programs require little investment by regulatory agencies and have been credited with reducing emissions far beyond what was originally expected.

Critics say that cap-and-trade programs represent a capitulation to market forces at the expense of the environment, and ultimately do little to reduce global emission rates. Most schemes give credits to companies freely, rather than auctioning them off, meaning the companies have no investment in the program at the outset. Many programs allocate too many credits at the outset (this is one of the main criticisms of the EU ETS). Cap-and-trade does not encourage polluters to find greener alternatives or invest in upgrades, because it is usually less expensive to purchase credits from other emitters. These critics also believe that the system relies too much on self-monitoring by industry, and does not have strict fines or punishments for failure to meet regulatory caps. This fosters a sense of business-as-usual that does not address the long-term impact of continued high emissions. They argue that other remedies, such as a carbon tax, would do far more to force compliance with reduction goals.

SEE ALSO: Carbon Dioxide; Carbon Emissions; Carbon Permits; Emissions, Baseline; Industrialization; Pollution, Air.

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Energy

ENERGY IS TYPICALLY defined as the ability to do the work. According to the First Law of Thermodynamics, energy is always conserved, so it cannot be destroyed nor created, it only can be transformed from one form to another. Examples of different energy forms include thermal, radiant, potential, and kinetic energy. In particular, thermal energy or heat is energy transported across the system boundary by temperature difference. The energy transfer in the Earth's atmosphere defines the energy cycle of the planet. The fundamental mechanisms for energy transport are radiation, convection, conduction, and evaporation/condensation.

Radiation is energy transfer due to the oscillations of electromagnetic fields or photons that have properties of both particles and waves. The properties of radiation are defined by its wavelength (λ), which represents a distance between two successive wave crests. Atmospheric science is usually concerned with wavelengths that fall into ultraviolet, visible, and infrared parts of the electromagnetic spectrum. All objects radiate energy, as long as their temperature is higher than absolute zero. The Stefan-Boltzmann law defines the total emitted energy in terms of a power law based on the object's surface temperature. Furthermore, Plank's law defines the inverse proportion between the surface temperature and the peak wavelength, which is characterized by maximum energy output. Typical wavelengths for the Sun's radiation are in the range of 0.15– 3.0μm, which is called short-wave or solar radiation, while Earth emits radiation in the wavelength range of 3.0–100μm, which is called long-wave radiation. The incoming solar radiation first encounters the atmosphere, which reflects, absorbs, and transmits this energy to the Earth's surface. The composition of the atmosphere plays an important role in reflectivity, absorptivity, and transmissivity. The atmosphere also emits energy to the surrounding environment, which is characterized as atmospheric emissivity.

Convection, also know as advection, represents heat transfer via bulk, or microscopic, motion of fluids, which can be liquids or gases. There is no convection in solids. For convection in the vicinity of solid surfaces, a boundary layer forms at the interface to reduce the velocities of the unobstructed fluid motion to the velocity of the solid surface, which is typically zero. Also, a temperature boundary layer forms in the vicinity of solid surfaces that have temperatures different than the bulk fluid. The connective transport due to the different densities of fluid is called natural convection. An example of natural or free convection would be vertical movement of the air masses heated at the warm Earth's surface, which receives energy via solar radiation. When free convection is the dominant motion for the air mass, the atmosphere is called unstable. A stable atmosphere has forced convection to take over the fluid motion. This forced motion is mechanically-induced by terrain roughness or pressure differences, and the atmosphere has a predominantly horizontal motion. In nature, the most typical mode of convection is mixed convection, which combines natural and forced convective heat transfer regimes.

Conduction is associated with random molecular motion. It represents an effective heat-transfer mechanism for solids, because of short molecular distances, while it is less effective for fluids and gases. For conduction, there is no bulk motion of molecule characteristics as for convection. Fourier's Law describes this process by relating the total heat transfer to temperature difference and the distance or length of the system under consideration. Conduction is important for heat transfer beneath the Earth's surface, but for atmospheric science conduction is negligible, except at the very thin laminar sub-layer in direct contact with the Earth's surface.

The evaporation/condensation process is a heat-transfer mechanism that involves a phase change of the matter in the system. Evaporation occurs when energy is added to the system during the heat transfer process, while condensation is characterized by energy release to the surrounding environment. The total energy necessary for the phase change from fully-saturated liquid to fully saturated vapor is called latent heat, and represents material property dependent on the temperature and pressure of the system. For example, the latent heat would be different for the same matter, such as water, at different elevations in the Earth's atmosphere. Furthermore, the water cycle is defined by the water evaporation at the ocean surface and condensation that forms clouds and rain. Another important contributor to the water cycle is plant life that releases water vapor to the atmosphere by evapotranspiration, because it combines evaporation and transpiration.

SEE ALSO: Condensation; Radiation, Absorption; Radiation, Infrared; Radiation, Long Wave; Radiation, Short Wave; Radiative Feedbacks.

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Energy, Renewable

GLOBAL WARMING IS the increase in near-surface air temperatures from the emission of greenhouse gases and particulate black carbon. Greenhouse gases result mostly from fossil fuel burning to produce energy. For industrial and household energy needs, humans compromise on greenhouse gas production, and endanger the future. However, the advent of renewable energy would reduce the production of greenhouse gases. Therefore, renewable energy is considered clean energy.

According to the International Energy Agency (IEA), renewable energy "is derived from natural processes that are replenished constantly. In its various forms, it derives directly from the sun, or from heat generated deep within the earth. Included in the definition is electricity and heat generated from solar, wind, ocean, hydropower, biomass, geothermal resources, biofuels, and hydrogen derived from renewable resources." The use of renewable energy is an old concept. More than a century ago, wood supplied up to 90 percent of the world's energy needs. The use of wood as an energy source has fallen in the last century because of low prices for fossil fuels and their conveyance advantage. With climate change concerns, the rising cost of fossil fuels, and increasing government support, renewable energy production is increasing. The disposal problem of biomass, such as manufacturing wastes, rice hulls, agricultural wastes, and black liquor from paper production is encouraging biomass burning to produce electricity and biofuels. Presently, about 13 percent of the world's primary energy comes from renewable sources such as the burning of traditional biomass. Hydropower provides 2–3 percent, and modern technologies such as geothermal, wind, solar, and marine energy meet less than one percent of world demand.

RENEWABLE ENERGY TECHNOLOGIES

There are many proven technologies available to produce renewable energy, and some new technologies are under development. One of the most promising renewable energy technologies for electricity generation is wind energy that uses airflows to run wind turbines. In good wind regimes, cost-wise, wind power is comparable to fossil alternatives, particularly when economic or environmental concerns are considered. Modern wind turbines range from around 600 KW to 5 MW of rated power. Most common wind turbines for commercial use are of a rated capacity of 1.5–3 MW. Wind energy is the fastest-growing renewable energy in the world. Since 1993, it is growing on average 30 percent a year. Windmills typically run at 25–35 percent of their capacity over the course of a year.

A photovoltaic module composed of multiple photovoltaic cells or arrays is used to convert sunlight directly into electricity. Photovoltaic power is also widely viewed as cost competitive, like wind power. As energy from the Sun is free and the cost of the photovoltaic cells is dropping, a solar energy boom is likely in the near future. Solar energy is good for many grid-connected and building-integrated uses. They are widely used for off-grid applications ranging from telecommunications, to village power in remote and rural areas. In general, solar energy is of two types: solar thermal and solar electric. Solar thermal technologies provide heat and hot water for residential, commercial, and industrial end uses. Solar electric technologies or concentrating solar power (CSP) creates heat to produce steam and/or electricity. At present, producing a few kilowatts to hundreds of megawatts of electricity is feasible through commercial solar electric technologies, but a hybrid application of the technology with fossil fuel would be more economically competitive.

Hydropower is another clean energy source and is the most mature form of renewable energy. It has a significant share of electricity generation worldwide. Because water is denser than air, water has more energy producing ability than wind. Hydropower units not only provide electricity, but also help in flood control, irrigation, pisciculture, navigation, and recreation. Energy from the ocean in the form of tidal forces, ocean currents, wave power, and thermal gradients can be feasibile to produce electricity. It can be harnessed using technology similar to underwater windmills. It is being deployed in many countries, although it is a new concept. Portugal has the world's first wave farm. It generates 2.25 MW of initial electricity using three Pelamis P-750 machines.

Geothermal technology obtains energy by tapping the heat of the Earth. It is expensive to build a power station, but operating costs are low, resulting in low energy costs for suitable sites. Geothermal electricity generation is a base load technology. It can be a low-cost option if hot water or steam from geysers is at a high temperature near the surface of the Earth. This technology contributes positively towards global warming as its taps some of the greenhouse gases emitted through geysers.

Biofuel is another renewable resource that is produced from biomass. It is not as clean as the other renewable energies. Biomass can be directly burned to produce heat energy or steam to run turbines for electricity generation. Liquid biofuel can be produced indirectly from biomass that is available worldwide in a variety of forms: wood, grasses, crops, and crop residues. These are converted to energy through thermal or biological conversion or as feedstock to produce liquid or gaseous biofuels. Biomass itself is carbon neutral, but when used for biofuel production, the emission of methane is blocked, thus helping the environment. Unsustainable ways of biofuel production are not environmentally friendly. However, the Roundtable on Sustainable Biofuels is working to define criteria, standards, and processes to promote sustainably-produced biofuels to positively impact global warming mitigation.

Biogas is produced through biogas plants. These plants operate using waste from paper and sugar production, sewage, animal waste, and other biodegradable wastes. These wastes are slurried together and allowed to ferment with bacteria to produce methane gas. This methane gas is a renewable natural gas used for cooking, heating, and electricity production. In Asia, many developing countries such as India, Nepal, Bangladesh, Laos, Cambodia, Vietnam, Bhutan, have individual household biogas plants to meet household energy demands. There is immense viability to having commercial biogas plants. Current sewage treatment plants can easily be converted to biogas plants. Once the methane gas is extracted from waste, the remaining sludge can be used as a fertilizer. It is five times higher in nitrogen than compost produced from the same biomass.

Hydrogen can act as a crucial storage medium and carrier of renewable energy. According to the IEA, hydrogen, along with renewable energy technologies, is a major potential contributor to the sustainability of the energy sector. Over the longer term, if costs can be dramatically reduced, hydrogen can act as the crucial storage medium and carrier of energy produced from renewables. Hydrogen is already being used in some vehicles. With proper research and development, hydrogen, battery-powered electricity, and solar energy will fully replace fossil fuels as energy source for vehicles.

RENEWABLE ENERGY POTENTIAL

Although renewable energy technologies are unreliable for the world's present energy demand, the market is growing for many forms of renewable energy. Approximately 74,223 MW of power is generated from windmills worldwide. Several European countries and the United States produce the largest percentage of wind energy. Denmark is the world leader in this technology. The present worldwide manufacturing output of the photovoltaics (PV) industry is more than 2,000 MW per year. Japan, Germany, and the United States contribute 90 percent of all photovoltaic installations in the world. Solar energy use is also growing at a faster rate in developing countries, such as Kenya and India. Worldwide, approximately 8,000 MW capacity of geothermal power plants are in operation. A 750 MW geothermal power plant, The Geysers in California, is the largest in the world. Brazil has one of the largest renewable energy programs in the world. It produces ethanol (biofuel) from sugarcane, contributing 18 percent of the country's automotive fuel demand. Ethanol fuel is also widely available in the United States and many other countries. Most countries are mandating using more than 10 percent ethanol or other biofuel as a mixture with fossil fuel. Renewable energy production and its use is very popular in rural settings without grid-based electric supply. Thus, renewable energy is popular among both the poor and rich countries of the world.

According to IEA, the potential of bioenergy is 200-300 EJ/a (Exajoules per annum) compared with the current potential of 50 EJ/a. The potential is so high because of the abundant resource base in all countries. Bioenergy crops and municipal wastes would be better used for producing bioenergy. Theoretically, wind energy is capable of supplying a large percentage of global energy needs as wind is ample everywhere. However, the practical potential is limited due to cost, variability, intermittency, and siting factors. However, researchers believe that these concerns are exaggerated, and that contributions of more than 1,000 percent of total electricity supply are possible without compromising grid reliability. It is estimated that total long-term wind energy potential is five times total current energy production.

Solar energy potential is immense. In Europe, this growth is anticipated around 20 percent per year. China has the highest potential growth of solar

One of the most promising renewable energy technologies is wind energy, which uses airflows to run wind turbines.

energy production and use. Solar heating and drying potential worldwide is estimated to be 600–900 PJ. Some estmates suggest that the worldwide potential installation capacity of PV systems for grid purposes might be 4,001,000 MW by 2010. The potential for large hydropower plants are hampered by environmental concerns. However, there is tremendous potential for small hydropower plants. There are potential geothermal resources in more than 80 countries in the world. The potential energy from these is estimated at 600,000 EJ. Ocean energy systems offer the promise of low-cost reliable electricity, principally to coastal regions, but technology must be improved to be economically viable. Hydrogen energy potential is promising due to serious research and development programs.

In 1983, physicist Bernard Cohen proposed that uranium is effectively inexhaustible, and therefore, can be used as a renewable energy source. Cohen believed that fast breeder-reactors fueled by seawater-extracted uranium could produce and supply energy for billions of years. Nuclear fusion technology is in the development stage; it would be very efficient and have a large potential for long-term energy production. Nuclear fusion technology produces less nuclear waste and has less containment issue than nuclear fission technology.

SEE ALSO: Alternative Energy, Ethanol; Alternative Energy, Overview; Alternative Energy, Solar; Alternative Energy, Wind; Nuclear Power.

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Energy Balance Models

ENERGY BALANCE MODELS represent the First Law of Thermodynamics applied to a system. In climatology, energy balance models are used for the Earth-atmosphere system. This is a closed thermodynamic system because it does not exchange matter with the surrounding environment, or space. Energy balance models can be applied to the Earth-atmosphere systems for different timescales such as a year, day, or hour. Depending on the timescale, the models would produce an annual, daily, or hourly temperature of the Earth-atmosphere system. Also, the energy transfer processes, the energy cycle, could be either steady-state or transient processes. For steady-state models, the energy input is equal to the energy output in the system, resulting in a steady temperature that does not change with time. This assumption is simple, and results in an energy balance model that can be easily solved. More complex models use transient assumptions and give more informative results, but their solution requires numerical simulations.

The simplest energy balance models assume that the incoming solar radiation, called the solar constant, is equal to the radiative energy lost by the Earth-atmosphere system over the period of one year. These simple balance models can calculate an average constant temperature, and cannot account for the climatic shift defined by the change of the Earth-atmosphere temperature. To study more realistic natural problems, these models can take into account more complicated energy-transfer processes, such as thermal storage of the energy in the upper layer of the ocean, which makes the model inherently transient. Another modeling improvement includes atmospheric energy transfer by convection and radiation. These models enable studies of the climatic shift by decoupling the incoming solar radiation, forcing, climatic shift, and response.

In terms of spatial distribution, the simplest are zero-dimensional models that assume the Earth-atmosphere system to be a single, uniform point. Dividing the Earth-atmosphere system into zones can refine this assumption. One-dimensional models divide the system into latitude zones to allow for latitude-dependent solar flux, albedo, and emissivity. Two-dimensional models create zones in both latitudinal and longitudinal directions.

Energy balance models can be coupled with mass balance models for the atmospheric air and species conservation models for particulate matter or CO_2. These comprehensive models are called Global Climate Models (GCM). With GCMs, the calculations become much more numerically complex, and provide results for weather forecasting and climate change predictions.

SEE ALSO: Climate Cycles; Climate Models; Computer Models.

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Energy Efficiency

ENERGY EFFICIENCY PROVIDES an immediate answer to an energy crisis because it can significantly reduce energy consumption, which further decreases greenhouse gas emissions. For example, during the first energy crisis during the 1970s, popular energy-efficiency measures included fuel-efficient cars and well-insulated buildings. With climate change considerations, the technological solutions to improve energy efficiency are much more diverse and more widely supported than the solutions from the end of the 20th century. To evaluate the performance of energy-efficient devices, products, and engineering-system solutions, an index called energy efficiency can be used. The definition of energy efficiency as an index depends on the thermodynamic system under consideration. In general, energy efficiency is defined as a desired output divided by a required input, and it represents a ratio of energy or work output to energy or work input for a particular thermodynamic system.

For systems that convert energy or work from one form to another, the values of energy efficiency are between zero and one. The maximum value is one, because the useful output cannot be larger than the costly input according to the First Law of Thermodynamics. For heat pumps that are transferring energy between outdoor and indoor environments, the efficiency is called Coefficient of Performance (COP) and can be larger than one. Adoption of energy efficient devices in households is enabled by the U.S. Energy Star and the European Union Energy Label to distinguish devices that produce more useful output for the same input as devices without these certifications. These marketing efforts are aimed at the faster adoption of energy-efficient technologies. Even though energy-efficient technological improvements are welcomed, they are not always adopted in the marketplace because of associated costs. In general, energy-efficient products cost more, but over their lifetime, they save energy and make their up-front investment worthwhile. This phenomenon is called the energy-efficiency gap, and can significantly slow or prevent adoption of these innovations. This gap can be bridged with appropriate government policies and economic incentives to stimulate technology invention, innovation, diffusion, and use of energy-efficient technologies.

SEE ALSO: Policy, International; Policy, U.S.; Technology.

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Environmental and Societal Impacts Group

THE FORMER ENVIRONMENTAL and Societal Impacts Group (ESIG) is now called the Institute for the Study of Society and Environment (ISSE). ISSE has a three-part motto: Integrative Research, Service to Society, and Education for the Future. Integrative research refers to ISSE's multi-disciplinary research groups, which includes members of different Laboratories in the National Center for Atmospheric Research (NCAR). ISSE is part of NCAR, itself part of the University Corporation for Atmospheric Research (UCAR). Within NCAR, there are five Laboratories: the Computational & Information Systems Laboratory, the Earth Observing Laboratory, the Earth & Sun Systems Laboratory, the Research Applications Laboratory, and the Societal–Environmental & Research and Education Laboratory. ISSE is part of the Societal–Environmental & Research and Education Laboratory (SERE).

The Integrative groups within ISSE are the NCAR Geographic Information System (GIS), the North American Regional Climate Change Assessment Program (NARCCP), a collaborative project with the National Oceanic and Atmospheric Administration (NOAA)'s Regional Integrated Sciences and Assessment (RISA) Program (RISA–NCAR Collaboration), the Collaborative Program on the Societal Impacts and Economics Benefits of Weather Information, and the NCAR Climate and Weather Impact Assessment Scientific Program.

The GIS works to combine data describing climate and weather with other sciences such as the geosciences, and physical, and social sciences. In this way, GIS aims to provide an infrastructure that allows a greater sharing of information between these fields in order to benefit all researchers involved. The NARCCP is a joint project with Canada and northern Mexico. This Program integrates regional data with global climate models and time-slice experiments to predict the weather-related needs of these countries and better prepare the available support services. The RISA–NCAR Collaboration aims to accomplish three goals: to work with the NARCCP to downscale the climate predictions; to further understand the interrelations among climate, water, and weather; and to understand the relationship between scientists and stakeholders.

The Collaborative Program on the Societal Impacts and Economics Benefits of Weather Information, also called the Societal Impacts Program (SIP), is funded by the U.S. Weather Research Program. The SIP works to determine how weather information can impact society and the economy. Finally, the NCAR Climate and Weather Impact Assessment Scientific Program aims to tackle three ambiguous fields in climate research: characterizing uncertainty, extreme weather and climate events, and how climate affects health conditions.

FOCUSED RESEARCH

In addition to its integrative research teams, ISSE also maintains research groups focused on five themes: Assessment Methods, Products and Tools; Climate–Ecosystem–Human Interactions; Use of Scientific Information in Decision Processes; Vulnerability, Adaptation, Thresholds and Resilience; and Integrated Science and Regional Applications.

UCAR collaborates with universities to manage the National Center for Atmospheric Research (NCAR) and the UCAR Office of Programs (UOP). The goal of these three organizations is: "Understanding our changing Earth system, Educating about the atmosphere and related sciences, Supporting a global community of researchers, and Benefiting society through science and technology."

SEE ALSO: Economics, Cost of Affecting Climate Change; Economics, Impact From Climate Change; National Center for Atmospheric Research (NCAR); National Oceanic and Atmospheric Administration (NOAA); Social Ecology; University Corporation for Atmospheric Research (UCAR).

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Environmental Defense

ENVIRONMENTAL DEFENSE (ED), an environmental advocacy group headquartered in New York, began when a group of scientists teamed up with a lawyer, went to court, won a battle to ban the pesticide DDT, and incorporated as the Environmental Defense Fund in 1967. Environmental Defense now prefers to work creatively, without confrontation, for solutions to environmental challenges, the most serious of which it views as global warming, "through partnership with powerful market leaders."

ED prides itself on having on staff "more Ph.D. scientists and economists than any similar group" and is noted for its "rigorous scientific approach." It seeks not only to oppose policies that it deems detrimental to the environment, but also to propose workable, innovative alternatives. In 2007, Environmental Defense was a founder and organizer of the U.S. Climate Action Partnership (USCAP), a coalition of environmental organizations and corporations advocating legislative action to address global warming.

Most of ED's more innovative solutions have been market-based. According to ED's chief economist, Dr. Daniel Dudek, market competition "has always been the most powerful engine of American innovation." Solutions reached using this approach have included a 1989 Environmental Defense plan in which Southern California's largest urban water district encouraged and financed farm water conservation by buying the conserved water. This followed the creation of a market for water rights in California in the 1970s, that gave farmers an incentive to conserve water and sell it to cities, thus avoiding the construction of new dams. As another example, the cap-and-trade mechanism for curbing emissions, which was designed by ED and introduced in the 1990 Clean Air Act to reduce sulfur dioxide emissions that cause acid rain, is viewed by the group as "the centerpiece of international plans to reduce global warming pollution."

ED has also proposed innovative solutions to wildlife conservation issues. Its Safe Harbor program assures landowners that protecting endangered species habitat will not result in burdensome restrictions on the use of their land. Its Catch Shares program advocates the creation of limited-access privilege programs that place control of specific marine fisheries in the hands of local fishing cooperatives, providing fishermen with incentives to limit their catch and restore depleted fisheries.

ED has also helped develop agreements among multiple stakeholders to set aside marine protected areas that allow fish stocks to recover. When working with McDonald's in 1991 to convince the fast-food chain to reduce packaging waste and introduce biodegradable food containers, the group used the market incentive approach to not on appeal to altruism, but to point out benefits to the corporation of improved efficiency and reduced waste. McDonald's Vice President Bob Langert commented, "Environmental Defense is probably the best non-governmental organization to find the intersection between profit and planet."

The group also spurred Federal Express's 2003 use of hybrid electric delivery trucks in Sacramento, California, New York City, and Tampa, Florida, which not only reduced emissions by up to 90 percent, but also cut fuel use, and thus costs, by up to 57 percent. More examples include an incentive program in California that encourages residents to purchase energy-efficient air conditioners and refrigerators, a joint air-quality management district on the U.S.-Mexico border to improve local air quality, a sulfur dioxide permit program in the electric-generating sector in China, and a program of incentives in Russia used to measure and reduce greenhouse emissions. Environmental Defense has convinced Petróleos Mexicanos (PEMEX), Mexico's state oil company, to promise to reduce greenhouse emissions, and has convinced the Texas State Environmental Agency to set strict pollution limits on backup electricity generators.

In February 2007, ED helped broker a major climate-related deal. Texas Pacific Group and Kohlberg Kravis Roberts & Co., two private equity investor groups, wanted to take over energy giant TXU Corporation, which had sought permission to build 11 new coal-fired power plants. These plants would add more than twice as many greenhouse emissions as would be reduced by California's enacted, but not yet implemented, climate change legislation. Environmental Defense had helped other environmental groups organize strong opposition to the TXU plans. The investment firms recognized that the success of a takeover largely depended on the reaction of environmentalists to their decisions regarding the TXU coal plants.

Realizing a deal had to made, William Reilly, former U.S. Environmental Protection Agency administrator and an executive at Texas Pacific, contacted Environmental Defense President Fred Krupp. As a result of the subsequent negotiations, the two investor groups scrapped plans for eight power plants, agreed to upgrade the environmental performance of the remaining three, committed to a $400 million efficiency and renewable energy program, including a commitment to wind energy, and promised to join USCAP. Fred Krupp saw this as a "watershed moment in America's fight against global warming" and ED endorsed the plans, but reactions from other environmental groups highlight the difference in approaches to global warming solutions.

A Greenpeace spokesperson said that, from their perspective, there was "no deal to cut" and that the only acceptable solution was a moratorium on any new coal plants.

Environmental Defense educates the public via internet and broadcast media campaigns. In September 2003, it created the Undo It campaign to stress the urgency of action to curb global warming. At the site, flightglobalwarming.com, there are lists of actions to take in the home, in relation to transportation, and in terms of neutralizing bad choices individuals might make. Viewers can find information on the dangers, science, and myths of global warming, plus a tool for calculating personal environmental impact.

Environmental Defense spends 78.9 percent of its budget on programs and services. It uses 5.3 percent of its total functional expenses on management and general administrative expenses. Fundraising expenses account for 15.6 percent of its total expenditures, and it costs ED $0.11 for every $1 it raises.

In fiscal year 2005, Fred Krupp received compensation of $357,057, which amounted to .71 percent of Environmental Defense's total expenses. The organization has 104 staff specialists working in 10 U.S. offices, with 25 of them experts in climate and air pollution issues.

SEE ALSO: Carbon Permits; Natural Resources Defense Council (NRDC); World Resources Institute (WRI).

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Environmental Development Action in the Third World

ENVIRONMENTAL DEVELOPMENT ACTION in the Third World (ENDA-TM) is an international nonprofit, nongovernmental organization based in Dakar, Senegal. Founded in 1972, on the occasion of the United Nations (UN) conference on environment held in Stockholm, ENDA is an association of autonomous entities coordinated by an executive secretariat. ENDA's representation is disseminated throughout the world and includes 24 thematic teams at the Dakar headquarters, each working on development and environment themes, 21 sections in southern countries (14 in Africa, five in South America, and two in Asia), a European delegation, and a Japanese representation to be established. The organization has about 100 staff members in Senegal and about the same number abroad.

Funding for the organization's activities mainly come from the governments of Switzerland, Austria, and the Netherlands, as well as from the United Nations. Community groups and multilateral organizations, both in Western and developing countries, also support the nongovernmental organization. The European Union also increasingly contributes to the support of the organization. The government of Senegal bestowed several facilities to the organization, which also has an extensive network of volunteers in developing countries. ENDA cooperates with grassroots groups in search of alternative development models based on the experience and objectives of marginalized peoples. It is one of the core members of the Climate Change Knowledge Network and shares its interest in climate change, and in sustainable models of development.

ENDA has stated its concern for acting on initiatives and on popular action. It has lent support to individual and collective initiatives for poverty relief and sustainable development. These initiatives have centered mainly upon the mobilization of inner-city inhabitants. The organization has backed community-based associations and community movements such as rural and urban associations, which bring together youth and women with professionals, consumers, and local or national federations.

The focus of ENDA is to provide socioeconomic, sanitary, and social services to serve the poor. ENDA took part in the 2005 World Social Forum at Porto Alegre, Brazil, in January 2006, joining focus groups on the right to the city, popular responses to privatization, youth, violence, urban segregation, Afro-descendants in Latin America, urban architecture and sustainable development. The organization also supports the activities of the African Social Forum. Participation in these events is part of ENDA's commitment to information exchange with other nongovernmental organizations and to awareness-raising among intellectuals and decision-makers. Communication and education are important sectors of ENDA, which produces films, video, and radio broadcasts, and publishes books and brochures.

ENDA closely works with grassroots groups to contribute to the search for alternative possibilities for development. It also aims to facilitate the access of intellectuals and trained personnel to development programs. ENDA favors integrated action, reflection, and training. Thanks to these actions, the organization seeks to prioritize local, technical, human, and national resources. ENDA particularly targets the area of human rights. This primary objective has led ENDA to support culturally-threatened peoples, to fight against socio-spatial disparities, to assist children and youth in the face of unemployment, and to favor a sustainable development respectful of ecology. ENDA also fights against "imported consumption patterns and production models" and supports actions against acquired immune deficiency syndrome (AIDS). All of ENDA's activities are based on the principle of making the positions of Third World countries in international debates visible and effective.

ACTION TEAMS

Within its different thematic groups in Senegal, ENDA has specific teams working on environmental schemes that highlight the effects of global warming in developing countries. The organization's Energy Program is centered around the use and development of energy in Africa. The program builds on the principles of research-action and training to contribute to the implementation of the UN's conventions on climate change and desertification in Africa, and to develop alternative energy technology, which will allow increased respect for the environment. The team is involved in collecting information on energy and carrying out projects on local, as well as regional, levels. Natural Plant Protection (PRONAT) is another action program concerning the environment, aimed at developing an African system of agriculture adapted to local resources. The scheme plans to raise awareness among farming groups and local authorities about the dangers linked to abusing chemical agricultural products, such as fertilizers and pesticides. PRONAT works with farming communities to develop and promote an alternative approach to rural development, which takes the environment into account.

SEE ALSO: Agriculture; Climate Change Knowledge Network; Education.

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Environmental Financial Products, LLC

ENVIRONMENTAL FINANCIAL Products, LLC (EFP) is a company that offers legal and financial services to businesses interested in the environmental management sector. EFP is based in Chicago, Illinois. A chief role of the company is to assist in designing and mediating arrangements between parties looking to develop business relations in environmental commodities trading, as well as other environmental or financial markets.

Richard Sandor, chair and chief executive officer, founded the principles driving EFP. Sandor earned his Ph.D. in economics from the University of Minnesota in 1967. He went on to play a large role in developing the idea of emissions credit trading after the Congressional Clean Air Act of 1990. Emissions credit trading began in an effort to reduce acid rain-causing emissions, by trading allowances for sulfur dioxide emissions at the Chicago Board of Trade, where Sandor served as nonresident director 1991–94. He later acted as second vice chairman of strategy 1997–98.

The concept of emissions credit trading is as follows: company that exceeds sulfur dioxide emissions allowances can sell its extra allowance credits to another company that cannot meet the standards. These extra credits will be at a lower cost to the purchasing company than the restructuring needed to meet the standards. The principle behind this trade is that the selling company is rewarded for exceeding standards, and the purchasing company is given extra time to meet those standards without being penalized. Overall, the same net amount of emissions is effectively released as if both companies had met standard allowances. In 2001, Sandor formed the Chicago Carbon Exchange, modeled after the original emission allowances trading for sulfur dioxide. This trading would be for emissions credits for carbon-based greenhouse gases (GHG).

EFP representatives have played a number of roles in assisting various institutions in meeting global GHG emissions standards. For example, they have consulted, advised, or acted as board members for various sectors, such as government, corporate, and nongovernmental organizations. Some examples include the Brazilian states of Amapá, Amazonas, and Paraná; the New York Mercantile Exchange; the U.S. Agency for International Development; the Toronto Stock Exchange; Lloyd's of London; the Hong Kong Futures Exchange; the Chicago Board of Trade; the United Nations; the Australian Greenhouse Challenge Office; and the Stock Exchange of Singapore.

EFP has given seminars and risk management programs at the University of Notre Dame in South Bend, Indiana; the Berkeley Program in finance at the University of California at Berkeley (where Sandor was once a faculty member); the Kellogg Graduate School of Management at Northwestern University in Chicago, Illinois (where Sandor works as a research professor); and the INCAE (Instituto Centro Americano de Administración de Empresas) business schools throughout Central and Latin America.

SEE ALSO: Cantor Fitzgerald EBS; Economics, Cost of Affecting Climate Change; Economics, Impact From Climate Change; Greenhouse Gases; Kyoto Protocol.

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Environmental History

ENVIRONMENTAL HISTORY IS the study of the interactions between human cultures and nature through time and space, examining how the natural environment has influenced the historical processes and, conversely, how people have recognized and transformed their environment using technology. This bilateral approach was designated by Christopher Smout. The goal is to place the natural world as an actor of history, an approach that social history has neglected. The object of study is ecological, where humans develop their habitat, examined from a historical perspective.

The emergence of modern environmental history as a field of study took place between the 1960s and the 1970s, when concern about both emerging environmental crisis and environmental activism arose, and historians incorporated the concepts and models of ecology. The science of ecology, as the study of the relationships between biotic and abiotic elements within their environment, was considered the scientific basis for the rational and sustainable economic development of human society. The difficulties associated with the study of the interactions emerge from the complexity of natural and human systems, the intervention of a large number of human groups and institutions, and the intervention of perception in the processes of decision-making.

History narratives began to link scientific and technological progress, social and political changes, land occupation, and the extraction of resources to environmental transformations. Historians began to talk with scientists from other disciplines, in order to fully comprehend natural systems, and the disciplines started to cross-fertilize. By 1980, the discipline had a differentiated itself, through publications and historians with an elaborated research program.

New global environmental problems include: transboundary air pollution, destruction of the ozone layer, carbon emissions and global warming, and biodiversity decline; indicating the need for policies to be discussed, adopted, and implemented at the international scale. This phenomenon challenges the classical approach of history as a national narrative. However, problem-oriented regional and local studies still dominate the field of environmental history and few authors have adopted a global scope. The theoretical and methodological influence of Carl Sauer and cultural geography is perceptible in the focused and in-depth nature of the studies.

General studies of the conceptualization of nature are found in Clarence Glacken's *Traces on the Rhodian Shore* (1967), Donald Worster's *Nature's Economy: The Roots of Ecology* (1977), Keith Thomas's *Man and the Natural World: A History of the Modern Sensibility* (1983), and Carolyn Merchant's *The Death of Nature: Women, Ecology, and the Scientific Revolution* (1980). Regional concerns deal with particular historical processes and environmental traits. American and Australian environmental histories share a common interest in the phenomenon of population of their land, from 1620 and 1788, respectively. Australian and European environmental histories converge in the study of the processes of colonization, settlement, and impact on the new environment and indigenous people.

European environmental historians examine the old and highly-humanized landscape with reduced areas of natural quality, a long history of environmental interaction, and exploration of forms of adaptation. In contrast, North American historians largely wrote about the significance of wilderness, the relationship of native Indian populations with nature, and the struggle for survival in harsh environments. In Australian history, the role of fire and the concept of the outback are more salient. The Canadian school of the staple theory of growth analyzes the economic and environmental impact of the exploitation of national resources such as fur, forestry, whale, or cod, based on exports in world trade.

THE VARIOUS APPROACHES

Various approaches on how to focus the study of the discipline are found in contemporary environmental history that can be ascribable to the principal authors. Donald Worster proposes three levels, suggesting an analysis agenda for environmental history: the review of past environments and the role of key species; the analysis of modes of production resulting from the invention of technologies and type of organization; and the study of the perceptions, ideologies, and values that led to environmental decisions and guided the interpretation of change. William Cronon, adopting a postmodern point of view, considers the perspective of Worster a simplification, for he claims for a more complex understanding of the concept of nature and the modes of production.

Alfred Crosby elaborated the concept of ecological imperialism associated with the ecological catastrophe derived from the biological invasion caused by the European colonization of the world. Settlers conveyed their own genes, diseases, weeds, varmints, crops, and livestock during their 500 years of expansion. After the colonial encounter, America suffered a demographic collapse followed by a repopulation with European and African immigrants and their accompanying species, while Africa saw a dramatic depopulation and resettlement caused by the slavery system. Those areas also experienced a process of predatory appropriation of natural resources (minerals, forests, and land) by companies and settlers, greatly reducing wildlife and partially displacing local populations into reduced areas.

Carolyn Merchant embraces a pessimistic view of the relationship between scientific advance and the environment, and identifies the roots of present ecological problems in the early 16th century with the introduction of modern science and technology. According to Merchant, the change from an organic to a mechanical view of nature, as the result of the use of technology, led to a disruption in the relationship between nature and people and, ultimately, to its destruction. Merchant introduces the phrase ecological revolution when referring to the periods, during which societies change their relationship with nature, once essential discordances between the system of production and the environment materialize. Keith Thomas adopts a more optimistic view of the role of technology, because it implies the detachment of humans from a risky position of dominion over nature, as defined in religious texts. Thus, scientific discovery brought nature back to a living condition and saved it from the effects of an anthropocentric conception.

When confronting environmental issues, it is difficult to separate science from ideology and political compromise. The dual character of the scientist, as a producer of knowledge and individual, leads to a conflict in the personal domain. However, the question is if environmental history has any moral or political agenda as a discipline. The contact with other close social sciences, particularly with environmental ethics and political ecology, favors the osmosis of approaches. Some historians within the framework of New Left history, adopt a bottom-up perspective and, embracing a Marxist methodology, judge that nature is an exploited subject, like workers in the capitalist industrial system of production.

Some authors claim that the model of politically innocent science broke down (and the public confidence in science with it) in the 1960s when the role of the scientist shifted. The non-political scientist evolved into a scientist committed to causes in his or her community and a political activist. William Cronon fights the application of environmental history to the practical solution of social problems and claims it only can be useful to society by providing stories that help people to think about those problems.

THE ORIGIN OF THE DISCIPLINE

The first scientific meeting on the matter, the International Symposium on Man's Role in Changing the Face of the Earth, was held at Princeton University, New Jersey, in 1955, under the sponsorship of the Wenner-Gren Foundation for Anthropological Research. It was co-chaired by Carl O. Sauer, Marston Bates, and Lewis Mumford. Inspired by George Perkins Marsh's *Man and Nature*, it served to identify a community of scholars as involved in a distinctive field of study. The following year, the contributions were compiled and published as a two-volume work with the same title, edited by William L. Thomas.

The American Society for Environmental History (ASEH) was founded in 1977, and launched the journal *Environmental Review*. In 1990, it continued as *Environmental History Review* and, in 1996, was renamed *Environmental History*. The first meeting of the society took place at the University of California-Irvine in 1982. The first European Workshop on European Environmental History was held in 1988, in Bad Homburg, Germany, under the sponsorship of the Werner Reimers Foundation. It resulted in the publication of the book *The Silent Countdown: Essays in European Environmental History* (1990), edited by Peter Brimblecombe and Christian Pfister. From then on, environmental history matured as a discipline and was included in the curricula of various universities, although it has not yet completely reached a fully-recognized status.

Roderick Nash published *Wilderness and the American Mind* in 1967, a book with a great public impact that offers a literary-style examination of the evolution of the concept of wilderness in North America, from an aversion to a wild hostile nature, to an attraction for a wilderness in process of disappearing. He examines environmental thinking in the United States from early settlement to the beginning of the 19th century, resolving the differences between New World and Old World conceptions of nature, and the formation of an American conception of nature. Nash details this progression, adopting a regional perspective, in response to a historical context of national introspection. Nash consolidated the general use of the term "environmental history" after he developed a course with this title at the University of California, Santa Barbara.

The *Making of the English Landscape* was published by William George Hoskins in 1955, a precursor of the dozens of titles edited between 1955 and 1985, pioneering the study of landscape history in England and the world. Through the examination of the overlying time layers hidden in the English landscape, Hoskins gathered information on the cultural features of past societies and their ways of interacting with their environment, which could explain how people related to the landscapes according to possible use and physical limitations.

Clarence Glacken published, in 1967, *Traces on the Rhodian Shore: Nature and Culture in Western Thought, from Ancient Times to the End of the Eighteenth Century*. This comprehensive work studies the history of Western thought, until the 18th century, from the point of view of the mutual influence between nature and culture. Thus, Glacken identifies three main themes of reflection about history: the question of if Earth was created deliberately, the influence of the physical environment on the character of the peoples and human culture, and the extent that change is induced by human activity.

SOURCES OF INFORMATION

Not only written documents, but also maps, engravings, pieces of art, instruments, and artifacts have been widely used as sources of information in environmental history. Other less common records investigated are farmers' logs and travelers' diaries, meteorological and phenological records, terrestrial and aerial photographs, and proxy data in the natural sciences. Proxy data are supplied by a heterogeneous set of information sources, with varied spatial and time coverage, record continuity, and degree of uncertainty in regards to dating. Numerous environmental processes have not been registered, for they have been neglected, remained unnoticed, or had non-human agents or actors.

Natural surrogates include: glaciological (ice cores, glaciers), geological (sedimentary rocks, ocean and terrestrial sediments), and biological (coral reefs, pollen deposits, tree rings) records, containing information on past environmental conditions that replace the actual data on those processes. Oral history captures the information obtained from memories and perceptions, from people who were witnesses or actors of past events and processes, or simple recipients of information. The interviewer collects data not available from other sources or in cultures where written documentation is rare, but with an extremely rich oral tradition. Nevertheless, memory, as a source of information, is interpreted through past and present perceptions, attitudes, and values, holding intrinsic difficulties for its interpretation.

Landscape archaeologists survey and conduct excavations in past cultural landscapes, interpreting and recording anthropogenic evidences of occupation and modifications of the natural landscape as the result of human adaptation to the resources available in the natural environment. The approach in the field has changed by adjusting the scale of study. While initially, research in archaeology was conducted in individual sites, understood as separate documents, the scope moved to studying settlement systems and then to compiling information in the gaps, of interstices, between sites.

The reconstruction of past landscapes and land use practices over the long term and at a geographical mid-scale developed from the environmental archaeology approach in the 1950s. The evidence comes from the constituents of the built environment, roads, fossilized field systems such as agricultural plots and walls, and water infrastructures in the form of ditches for draining or irrigating.

The protection and proper management of archaeological sites sometimes becomes subject to ethical debate when sites are presently inhabited or are claimed by successors of the former population, so that use has to be negotiated with the descendant communities.

The humanities, social sciences, and natural sciences are all under the umbrella of environmental history. Landscape archaeology examines past cultural landscapes, such as Roman ruins in Algeria above, and human adaptation to natural resources.

The analysis of the ample range of complex and interrelated social, political, cultural or technological facets of the human system leads to interactions with other disciplines. Environmental history, while rooted in landscape history, developed as a multidisciplinary field of study where the humanities, social sciences, and natural sciences come together. Landscape remained as a central topic, but many other matters are studied. Economic history, environmental sociology, cultural ecology, political ecology, and historical geography provided the conceptual and methodological background, although the process of systematization and consolidation still continues in all these fields due to their recent origins.

According to the hybridization model elaborated by Mattei Dogan and Robert Pahre, scientific disciplines undergo a twofold process, fragmentation and recombination. Gradually, subjects increase their field of study and, eventually, become too broad for scholars to comprise, so that the discipline fragments into subfields and the practitioners move toward the margins of the field. Specialists from peripheral subfields interact, filling in the gaps between sciences and recombine the fragmented subdisciplines into a new hybrid. Innovation takes place with the cross-fertilization of concepts, theories, methods, or paradigms, and new themes of study arise. Ultimately, the new hybrid may become completely independent or retain a dual character.

THE HUMAN-ENVIRONMENT RELATIONSHIP

Two major paradigms have animated theories of the conceptualization of the relationships between humans and the natural environment: environmental determinism and possibilism, even though other debates in the social sciences should not be dismissed. Environmental determinism holds that the physical environment is a factor that shapes human occupation of the land and the use of resources, determining the course of history, the culture of an area, the settlement pattern, and human behavior. The people inhabiting a region are constantly adapting to the changing nature of their environment. The controversial aspect of this theory, which was used as a rationale for racism and imperialism, led some authors to accept the idea that the environment imposes constraints, but does not override human potential to adapt, approaching possibilism.

Thus, environmental historians, evading determinism, have neglected the study of nature's influence on populations. From the perspective of environmental possibilism, nature constraints allow for a range of possibilities or opportunities for development, so that a variety of human responses are practicable in a certain physical environment, as a function of its culture and history. The relationships between culture and the environment are flexible. The particular arrangement between a certain land and a culture was termed *genre de vie* (way of life) by the French geographer Paul Vidal de la Blache, the result of the people's response, configuring the personality of the region. His influence in the Annales School of history was decisive.

George Perkins Marsh, who published *Man and Nature or, Physical Geography as Modified by Human Action* in 1864, observed and analyzed the historical impact of civilization, particularly deforestation and watershed degradation, in various regions of the world, arguing for a moral compromise with the land to ensure human survival. Aldo Leopold, a conservationist who worked for the U.S. Forest Service, published his thoughts in the book *A Sand County Almanac* (1949). His major contributions were his understanding of environmental change as a historical process, and his concept of the land ethic. According to Leopold, human ethical values and responsibility could be extended to land, by enlarging the community to include environmental components. This attitude does not prevent nature exploitation, but affirms its right to be preserved.

Lynn Townsend White, a historian of the technological innovations in medieval society, thought that history could shed light on contemporary problems. In his paper in the journal *Science,* entitled "The Historical Roots of Our Ecologic Crisis" (1967), he examined the role of religion in the formation of a Western perception of nature and its control through technology. He traced back to the Judeo-Christian ethic, the trigger of the exploitative attitude, based on the dominion of the resources on Earth that God gave to humankind, which led to the contemporary environmental crisis. The work initiated an inflamed debate inside and outside the academic world, with arguments against non-Western or pre-Christian cultures that support human control of nature.

THE ANNALES SCHOOL

The most influential contribution to environmental history came from the field of history. The Annales school, which flourished at the University of Strasbourg, France, agglutinating a first generation of scholars around the journal *Annales d'histoire économique et sociale*, founded in 1929 by the medievalist historian Marc Bloch, and modern historian Lucien Febvre. This approach, a reaction to the dominant history of political events and the function of leaders, minimized the role of individuals and economic factors by interpreting the processes of innovation as a result of the intervention of social forces. Scholars were interested in identifying the latent and slow-changing social, economic, and political structures at the various scales of analysis, hence favoring the long-term processes over time. Following this interpretation, environmental history is then concerned by a long course of action.

Their proposal for a comprehensive study of society induced historians to collaborate with other social disciplines, such as economy, sociology (such as Marc Bloch); and anthropology and particularly geography (such as Lucien Febvre), and to adopt their methodologies, composing a global history. Questions concerning this approach focus on their disregard of the role of abrupt technological or social changes and the underestimation of the phases previously identified in economic history. Also, an examination of the application of this method to contemporary issues, with technology rapidly and deeply modifying the environment, is necessary as, according to Braudel, technology shapes civilization.

Marc Bloch challenges the idea of an escalating innovation and technological progression throughout history with his analysis of the history of the watermill in Europe, an instrument of feudal dominance and taxation. Lucien Febvre, who proposed to study human history within the framework of the natural environment, supported the contribution of geography to history. This influence is noticeable in his book *La Terre et L'Évolution Humaine* (1922).

Fernand Braudel, a disciple of Lucien Febvre, in his major work *The Mediterranean and the Mediterranean World in the Age of Philip II* (1949), adopted the approach of his mentor when he placed the space itself, the Mediterranean area, as the main actor. He contemplates the Mediterranean as an environmental unit, with a specific character, and studies how it shapes the social processes of Mediterranean history. However, opposing Febvre, he goes back to determinism when he recognizes the environment as an actor of long duration playing a decisive function in history.

Braudel identifies three layers when using separate resolutions and frameworks of analysis, which allows him to recognize hidden structures. The three layers are: events with a short duration, such as those reflected in the media, mid-term conjunctures of an economic nature, and *longue durée* (long-lasting) cycles of history that extend for centuries. The three classes of events are stable foundations of civilizations, driven, respectively, by the individuals, social phenomena, material flows, and the environment. As to the mid-scale processes, Braudel emphasizes the function of long-distance exchange, the result of productive imbalances, a phenomenon that stimulates advance and innovation. After its consolidation as a school of thought with Braudel, a third generation of scholars contributed to the fragmentation of the *Annales*, by putting a greater emphasis on anthropological methods.

Alfred Hettner (1859–1941), the German geographer, used a chronological approach, focusing on the understanding of regional identity. Studying the distributions of the physical and cultural geofactors through history, he considered geography could explain origin and process, and supported the adoption of a genetic perspective. Otto Schlüter looked at landscape as the essential object of study, as a space for the integration of factors where changes are identifiable, and particularly focused on the transition between natural and cultural landscape. A key concept in the study of landscape change is sequential occupation, proposed by the geographer Derwent Whittlesey in 1929. The term designates the process of consecutive and accumulative modification of the land by subsequent generations, so that each culture produces a distinct landscape at each time frame. Dewey was interested in the evolutionary and dynamic nature of the landscape, adopting, together with Sauer, Hettner's genetic approach.

Carl Ortwin Sauer, the cultural and historical geographer, emphasized the mutual influence between landscape and culture through history at the regional scale, in order to fully understand the interactions. He thought of landscape as the single object of study of geography. Sauer's early focus was on the reconstruction of past cultural landscapes, using the empirical recollection of narratives as a method and the elaboration of very detailed descriptions. In his work *The Morphology of Landscape* (1925), he identifies people and culture as agents, the natural area as the medium, and the humanized cultural landscape as the result, reshaped and renewed by incoming new cultures, agreeing with Whittlesey. Sauer distrusts technology for its detachment of land, and identified it as the causal factor of the destruction of values.

Henry Clifford Darby belongs to the school of British historical geography and local history. He studied and published the geography contained in the *Domesday Book*, a survey of 13,418 English settlements completed in August 1086. Darby adopted a close scholarly relationship with history for the study of the course of landscape construction by humans as agents, as shown in his book, *The Draining of the Fens* (1940). His earlier works are seen in the with landscape history, anti-modern, disclaiming technology (like Sauer), while in later works he advocates development over the preservation of hostile wilderness.

RELATED DISCIPLINES

Historical geography brings a long, scholarly tradition. Its theoretical background focuses on a description and explanation of spatial differentiation, and helps to reconstruct past environments and landscapes. Patterns are produced by different cultures along history as the result of their interaction with the Earth's surface. The study of landscape history approaches historical geography, but where the former analyzes single landscapes and applies a nostalgic narrative of the natural landscape lost, the latter makes generalizations and elaborates theories of construction.

The debate between determinism and possibilism also occurred in the field of anthropology. However, whereas Alfred Kroeber notably represented the latter paradigm, determinism saw two different perspectives. Environmental determinism understands culture as determined by nature, while cultural determinism, represented by Leslie Alvin White, maintains that culture determines environment. The cultural ecology perspective seeks to explain the interactions of human populations or societies with their environment at the local scale in terms of ecological knowledge gained, human strategies of ecological success, and cultural adaptation to the local environmental conditions, in particular techniques, economy, and social organization.

This subfield of anthropology materialized with the publication of Julian Steward's book *Theory of Culture Change* in 1955, which challenged the dominant determinist paradigm of culture determining nature, with an ecological or ecosystemic paradigm, where the physical environment influences culture and the formation of political, social, and economic structures. The fragmentation in the field of cultural ecology, due to the conceptual differences with respect to the mutual interaction between the environment and culture, has led to the birth of ecological anthropology. In this approach, interaction occurs with some of the components of the habitat, and the process of adaptation takes place at the scale of the technology used.

The concept of political ecology originated in a paper written by Eric Wolf, a disciple of Julian Steward, titled *Ownership and Political Ecology* (1972). The discipline is a synthesis of cultural ecology and political economy, and it studies the organization of the world political economy and its impact on the environment. Political ecology works at various spatial scales and takes into account the implications of political structures. It accounts for the effect of resource location on political, economic, and social structures, and the role of these in resource distribution, allocation, and extraction, and their environmental effects.

Decision-making involves interaction among groups based on categories of power, status, and hierarchy in processes of social dynamics; it also implicates the adoption of measures to mitigate environmental problems and the participation of stakeholders, including: state and international institutions, companies, transnational corporations, social organizations, and society at large. In this context, ideology is a factor that figures prominently in the interactions and the adoption of measures. In his book *Theory of Cultural Change* (1955), Steward introduces the concept of multilinear evolution. He proposes that certain basic types of cultures may develop synchronically and similarly, with some common cultural features, under comparable conditions, so that their variations are more adaptative strategies than stages in a single path or unilinear cultural evolution, as supported by Leslie White.

The study of the interactions of social organizations with the natural environment, taking into consideration behavior, as well as the resulting societal well-being and environmental quality, is the concern of environmental sociology. This subfield of sociology concerns the perceptual and behavioral factors, social structures, and processes that intervene in the degradation of the natural assets society depends on, and which threaten the sustainability of the human system. It explores social movements as a response to environmental change (modern environmentalism), and the inequities in social exposure to natural and technological hazards, and access to natural resources and environmental quality.

It introduces the concept of environmental justice. The discipline has moved from sociology of the environment, with the environment as an object of study but without changing the classical mainstream perspective of sociology, to an approach with society-environment relationships as the pivotal subject. Several pre-existing areas of interest converged into a unified discipline around the 1970s, in particular, the subfields of human ecology and rural sociology, which have long adopted a human-environment perspective, and then consolidated with the manifestation of global environmental change in the 1980s. The principal themes that human ecology brought to the new field, were the study of resource-dependent communities, natural resource sociology and resource availability, and social movements research.

Riley Dunlap and William Catton published a paper in 1978, reporting the limitations of mainstream sociology in addressing environmental problems. These include the adoption of the human exceptionalism paradigm (humankind as a differentiated species) and the socially dominant Western worldview, which fails to acknowledge the roots of human society in nature. Modern society is unsustainable and vulnerable for its excessive dependence and rapid depletion of nonrenewable natural resources. Dunlap and Canton also introduced the concept of ghost acreage, resembling ecological footprint and ecological overshoot, to identify the societal dependence on distant areas for procuring natural resources and the resulting large inputs of energy required for transportation, as well as exceeding carrying capacity of the ecosystems and stocks. They acknowledge the insufficiency of the present paradigm and the urgency for the elaboration of a new ecological paradigm (NEP), based on the necessary adjustments and adaptations to the increasingly disturbing and threatening global environmental change.

The new paradigm first should be adopted by the scientific community, and then extended to the whole society. Allan Schnaiberg proposed, in his book *The Environment: From Surplus to Scarcity* (1980), the notion of the treadmill of production. It denotes the self-reproducing nature of modern capitalism, promoting economic growth and private capital accumulation. Corporations are forced to expand their activity to survive in a very competitive market, and administrations favor growth to gain increasing tax revenues. The escalating process of accumulation leads to an intensification of the demand of inputs, in the form of natural resources, and the production of outputs, as pollution. Frederick Buttel indicates there are two key environmental phenomena that need attention. First, human consumption of goods and services, driving production, with little awareness of the environmental implications, a phenomenon that he designates with the term substructural environmental practice. The second phenomenon consists of the engagement in intentionally environmental practices, such as active environmentalism and environmental regulation, the result of the adoption of the new ecological paradigm.

SEE ALSO: Conservation; Historical Development of Climate Models; History of Climatology; History of Meteorology; Social Ecology.

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THE ENVIRONMENTAL LAW Institute's mission statement is to advance environmental protection by improving enviromental law, policy, and management.

Even if aggressive mitigation measures are undertaken, the effects of climate change will be felt for decades. In response, countries and communities are developing and revising legal and institutional frameworks to improve adaptive capacity. Adaptation measures center on improving resilience, adaptive management, and early warning and emergency response. Laws and institutions can improve resilience to the potential effects of climate change by ameliorating other stressors. Laws governing planning and development, such as environmental impact assessment guidelines, can, and should, take climate change into consideration. Resilience alone is not sufficient to cope with the potential effects and uncertainties associated with climate change.

Adaptive management provides a framework for managing uncertainty. This iterative approach, which recognizes the uncertainties inherent in climate change and response measures, assesses needs and options, develops and implements response measures, monitors and assesses these measures, and modifies them, as appropriate. These different measures are illustrated by examples from managing water resources, the coastal zone, forests, and livelihoods, including agriculture.

PRECIPITATION PATTERNS

Changes in precipitation patterns foreshadow potentially substantial effects on ecosystems and human communities, including wetlands, lakes, rivers, agriculture, and domestic use. Measures to improve efficient water use, manage water demand, reuse water, and expand water resources can all improve resilience. Such measures include differential pricing structures, permitting, and requirements for water-conserving techniques. Adaptive water management, though still a developing field, is equally important. Experiences to date include the Murray-Darling Basin (Australia), and in the United States, experiences in hydropower licensing (Clark Fork Project), and management of the Platte River.

Early warning systems are essential to identifying potential climate-related threats, such as drought or hurricanes, and enabling timely and appropriate responses. Though developed countries have more sophisticated warning and response systems, developing countries have created a variety of cost-effective warning and response systems to cope with El Niño or to respond to hurricanes, typhoons, earthquakes, and other natural disasters.

COASTAL ZONE

The combined threat of sea-level rise, more severe hurricanes, and global migration toward the coasts has made it increasingly important for coastal zones to adapt to climate change. Coastal adaptation measures must cut across sectors and improve resilience of both existing and planned development. In addition to land-use planning, other laws and programs, such as those governing flood insurance, can have a profound effect on coastal development. National, state, and local laws and policies should be amended to steer development in more appropriate directions. Initiatives to retain and strengthen wetlands and barrier islands, which help buffer hurricanes and storm surges, can also improve the resilience of coastal areas.

A threshold question in coastal adaptation is whether to accept the effects of climate change (for example, by adopting a Living Coastline) or to rely increasingly on engineered solutions to resist such changes. Engineered solutions, such as the levies in New Orleans, often pose small risks of failure, but catastrophic results if they do fail, these are already leading to the armoring of coasts in many places, degrading rich tidal areas.

Finally, early warning and emergency response systems must be strengthened. As Hurricane Katrina demonstrated, both developed and developing countries are vulnerable to hurricanes, and the ineffectual emergency response revealed the challenges of implementing an effective response system. Fortunately, other experiences in emergency environmental response, such as the Joint United Nations Environment Programme (UNEP)/Office for the Coordination of Humanitarian Affairs (OCHA) Environmental Unit (though it does not address climate change) can provide guidance for the development of more effective emergency response systems.

FORESTS

Forests, and the millions of species that depend on them, are valuable economically and ecologically, providing an estimated $4.7 trillion in goods and services annually. Their ecosystem services include nutrient cycling, carbon sinks, climate regulation, and raw materials. Approximately 60 million people rely on forests for their livelihoods, with the production and manufacturing of industrial wood products estimated to contribute $400 billion to the global economy, approximately 2 percent of the global Gross Domestic Product.

Forests are especially vulnerable to climate change, given the difficulty in migrating to keep pace with temperature changes, and the varying climate tolerance levels of forest ecosystem species. Mountain forests are limited to migrating upslope to mountain peaks, while development may block migration of lowland forests. Climate change will also exacerbate existing stress from changing land use patterns that fragment habitats. Impacts such as unusually intense fires and devastating parasite infestations, historically stemmed by cold winter temperatures, are already occurring. Such impacts affect both the economic productivity and biodiversity of forests.

Increasingly, forests are managed adaptively, if not specifically in response to climate change. Adaptive measures have sought to reduce pressures on biodiversity from habitat conversion, over-harvesting, pollution, and alien species invasions. Specific projects include an adaptive management approach by the U.S. Forest Service to stem decline of the northern spotted owl. In addition, the 1994 U.S. Northwest Forest Plan established 10 Adaptive Management Areas, each with a focus, strategic plan, and activities consistent with their purpose. The Northwest Forest Plan demonstrates the importance of a clear organizational commitment, capacity, and leadership; effective public participation processes; clearly-defined elements of an adaptive management plan (including goals and objectives); and the use of creative and innovative approaches.

The mere presence of forests will help bolster environmental resilience to climate change by preserving biodiversity. Conservation of biodiversity and maintenance of ecosystem structure and function are important climate change adaptation strategies, because genetically-diverse populations and species-rich ecosystems are better able to adapt to climate change. Management structures can help build forest resilience by minimizing factors that degrade forests. For example, forests with natural species diversity can better adapt to other threats, such as population growth and depletion and degradation of forests, than can monoculture tree farms. Methods for maintaining species diversity without prohibiting tree harvesting include selective cutting and controlled burning.

LIVELIHOODS

The relationship between climate change and livelihoods is multi-dimensional; livelihoods are affected by climate change and used to mitigate its impacts. By restricting the availability of natural resources and ecosystem services (through drought, floods, and disease), climate change can make it more difficult for people to engage in the traditional livelihoods with which they have supported themselves and their families. At the same time, natural resource-dependent communities can reduce their vulnerability to climate change by diversifying their livelihoods and, consequently, the resources upon which they depend. To that end, laws, policies, and institutions can play a key role in facilitating the use of alternative resources and materials by communities seeking to adapt to the impacts of climate change. These tools can also be used to promote stakeholder participation in natural resource management decisions.

Climate change can hinder agricultural productivity and make certain crops less suitable for planting. Laws and institutions can be employed to improve water-management regimes, techniques, and practices; facilitate the continued development of drought-resistant crops and the use of genetically diverse crops and species; provide incentives for the planting of crops that are better adapted to changing climatic zones; and introduce new agricultural technologies. Climate change can affect fisheries, another key source of livelihoods, through changes in water temperatures and levels, as well as circulation and flows. Laws and institutions can facilitate adaptation by enforcing existing restrictions on pollution and habitat degradation, monitoring the impacts caused by climate change, creating protected areas for vulnerable species or habitats, and establishing commercial permitting and licensing systems for new species, when necessary and appropriate.

THE WAY FORWARD

Broad popular and political support is essential for successful adaptation, given that it will require measures that are challenging, costly, and innovative. Much of the burden and cost of changes ultimately will be borne by potentially affected communities. In order to be effective, then, adaptation must be done in a participatory and transparent manner.

Among the most significant challenges for adaptation is the uncertainty associated with specific effects of climate change in particular locales. Legislative bodies typically have found it difficult to draft laws that effectively deal with uncertainty and contingencies, but these will become increasingly important. One mechanism for coping with uncertainty is to set aside funds to pay for projects that may be needed, depending on changed circumstances. This is less likely to be viable in developing countries, unless such funds are made available through the World Bank or other multilateral institutions.

The transition to adaptive management likely will focus on four broad themes. First, policymakers, regulated entities, and the public must become more comfortable managing uncertainty. Carefully constructed and implemented adaptive management pilot projects can help increase confidence. Second, mechanisms for collecting and sharing information must be strengthened. Most countries have such mechanisms, but they often suffer from inadequate staff, funding, and technical resources. In addition, a clear legal framework for adaptive management can provide a mandate and serve to address barriers to sharing information. Third, processes must be developed to periodically assess the information that has been gathered. Finally, there must be an ability and willingness to periodically revise the laws, regulations, permits, and other measures, based on these assessments. Because provisions requiring periodic revision are lacking in most current environmental laws, policymakers should be educated about why and how to draft such provisions. Some

U.S. states have experience with these provisions and may be considered as models.

SEE ALSO: Adaptation; Forests; Policy, International; Policy, U.S.; Sea Level, Rising.

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Environmental Protection Agency (EPA)

IN 1970, PRESIDENT Richard Nixon established the U.S. Environmental Protection Agency (EPA) as part of an executive reorganization plan. William Ruckelshaus served as the first administrator, which is the title of the head of the EPA. The mission of the EPA is to protect human health and the environment. Because global warming and climate change can have effects on both human health and the environment, they are encompassed as part of EPA's mission.

STRUCTURE AND MISSION

The vigor in which EPA pursues climate change research and policy recommendations is usually dependent upon how sympathetic the presidential administration is to such policies. In 2005, the EPA faced some criticism after a former oil lobbyist influenced reports about climate change. Since then, the agency has taken a closer look at the potential effects of global warming. More recently, the U.S. Supreme Court ordered EPA to become even further involved in global climate change remediation by regulating carbon dioxide (CO_2) and other greenhouse gases under the Clean Air Act. In *Massachusetts v. Environmental Protection Agency,* 12 states and U.S. cities brought suit against the EPA. The U.S. Supreme Court handed down the five to four decision in April 2007.

The EPA is organized into different program and regional offices across the United States, as well as several laboratories. The EPA is charged with several tasks. First, it develops and enforces regulations. Next, the EPA offers financial assistance in the form of research and community grants. Environmental and risk management research is also performed at some of the EPA's laboratories. The EPA also sponsors and facilitates partnerships with a variety of governmental and nongovernmental organizations and businesses. The different divisions engage in environmental education and outreach, as well. Finally, the EPA creates many of publications that are used by multiple stakeholders, businesses, and educational institutions.

The EPA's headquarters are located in Washington, D.C. There are 10 regional offices throughout the Unites States and 12 EPA laboratories. Native American tribes work with the EPA region that includes the state that their reservation borders. In some instances, tribes are delegated specific authority to implement EPA programs on their lands. In other instances, tribes work with the EPA to enforce regulations and alter guidelines. The EPA employs over 17,000 scientists, lawyers, policy analysts, and engineers. Many employees hold post-baccalaureate degrees. The EPA is not considered a cabinet-level agency, however, most presidents appoint the administrator to their cabinet. Usually, when choosing an EPA administrator, a public servant is sought, who is not necessarily a scientist.

REGULATION AND FINANCIAL ASSISTANCE

The EPA works to achieve positive results in several program areas. The first of these is to develop and enforce regulations that protect human health and the environment. Congress promulgates laws to limit environmental degradation and maintain human health. The EPA is charged with the task of creating regulations to fill in the specific requirements of the legislation. The EPA's employees conduct research and then set national standards and requirements. At times, the EPA delegates authority to states and tribes for monitoring and compliance. If necessary, the EPA can assist states and tribes in ensuring that specific environmental quality standards are met, or revoke enforcement authority all together.

Next, the EPA offers financial assistance to many stakeholders. Most money is provided directly to states as grants to assist them in administering delegated enforcement requirements and state environmental programs. The EPA also provides many research and fellowship grants for graduate and undergraduate students. These include funding for research, community involvement, small business initiatives, internships, and tribal collaboration programs. The EPA offers several well-known fellowships, such as the National Network for Environmental Management Studies Fellowships, Science to Achieve Results (STAR) fellowships, Public Health fellowships, and American Association for the Advancement of Science fellowships. Each of these opportunities allows graduate students to fund their education, as well as participate in training programs, and conduct innovative research, often incorporating some aspect related to climate change.

ENVIRONMENTAL RESEARCH

The EPA is considered a leader in confronting environmental problems and advancing risk assessment technologies and decision-making mechanisms. The EPA labs throughout the United States conduct basic scientific and groundbreaking research on current environmental issues. Together, with collaborations from business, academia, and industry, the EPA evaluates the environmental conditions of the United States and identifies, recognizes, and resolves present and future environmental problems.

The EPA has several offices and programs devoted to accomplishing the goals of environmental research. One is housed within the Office of Research and Development (ORD). This office focuses on producing basic peer-reviewed environmental research and engendering cost-effective new technologies. To further this goal, the office awards research grants and fellowships to universities. Another research program is designed to monitor and assess the nation's biological resources. The Environmental Monitoring and Assessment Program (EMAP) tracks the current status of U.S. ecological conditions, and predicts future trends and risks associated with natural resources.

The Lake Michigan Mass Balance Study is another EPA project. From 1994 to 1999 the Great Lakes National Programs Office undertook this research effort. The goal of this project was to better understand the types and amounts of toxic substances in Lake Michigan, as well as how to manage the associated risks. Another research program administered by the EPA is the Microbiology Home Page. This is a comprehensive information clearinghouse that provides detailed information about methods relating to a variety of microorganisms. The website is maintained by Human Exposure Division of the National Exposure Research Laboratory (NERL).

The EPA sponsors the National Center for Environmental Assessment (NCEA). This center is a general information resource about the overall process of human health and ecological risk assessments. Also, the center works to integrate dose-response, hazard, and exposure data into accepted risk characterization models. The National Center for Environmental Economics (NCEE) explores the different relationships among the economy, environment, human health, and pollution control mechanisms. The NCEE also communicates and resolves multidisciplinary issues relating to the environment and economics.

Another research program managed by EPA is the National Center for Environmental Research (NCER). This organization mostly supports extraneous research through grants and fellowships. It is part of the ORD and oversees the Science to Achieve Results (STAR) funding program for universities. Next, the National Environmental Scientific Computing Center (NESC2) administers EPA's first supercomputing center. This provides High Performance Computing and Communications (HPCC) that allow EPA to undertake global-scale modeling and research, better science to create improved regulations, and educational environmental and computer science programs. This program is part of the Environmental Modeling and Visualization Laboratory. The final research program administered by EPA is the Office of Science and Technology (OST), Office of Water. The OST is charged with developing standards under the Clean Water Act and Safe Drinking Water Act. This office also issues guidelines and advisories in conjunction with other water-related laws.

The U.S. Environmental Protection Agency also administers several research offices across the United States. These include the following: National Air and Radiation Environmental Laboratory (NAREL), Montgomery, Alabama; National Enforcement Investigations Center Laboratory, Denver, Colorado; National Exposure Research Laboratory (NERL), various locations; National Health and Environmental Effects Research Laboratory (NHEERL), various locations; National Risk Management Research Laboratory (NRMRL), various locations; National Vehicle and Fuel Emissions Laboratory (NVFEL), Ann Arbor, Michigan; and Radiation and Indoor Environments National Laboratory, Las Vegas, Nevada.

PARTNERSHIPS AND PROGRAMS

Another significant area of programming for the EPA is the sponsorship of voluntary partnerships and programs. The regional offices and headquarters of the EPA work with over 10,000 businesses, nonprofit organizations, local governments, and industries on voluntary programs. These groups engage in approximately 40 different programs promoting energy conservation and efficiency, as well as pollution prevention and education. Partners undertake projects in many areas including finding ways to conserve water, reducing greenhouse gases and toxic emissions, recycling solid wastes, mitigating indoor air pollution problems, and better understanding pesticide risks.

In addition to voluntary programs, the EPA promotes several other partnerships, such as stewardship programs, information exchange partnerships, and general partnerships. For instance, the environmental stewardship program provides resources for industry, governments, and other agencies to promote sustainable actions and environmental protection. The Information Exchange Partnership is an internet-based exchange of standards-focused secure data. This resource ensures integrated information, real-time access, and the ability to electronically collect and store accurate information. The Information Exchange Partnership also includes the Central Data Exchange. This allows the EPA and contacted program offices to receive environmental data submissions from state and local governments, tribes, industry, and other collaborative partners. The Central Data Exchange provides a means for fast and efficient communication between stakeholders and the EPA.

The EPA also participates in several other collaborative initiatives. For example, Binational.net is a program in which the EPA and Environment Canada work to preserve the Great Lakes. This program fulfills the requirements set forth in the Great Lakes Water Quality Agreement. The EPA and U.S. laboratories have also formed a voluntary partnership dedicated to improving the performance, environmental sustainability, and energy efficiency of nationwide laboratories. This is called Labs for the 21st Century. A final collaborative program of note is the Office of Pollution and Prevention and Toxics (OPPT) and Tribal Environmental Network. The EPA established this program to better facilitate communication with tribes and to assist Native American tribes with the protection of the environment.

Promoting environmental education is another area of EPA programming. It is the goal of this agency to promote environmental consciousness and respect by inspiring individual responsibility for caring for the environment. To accomplish this, the EPA provides a variety of resources to educators, students, and interested citizens. The Office of Environmental Education promotes grants, fellowships, educator training programs, and the President's Environmental Youth Awards.

The final program goal of the EPA is to publish and disseminate information. This is one way that EPA keeps the public abreast of current activities and the status of environmental regulations. The E-Government Act of 2002 requires that federal agencies keep an up-to-date inventory of information to be published on their websites, to establish and convey a publications schedule, and to allow public comment on those schedules. The EPA maintains this on their website and makes an effort to distribute publications as soon as printed.

SEE ALSO: Compliance; Policy, U.S.; Pollution, Air; Pollution, Land; Pollution, Water; Regulation.

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Equatorial Countercurrent

EQUATORIAL COUNTERCURRENTS ARE major surface flows that carry water eastward in the Atlantic, Indian, and Pacific Oceans. They are located near the equator and are sandwiched between two westward-flowing currents, the North Equatorial Current and the South Equatorial Current. Equatorial countercurrents are unique, in that they flow in the opposite direction of the surface winds. The other major surface currents in the tropics flow in the same direction as the prevailing winds.

The equatorial countercurrents are driven by a distinct surface wind pattern in the tropics. Strong westward trade winds result in westward surface flow in most of the tropical Atlantic and Pacific Oceans. However, several hundred mi. (km.) north of the equator the winds are much weaker, in comparison. The stronger winds to the south pile up water where the winds are weak. As a result, the surface of the ocean can be up to 6 in. (15 cm.) higher and the thermocline (region of strongest decrease of temperature with increasing depth) as much as 328 ft. (100 m.) deeper than it is directly to the north. The excess water flows eastward under the influence of the Earth's rotation, giving rise to the equatorial countercurrents. In the Indian Ocean, the equatorial countercurrent is located several hundred mi. (km.) south of the equator, but is caused by a similar mechanism. In all three oceans, the equatorial countercurrent is concentrated in the upper 656 ft. (200 m.), above the thermocline.

The intensity of the equatorial countercurrent varies from season to season and from month to month. The strongest seasonal changes occur in the Atlantic Ocean. Eastward flow reaches a maximum in the summer and fall, with speeds of up to 12 in. (30 cm.) per second, and disappears in the spring. Seasonal changes are weaker in the Pacific Ocean. Here, the equatorial countercurrent exists year-round, and is strongest in the fall and winter, with speeds slightly greater than those in the Atlantic. In both the Pacific and Atlantic the equatorial countercurrent is located farthest north in the fall, centered near 8 degrees north. In the Indian Ocean, the countercurrent is present only during the winter.

Equatorial countercurrents, driven by tropical surface wind patterns, flow in the opposite direction of the surface winds.

There are large month-to-month changes in the strengths of the Pacific and Atlantic equatorial countercurrents. The changes are most pronounced during fall in the Pacific, and during summer in the Atlantic, and are associated with clockwise rotating eddies centered between the equatorial countercurrent and the South Equatorial Current to the south. The eddies move westward, driven by the contrast in temperature and flow between the equatorial countercurrent and the South Equatorial Current. Over an entire season, they act to decrease the strength and temperature of the equatorial countercurrent.

The equatorial countercurrent plays an important role in the circulation of mass, heat, and salt in the tropical oceans. It provides one of the pathways through which warm surface water returns eastward after being transported westward in the South Equatorial Current. In the Atlantic Ocean, the equatorial countercurrent also transports significant amounts of fresh water eastward from the mouth of the Amazon River. The Amazon water transported eastward decreases the surface salinity of the western tropical Atlantic Ocean. The strength of the Pacific equatorial countercurrent changes during alternating cycles of El Niño and La Niña. During La Niña, the equatorial countercurrent increases in strength, along with an intensification of the other major equatorial currents in the equatorial Pacific. The equatorial countercurrent becomes weaker during El Niño.

SEE ALSO: Atlantic Ocean; Ekman Layer; Equatorial Undercurrent; Indian Ocean; Pacific Ocean; Wind-Driven Circulation.

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Equatorial Guinea

ONE OF THE smallest and least developed countries in Africa, Equatorial Guinea was formerly the colony of Spanish Guinea, in central Africa, with the mainland bordering with Gabon and the Cameroon, and the capital, Malabo, located on the island of Bioko (formerly Fernando Po) in the Bight of Biafra. It has a land area of 10,828 sq. mi. (28,051 sq. km.), with a population of 504,000 (2005 est.), and a population density of 47 people per sq. mi. (18 people per sq. km.). Located in the tropics, only 5 percent of the country's land is arable, with much of it used for subsistence farming, and growing cocoa and coffee; another 4 percent is used for meadows and pasture. In addition, 46 percent of the land is forested, some of it covered in dense tropical jungle, especially in the south. The country remains undeveloped, although oil deposits have recently been found offshore, promising prosperity for the ruling class in the country.

Approximately 91 percent of the Equatorial Guinea's electricity production comes from fossil fuels, with 9 percent from hydropower. In 1990, the country's per capita carbon dioxide emissions were 0.3 metric tons, rising to 0.35 metric tons in 2003. All the country's carbon dioxide emissions come from liquid fuel, since the country has a very poor public transportation network. Transportation from one part of the country to another is undertaken mainly by minibus or bush taxi along badly maintained roads, except on Bioko, where many of the roads are sealed. The discovery of oil is likely to lead to a higher demand for electricity and greater private ownership of automobiles.

The effects of climate change and global warming on Equatorial Guinea involve a greater risk of flooding, with much of the coast of the mainland low-lying. This would not only damage the coastal infrastructure, but could also lead to increased breeding grounds for mosquitoes, leading to increased prevalence of malaria, dengue fever, and other insect-borne diseases. The Equatorial Guinea government ratified the Vienna Convention in 1988, and took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992. It accepted the Kyoto Protocol to the UN Framework Convention on Climate Change on August 16, 2000, which took effect on October 16, 2005.

SEE ALSO: Diseases; Floods; Transportation.

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Equatorial Undercurrent

THE EQUATORIAL UNDERCURRENT (EU) is a strong subsurface equatorial eastward jet, which is situated under the surface of the westward south equatorial current in the Atlantic, Indian, and Pacific oceans. The main EU core (in which velocity exceeds 20 in. [50 cm.] per second) occurs within an equatorial thermocline. EU wideness is about 428 mi. (400 km.) (plus or minus 2 degrees to the north and south from the Equator). Thickness of EU varies from 656–1,312 ft. (200–400 m.). Typical maximum velocity within the EU core is about 3.3–5 ft. (1–1.5 m.) per second.

TWO PRIMARY FACTORS

There are two principal reasons for EU, namely the southeast trade wind blowing over the equatorial zone, and the convergence of equatorial eastward nonlinear current. Long-term southeast trade wind forcing, as shown by George Philander, leads to pressure gradients directed from western boundaries of the oceans to the east. Convergence of eastward nonlinear current at the equator (due to changes in the sign of Coriolis force between the Northern and Southern Hemispheres) causes the generation of strong narrow undercurrents in the vicinity of the equator.

EU intensity is at a maximum in the Pacific Ocean (where it is called the Cromwell current). The maximum velocity of EU exceeds 59 in. (150 cm.) per second there. In the Atlantic Ocean (where it is sometimes called the Lomonosov current), its velocity is about half that of the Cromwell current. In the Indian Ocean, EU as a strong subsurface equatorial jet does not exist throughout the year. It occurs in boreal winter, when northeast monsoons are developing, and disappears in summer during southwest monsoon action.

EU is situated deeper in the western side of Atlantic and Pacific oceans because thermocline deepens just there (a long-term effect of southeast trade winds). The depth of EU core is up to 820 ft. (250 m.) in the western equatorial Pacific. To the east, EU becomes shallower and more intense. Maximum EU velocity occurs in the mid-equatorial oceans. Further to the east, EU is shallower, too. However, its intensity decreases. EU intensity decreases in the western and eastern sides of the equatorial basins is due to intensified horizontal mixing there, restricting its velocity. Often, there is the secondary (deep) core of EU that is mostly due to a barotropic eastward pressure gradient along the equator. However, the eastward velocity within this core does not usually exceed 8–12 in. (20–30 cm.) per sec.

The total transport of EU is about 50 Sverdrups in the central equatorial Pacific, while it is about 30 Sverdrups in the central equatorial Atlantic (one Sverdrup = 106 cu. m. per second). This transport is at a maximum in boreal spring (in the Pacific Ocean) and in fall (in the Atlantic). Such phase differences in seasonal cycles between two oceans is due to their different sizes. As was shown by Vitaly Bubnov in his comprehensive monograph, a seasonal EU cycle in the equatorial Atlantic is approximately in phase with the southeast trade wind forcing (in accuracy of a month), while in the equatorial Pacific they are approximately out of phase, as a result of different sizes and, hence, different equilibrium times.

Abrupt forcing of equatorial ocean (for instance, before El Niño, when trade winds weaken very quickly) generates different classes of equatorially trapped waves (such as, Kelvin, Rossby, inertia-gravitational, and mixed Rossby-gravitational or Yanai waves), most of them are modified by EU. Low-frequency (decade-to-decade) variability of southeast trade wind generates quasi-equilibrium EU variations. More/less intense southeast trade wind leads to more/less intense EU. As was shown by Albert Semtner and William Holland, EU becomes unstable if its velocity exceeds 39 in. (100 cm.) per second. As a result of instability, long planetary equatorial waves are generated. Their periodicity/wave length is about 30 days per 497 mi. (800 km.)

SEE ALSO: Equatorial Countercurrent; Monsoons; Trade Winds; Upwelling, Equatorial; Waves, Kelvin; Waves, Planetary.

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Eritrea

ERITREA IS LOCATED in the Horn of Africa between 12 degrees 22' and 18 degrees 02' north and between 36 degrees 26' and 43 degrees 13' east, bordering Sudan in the west, Ethiopia in the South, Djibouti in the Southeast and with the Read Sea in the East. Total land area is 77,236 sq. mi. (124,300 sq. km.) with a coastline of 1,180 mi. (1,900 km.), territorial waters are around 74,564 sq. mi. (120,000 sq. km.). Around 390 islands are located in the Eritrea Red Sea Zone, among them the prominent Dahelak Archipelago. The population is estimated to be around 3.5 million (2001 estimates), 20 people per sq. mi. (33 per sq. km.), with about 431,000 located in the capital, Asmara. Eritrea became independent as a nation after separation from Ethiopia in 1991, and similarly, Eritrea has suffered from erratic rains, droughts and famines.

Precipitation ranges from 7.8–43 in. (200–1,100 mm.). Due to high topographic variations it has diverse climatic zones with major rainfall in the Central Highlands and Western Lowlands during June and September. Summer rain is caused by southwesterly monsoon winds. Eastern lowland and the escarpments have rainfall between November and March, because of continental winds blowing over the Red Sea. The escarpment is the wettest area of the country due to orographic effects and bimodal rainfall regimes, in some places. The six agro-ecological zones are the moist highland, the arid highland, sub-humid, moist lowland, arid lowland, and the semi-desert, betweeen altitudes from 328–9,901 ft. (100–3,018 m.) above sea level.

The six major drainage basins are the Setit, the Mereb Gash, the Barka-Anseba, the Read Sea, the Danakil Depression, and the small catchments flowing to the Sudan. They are currently not used for irrigation and other infrastructure services. About 80 percent of the population is engaged in agriculture, mostly subsistence agriculture. Eritrea has a potential to expand fisheries and tourism in the coastal and marine areas as well as the industrial sector, but these efforts are just beginning. Currently, Eritrea as a Least Developed Country (LDC) is one of the world's poorest country with per capita income below $100 per year. Biomass accounts for about 75.5 percent and petroleum, the only fossil fuel, for 24.5 percent of the total energy consumption.

CO_2 emissions amounts 622,5 Gg, equivalent to 0.133298 per 1,000 people according to latest estimates, which is not much different from 1994 data. However, the major share of CO_2 emissions comes from the land-use change and forestry (LUCF) sector by burning fuel wood, deforestation and soil degradation with an additional net balance of emission of 1676 Gg in 1994. So the LUCF in Eritrea is a source rather than a sink for emissions. The second major source is from petroleum combustion in road transport and energy industries, accounting for about 283 and 241 Gg of CO_2. Nitrous oxides account for about 6 Gg, mainly from the energy secotor, methane 74 Gg mainly from agriculture.

Eritrea is most vulnerable to climate change. The UK8 model turned out to be the best predictor for climate change in Eritrea. With doubling greenshouse gases, temperature is expected to rise by 7.2 degrees F (4.1 degrees C) within the next century, affecting especially the Port City of Massawa, which is mainly located at sea level, leading to estimated economic losses of $14–$243 million. Harsh climatic conditions and periodic droughts already limit the scope of regeneration of biodiversity. Climate change would diversify and shift the bio-climatic zones. Surprisingly, agricultural yields are predicted to increase due to possible beneficial atmospheric effects of CO_2.

Climate change policies in Eritrea are intended to complement the country's objective for attainment of food security and poverty reduction. Planned adaptation programs are: reforestation/afforestation, mainly implemented by area closure systems; introduction of energy efficient technologies for power generation such as the Hirghigo Power Plant Project and into households; introduction of renewable energies; formulation of laws and standards; introduction of efficient public transport systems, particularly in urban centers; education and awareness measures. The country will require financial support and technology transfer from developed countries to be enabled for full implementation of the United Nations Framework Convention on Climate Change (UNFCCC) process. Eritrea ratified the Convention on April 24, 1995 and the Kyoto Protocol on July 28, 2005.

SEE ALSO: Carbon Dioxide; Ethiopia; World Resources Institute (WRI).

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Estonia

THE NORTHERNMOST OF the three Baltic States, the definition usually excluding Finland, Estonia has a land area of 17,413 sq. mi. (45,226 sq. km.), with a population of 1,342,409 (2007 est.), and a population density of 75 people per sq. mi. (29 people per sq. km.). With 25 percent of the country arable land, 11 percent is used for meadows and pasture, 44 percent of the country remains forested.

With a high standard of living, and located in northern Europe, the energy usage in the country is high, with 7.9 billion kWh (2001) produced each year, and some 1.2 billion kWh exported. Only 0.1 percent of this comes from hydropower, with 99.7 percent from fossil fuels. This has resulted in Estonia having the 10th highest per capita carbon dioxide emissions of any country in the world: 16.1 metric tons in 1992, falling to 13.6 metric tons in 2003. Of the country's carbon dioxide emissions, 75 percent come from solid fuels, mainly coal, and also wood; 17 percent from liquid fuels, and 7 percent from gaseous fuels, with 1 percent from cement manufacturing. Because of the cold climate in the winter, 75 percent of carbon dioxide emissions come from public electricity and heat production, with 9 percent from transportation, and 7 percent from manufacturing and construction.

Global warming and climate change are causing higher average temperatures in Estonia. In addition, some of the snow has melted, creating more land for farming. However, this has led to a change in the crops that can be grown, and the warmer temperatures in the seas around Estonia have affected the local fishery industry. In 1989, the government of the Estonian Soviet Socialist Republic (a constituent part of the Soviet Union), ratified the Vienna Convention, and the Estonian government took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, and signed the Kyoto Protocol to the UN Framework Convention on Climate Change on December 3, 1998, ratifying it on October 14, 2002; it took effect on February 16, 2005. When ratifying the Kyoto Protocol, Estonia undertook to reduce per capita carbon dioxide emissions by 8 percent before 2012.

SEE ALSO: Agriculture; Coal.

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Ethics

THE CONSIDERABLE SOCIAL challenges posed by global warming and associated climate change, and the related scientific, policy, and public health issues are amenable to ethical analysis and inquiry. The role of ethical decision-making is to identify and analyze instances of ethical conflict or uncertainty, with the goal of making and implementing sound decisions, especially with attention to the rights, responsibilities, and interests of the parties involved. Several approaches for ethical analysis have been proposed for use in biomedicine and public health. Examples include principle-based approaches (such as beneficence, autonomy, and justice) and case-based methods based upon analogical reasoning (comparing like cases). Other theoretical approaches depend on rights or duties. In humanitarian approaches to ethics, people respond to human suffering by acting in a virtuous manner based on compassion or altruism. In fields such as biomedicine and public health, ethical frameworks tend to be anthropocentric: they focus on the welfare of humans and human populations and on interactions between human beings.

For environmental science, additional approaches to ethics have been proposed that consider the ethical relationship between human beings and the natural environment. Many current ecological problems are tied to human attitudes, values, ethics, and behaviors. Although environmental ethicists strive to avoid anthropocentric viewpoints (for example, by explicitly considering the impact of ethical decisions on animals, plants, and the ecosystem), they frequently draw upon traditional ethical theories and frameworks developed to decipher right or wrong human conduct. Environmental ethicists consider biological entities and the nonbiological world (for example, the atmosphere, land, and ocean) fundamentally interdependent and involving complex systems. Examples include coral reefs and related fisheries that are being destroyed by warmer waters and pollution. Thus, environmental ethics provides support for arguments that a sustainable environment is essential to human beings, including future generations. Some environmental ethicists have argued that the environment, with all its diversity and complexity, has intrinsic worth, even without its importance to humans.

Practical steps in ethical decision-making include: assessing the available factual information; obtaining additional factual information about issues at the center of the controversy (for example, comparing collective actions that could be taken to reduce emissions of greenhouse gases and forecasting the potential economic consequences); identifying the relevant ethical issues or questions; identifying the stakeholders and values at stake; identifying the available options, including possible alternative courses of action; and more clearly defining the language used by the disputing parties (for example, what is meant by "environmental sustainability"). The remaining steps are selecting the best alternative supported by the analysis and evaluating the actions taken and their eventual outcomes.

Principles of justice or equity have figured prominently in public debates about such issues. It has been observed that the people least likely to be responsible for greenhouse gases (for example, people in parts of Africa, Asia, and Oceania) are also those most likely to be adversely affected by global warming. Many of the world's poorest people are among the most vulnerable to storms, flooding, or rising sea levels. Poorer nations and communities may also be at increased risk for vector borne illness, hunger, or famine due to drought, heat, and extreme weather events, raising concerns about health or survival. Environmental ethicists have argued that those who could benefit most from mitigation and adaptation measures are often those who are least responsible for greenhouse gas emissions. Principles of procedural justice have informed discussions about the need to assure fair representation in decision-making related to global warming and climate change. Intergenerational equity underlies concerns about the need to look out for the interests of future generations. This includes taking steps to help ensure that the world inherited by future generations is not diminished by loss of animals, plants, ecosystems, or land that is suitable for homes or growing crops.

Ethical analyses also have contributed to policy decisions made about how best to respond to climate change in the face of scientific uncertainty. Although there remains some scientific uncertainty about the timing and magnitude of future effects of global warming and climate change, ethical analyses have contributed to policy decisions by governments, corporations, and other organizations about what steps should be taken to mitigate the adverse effects of climate change. Ethical principles and values such as beneficence, utility, prudence, and the precautionary principle underlie the need to take appropriate action, even in the presence of some scientific uncertainty.

Examples include limiting emissions of greenhouse gases, developing new technologies, strengthening public systems needed for emergency preparedness (for example, preparing for severe storms or flooding), protecting forests, improving irrigation systems, and developing sustainable agriculture to alleviate human suffering and ecological destruction. Finally, ethical principles also highlight the need for adaptation, a process by which individuals and communities institute policies, countermeasures, and appropriate actions to mitigate the adverse effects from climate change. Examples include improving and strengthening warning and forecasting systems, educating the public at large, and heightening community preparedness.

SEE ALSO: Anthropogenic Forcing; Climate Change, Effects; Developing Countries; Social Ecology.

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Ethiopia

ETHIOPIA IS LOCATED in eastern Africa, along the continent's Great Rift Valley. Some of the earliest humans emerged from this part of Africa millions of years ago. Ethiopia is expected to be one of the countries hardest hit by climate change, putting much of its 76.5 million residents at risk. In fact, some climate researchers now believe Ethiopia was one of the first victims of climate change, more than 20 years ago. Global dimming, a problem just now being studied by climatologists, is a reduction in the warmth of the Sun, as particulate matter in the atmosphere blocks the Sun's rays from reaching the Earth's surface. That solar heat is vital to the development of monsoons in that part of Africa. A dimming event in the 1980s was probably behind the catastrophic droughts of 1984–85, which led to a famine killing more than a million Ethiopians.

More frequent droughts in recent years have strained the Ethiopian economy, more than 80 percent of which is based on agriculture. In 2007, world health officials estimated that at least 1.5 million Ethiopians were at risk of starvation in the aftermath of a particularly dry year. Deforestation, soil erosion, overgrazing, and desertification have also put pressure on the ecosystem at large, with the loss of several native plant species, and some native bird species on the brink of failure. Climate change is hurting the lifestyle of 20 million nomads who live across the Horn of Africa. In recent years, intertribal fights over dwindling water resources and vanishing grasslands have been on the increase. In 2006, several tribal leaders gathered in Ethiopia for peace talks, but conflict is likely to continue, as resources grow scarcer.

Total carbon emissions in 1998 were 1,990,000 metric tons, a 33 percent decrease from 1990 levels, and well below the regional averages. An estimated 79 percent of emissions come from liquid fuels, and 21 percent from cement manufacture. The Ethiopian government is signatory to a number of international treaties, including biodiversity pacts, desertification reduction, and protection of endangered species and the ozone layer. It has also signed on to the Kyoto Protocol. The government has shown commitment to educating the public and supporting the development of sustainable practices and green technologies.

SEE ALSO: Deforestation; Desertification; Drought.

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European Commission

THE EUROPEAN COMMISSION (EC) is a part of the European Union (EU) that functions to manage issues related to the environment, natural resources, sustainable development, and grants for research and development in matters of importance to the EU, such as the environment.

The EC holds numerous events throughout the year as well as throughout the EU in order to raise awareness of the environment and its protection, as well to honor people and organizations that are exemplary in their stewardship. One such occasion is European Mobility Week (EMW), an annual event taking place since 2002 in the European Union. During this week, the latest ideas and technologies for sustainable travel are showcased for the public and investors alike, taking place in each participating city.

Each local government participating in EMW is required to make one permanent change annually. Between EMW 2006 and EMW 2007, the average number of permanent changes per participant was actually 2.4. There is an annual contest comparing these permanent changes. In the year 2006, Copenhagen, Denmark won this contest by thinking of and testing fifteen new traffic changes, including novel parking strategies. In the year 2007, León, Spain won the contest by opening a new bus route as well as new city bicycle routes for noncar modes of transportation. EMW also includes a car-free day, which often has non-EU countries participating. In the year 2007, a Chinese city participated for the first time. Other returning countries included Brazil, Canada, and Thailand.

On June 15, 2006, the EU via the EC established EU Forest Action Plan. Trees and forests play a crucial role in global warming prevention, because they act as important carbon sinks, absorbing carbon dioxide from the atmosphere. The EU Forest Action Plan is targeted for the years 2007–11, and has four key foci: long-term improvement in economic competitiveness, namely using sustainable harvesting; environmental stewardship; quality of life enhancement; and improved coordination and communication. The EC stresses in this plan that protected forests are a necessity, and that to ensure their status, it is imperative to have international cooperation. Additionally, the plan states that forestland will contribute to the goals of the Lisbon Strategy, including the Gothenburg Objectives, for Economic, Social, and Environmental Renewal.

In addition to drafting its own plans and goals for carbon emissions reductions and limiting use of fossil fuels, the EC also respects international accords regarding the environment and its protection.

The EC is also investigating numerous alternative energy sources so as to reduce carbon emissions, such as Bio-energy, Concentrating Solar Power, Geothermal Energy, Ocean Energy, Photovoltaics, Small Hydro Energy, and Wind Energy. The EC recognizes that much advancement has been made already, but that further advancement will depend on public and international policies and their support for the abovementioned alternative means of energy. In 2005, a report from the European Commission (EC) entitled the Biomass Action Plan stated that at that time, the EU was obtaining four percent of its energy from biomass utilization, and that it had the potential to use up to eight percent by 2010, if policies were supportive.

In order to continue to uphold the Kyoto Protocol and future resolutions, the EC has established the European Strategic Energy Technology Plan (SET Plan). The goals are to incorporate renewable energy into twenty percent of the energy pool for the EU, to lower greenhouse gas emissions by twenty percent, and to reduce primary (fossil fuel) energy usage, also by twenty percent. These three goals are set for the year 2020. By the year 2050, the EC hopes to have the EU emissions reduced by 60 to 80 percent.

SEE ALSO: Carbon Emissions; Carbon Footprint; European Union; Kyoto Protocol.

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European Union

THE EUROPEAN UNION (EU) is a democratic organization of member European countries. The European Union was established neither to join all nations into one state nor to manage international cooperation; rather, it was established to act as a democratic forum in which policies could be made, affecting all member countries equally. The EU supports the diversity of its member nations, working together to foster shared values. Countries wishing to join the EU must apply and be approved.

The EU was originally formed after World War II in an effort to prevent further war among the European countries. Six initial countries formed the first version of the EU, and their interests were mostly in trade and economy. These six founding countries are Belgium, France, Germany, Italy, Luxembourg, and the Netherlands. Since then, Denmark, Ireland, and the United Kingdom joined in 1973, with Greece joining in 1981. Portugal and Spain joined in 1986; Austria, Finland, and Sweden joined in 1995; Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia, Slovenia joined in 2004; and Bulgaria and Romania joined the EU in 2007. As of 2007, the EU included 27 countries, home to nearly 500 million people. The euro, the shared currency of the EU, was introduced in 2002, and was used in 13 countries by 2007. As each member nation improves its economy, this number will rise.

Beginning in 2004, former rifts between Eastern and Western Europe began to heal when 10 nations, primarily from Eastern Europe, joined the formerly Western Europe-dominated EU. Since then, other developing European nations joined as well; as of January 2008, Croatia, the Former Yugoslav Republic of Macedonia, and Turkey were candidate EU countries.

The Schuman declaration is often cited as the blueprint for the EU. On May 9, 1950, French foreign minister Robert Schuman proposed an organization of European nations, to promote peace. In honor of his proposal, May 9, is Europe Day in today's EU. The Schuman declaration proposes that Europe come together over a series of unions, not all at once in one large plan.

One such union that Schuman proposed was the alliance of French and German coal and steel production, into an alliance in which other European nations could participate in. In fact, the Treaty of Paris, signed April 18, 1951 and enacted July 25, 1952, established the first European Steel and Coal Community and is considered the foundation of the modern European Union.

Although many subsequent treaties have been signed, which have amended the initial treaties of the EU, the Treaties of Rome are considered the first documents of the EU and the basis of its constitution. They are made up of the Treaty Establishing the European Economic Community and the Treaty Establishing the European Atomic Energy Community. Both were signed as the Treaties of Rome on March 25, 1957, and enacted on January 1, 1958.

In 2004, three years prior to the 50th anniversary of the European Union, a Constitution was written. The Official document is called the Treaty Establishing a Constitution for Europe and serves to unite and replace all pre-existing Treaties regarding the European Union.

The Treaty of Lisbon was signed on December 13, 2007, amending the original Constitution Treaty and, thereby, all prior EU Treaties. Also in 2007, the 50th anniversary of the signature of the Treaties of Rome was celebrated throughout Europe. A declaration at the Berlin celebration states "We are facing major challenges which do not stop at national borders. The European Union is our response to these challenges."

The EU acts much like a large nation in some respects, especially in its policies regarding economic improvement and environmental stewardship. Europe takes pride in its agriculture and agricultural products such as olive oils, meats, and cheeses. The EU recognizes that global warming and climate change would negatively impact this agriculture. Therefore, it has arranged conferences to discuss policies regarding agriculture, forests and deforestation, and sustainable economic growth that will protect the environment. For example, in March 2000, the EU held its Lisbon Summit, geared to stimulate the EU economy into becoming the leading global economy with sustainable economic growth. The resulting document was the Lisbon Strategy, including the Gothenburg Objectives, for Economic, Social, and Environmental Renewal. The strategy stresses environmental sustainability as a foundation for the economic growth and maintenance of Europe. The Lisbon Strategy is distinct from the Treaty of Lisbon, also sometimes called the Lisbon Treaty.

The large population of the European Union requires a large amount of energy, not much of which comes from the EU itself; changes are underway to improve the self-reliance of EU nations in terms of energy. For example, while approximately one-quarter of EU gas and oil is purchased from Russia, not a member nation, in 2005 a report from the European Commission (EC) entitled the Biomass Action Plan stated that at that time, the EU was obtaining 4 percent of its energy from biomass utilization, and that it had the potential to use up to 8 percent by the year 2010, if policies were supportive.

According to the Oak Ridge National Research Laboratory at Oak Ridge, Tennessee, in 1996, member countries of the European Union were among the top 20 carbon dioxide emitters in the world. These countries were Germany, the United Kingdom, France, Poland (which would join the EU in 2004), and Italy. The EU imports nearly one-half of its energy used.

This dependence on foreign oil puts the EU in a risky position, should another energy crisis occur. For this reason, as well as for environmental stewardship, the EU nations are actively investigating and incorporating alternate sources for energy. A goal value for energy from renewable sources is to generate 21 percent of EU electricity from renewable sources by 2010. As of early 2008, the only EU country that had a net export of energy was Denmark. Another energy goal of the EU is to open international, EU energy networks that would stabilize electricity prices across member nations and foster a more efficient use of power.

The EU has data on its website citing the amount of energy imported per member nation as well as the percentage of electricity generated that came from alternate, renewable sources for energy. These numbers, compiled by Eurostat, are for the year 2004.

Additionally, the website describes the 2003 Greenhouse Gas Emissions numbers, as well as target emissions for 2008–12. The target values are given as a percentage of their 1990 values. This percentage is because the Kyoto Protocol aims for each nation to reduce its greenhouse gas emissions to 8 percent lower than the 1990 emissions, by 2008–12. In order to make this goal feasible for the joint nations of the European Union, the EU has spread the numbers among each member nation, such that developing nations are allowed to increase their emissions in order to continue development while larger, more developed, and economically stable nations will reduce their emissions further.

The participating countries are those that were members of the EU prior to the year 2004; these countries are called the EU-15. The countries that joined in 2004 have individual reduction plans, and the countries of Cyprus, the United Kingdom, and Malta do not have target emissions values. The values for emissions in 2003 as well as the projected emissions for 2008–2012 (all as a percent of 1990 values) were compiled by the European Environment Agency, European Topic Center on Air and Climate Change.

Large numbers of cars and trucks and the ensuing traffic in the European Union add to global warming by emitting greenhouse gases. In order to curtail these emissions, the EU urges its citizens to use public transportation, and requests industries to use ships or trains to transport freight. In fact, trade between member EU nations totals approximately two-thirds of all EU trade. Additionally, one unified air-traffic control module for Europe is under consideration, to reduce air congestion.

SEE ALSO: Agriculture; Austria; Belgium; Bulgaria; Croatia; Cyprus; Czech Republic; Deforestation; Denmark; Economics, Cost of Affecting Climate Change; Economics, Impact From Climate Change; Estonia; European Commission; Finland; France; Forests; Germany; Greece; Greenhouse Gases; Hungary; Ireland; Italy; Kyoto Protocol; Latvia; Lithuania; Luxembourg; Macedonia (FYROM); Malta; Netherlands; Poland; Policy, International; Portugal; Romania; Russia; Slovakia; Slovenia; Spain; Sustainability; Sweden; Turkey; United Kingdom.

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Evaporation and Transpiration

EVAPORATION AND TRANSPIRATION are the two processes by which water is removed from the Earth's atmosphere. Because it can sometimes be difficult to ascertain which one is occurring, the term evapotranspiration is often used to describe the sum total of both processes. Evapotranspiration is an important part of the planet's hydrological cycle, and it is likely to change in a warming world.

Evaporation is the process of changing water from a liquid to a gaseous state. Water molecules are in motion, and if they generate enough speed and are going in the right direction, they essentially heat themselves to the equivalent of boiling, at which point, they have enough energy to escape the liquid state and pass into the atmosphere. Only a small percent of molecules will find themselves in these favorable conditions at any one point, so the overall rate of evaporation from any body of water is relatively low. Evaporation rates ebb and flow depending on local conditions. Bodies of water with a large surface area evaporate more than smaller bodies, as there are more water molecules near the surface. If the relative humidity is low, the evaporative rate is correspondingly higher. High temperatures also increase evaporation, as do high or sustained winds. In all, about 80 percent of evaporation comes from the Earth's oceans, with the remaining 20 percent coming from inland waterways and vegetation.

Transpiration is the evaporation of water from plants and trees. Approximately 90 percent of all water taken up by a plant is lost to transpiration. Generally, the ratio of transpiration is 200 to 1,000 kg. of water evaporates for every kg. of dry matter produced. One acre of corn will release 400,000 gallons of water into the atmosphere in a growing season, and a 49 ft. (15-m.) tall maple tree could lose 58 gallons (220 liters) of water per hour on an average summer's day.

Water evaporates through small openings in the leaf surface called stomata. These openings expand when light hits the surface of the plant, and close up at night. The stomata allow the leaf to expel oxygen and carbon dioxide. Transpiration helps a plant by pulling water up from the ground, and transporting minerals and fluids throughout the plant; the release of water also cools the plant.

Several forces act on a plant to increase transpiration. Unless the air around the plant is at 100 percent of relative humidity, the plant quickly begins to dry out and starts pulling moisture from the soil. Wind tends to enhance the effect by blowing humid air away from the plant. Sunlight warms up the leaves and opens the stomata; warm air temperatures create the same response. If the soil around the plant becomes too dry, the stomata close off to preserve as much moisture as possible, and the plant quickly begins to wilt.

The Earth's water budget is fixed and cyclical, and evapotranspiration is one of the processes by which water is exchanged between the surface and the atmosphere. The water vapor expelled by evaporation and transpiration forms clouds, which travel high into the atmosphere, cool, and produce rain, which then falls back to the surface, where the cycle begins anew. Some of the water that reaches the surface nourishes plant life, which transpires most of that water back into the atmosphere. Some of it sinks far enough into the soil to reach the water table, and recharges freshwater sources. The amount of water vapor in the atmosphere remains relatively constant at 12,900 cu. km., but each year, approximately 490,000 cu. km. of vapor cycles through the whole system.

Increased evapotranspiration is one of likely outcomes of global warming. Higher air temperature enhances both evaporation and transpiration. This will contribute to longer and more frequent periods of drought in the lower and middle latitudes in coming years.

For example, one computer model built in the 1990s estimated that by the end of the 21st century, summertime evapotranspiration in the American southwest could increase by 27 percent. The model found similar increases in 12 regions around the world. Between the growing human population in need of drinking water and the heightened probability of drought, the world's water deficit will probably increase in coming years.

SEE ALSO: Deforestation; Drought; Evaporation Feedbacks; Forests; Hydrological Cycle.

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Evaporation Feedbacks

THE INCREASE OF greenhouse gas concentrations in the Earth's atmosphere, above natural levels, is causing anthropogenic changes to Earth's climate. The temperature at the Earth's surface has shown a significant and rapid rise since the 1990s, compared to the past two millennia. It is challenge for scientists to attribute these known changes to specific mechanisms. Some of the complex feedback processes that add to these changes are not fully understood.

The energy balance, the distribution of energy in space (or Earth's atmosphere), and temporal energy variations characterize the Earth's climate system. The Earth's radiative energy balance is governed by the balance between solar radiation and absorption by the Earth and subsequent radiation from the Earth to outer space. The Earth absorbs solar shortwave radiation in the daytime, and emits thermal infrared or longwave radiation back to outer space to maintain the heat energy balance. However, this energy balance is more imbalanced recently, because of the many components of the Earth-atmosphere system, such as clouds or aerosols and other radiation scattering particles present in the atmosphere.

The National Aeronautics and Space Administration (NASA) CERES (Clouds and the Earth's Radiant Energy System) instrument on the Tropical Rainfall Measuring Mission (TRMM) and Terra satellite mission provide a new set of Earth radiation balance data. Along with these data and a 16-year record of the Earth Radiation Budget Satellite (ERBS), NASA has compiled the 22 years of accurate satellite observed broadband radiative fluxes, showing the huge energy imbalance or long-wave anomalies since 1995.

THE HYDROLOGIC CYCLE

The hydrologic cycle is part of this heat energy imbalance process. This feedback process complicates the global warming phenomena and involves water vapor, clouds, and aerosol particles. Evaporation is the basis of this important process. Water is evaporated by Sun, incorporated into clouds as water vapor, falls to the land and water bodies as rain, and enters water bodies to complete the cycle. Conversely, to make matters worse, water vapor acts as a prominent greenhouse gas as it is involved in an important climate feedback loop. Due to ascending evaporation from water bodies, the water vapor amount in the atmosphere increases.

The additional water vapor absorbs radiated thermal infrared energy that would otherwise escape from Earth's surface to outer space, and radiates the heat back to the Earth again. Thus, it makes the Earth's surface even warmer. This somber picture is further complicated by important interactions among water vapor, clouds, atmospheric motion, and radiation from both the Sun and the Earth.

Moreover, continuous increases of the Earth's surface temperature augments the sea or ocean surface temperature. Therefore, increased evaporation and higher annual rainfall amounts should occur. Computer simulation models found that a global warming of 7.2 degrees F (4 degrees C) is expected to increase global evaporation and precipitation by about 10 percent. Scientists found through models that the upper tropospheric water vapor amount will increase by 15 percent with each degree of atmospheric temperature rise, because of increased evaporation.

Another evaporation feedback mechanism involves the atmospheric wind-evaporation-convection feedback in the tropics. The feedback is shown to be very effective in channeling perturbations from one component of the climate system to other components, such as from evaporation to surface wind, and from atmospheric convective activity to evaporation. Through this feedback process, it is also observed that surface evaporation over tropical oceans is connected with cloud absorption of shortwave radiation. Diminished shortwave absorption by clouds causes excessive shortwave radiation at the Earth's surface, leading to excessive evaporation. As the loop continues, the Earth's surface gets warmer and warmer.

This same wind-evaporation-convection feedback in the water is also a concern. This is a huge contributor toward spatial variability of evaporation and precipitation on the Earth. Recent rises in the Earth's surface temperature may lead to a near-term collapse of the ocean's thermohaline circulation. Thermohaline circulation is a global ocean circulation pattern or convection mechanism. It distributes water and heats both vertically, through the water column, and horizontally across the globe. Due to this collapse of thermohaline circulation, warm surface waters move from the tropics to the North Atlantic and extra-warm water surfaces in the Pacific Ocean surface surrounding the equator.

Therefore, spatial variation in ocean temperature is observed. This spatial change in ocean surface temperature is changing usual wind direction, creating unusual evaporation rate, and subsequent spatial variability in rainfall. This pattern has been evident for the past two decades. Therefore, more precipitation is occurring in northern Europe, Canada, and northern Russia, but less to swathes of sub-Saharan Africa, southern India, and Southeast Asia. El Niño and La Niña are examples of the recently observed changed thermohaline circulation process. Scientists working specifically on polar warming amplification observation found that much stronger evaporation feedback leads to a final warming in low latitudes that is stronger in the atmosphere than at the surface.

Atmospheric water vapor or the evaporation feedback is supported by many studies and researchers concluded that this feedback process is positive, continually increasing the Earth's surface temperature. Scientists proved this observation with profound evidence using new satellite-generated water vapor data and concluded that the feedback is not overestimated in models. It is also observed that the global water vapor amount will increase by 7 percent with each degree of atmospheric temperature rise, thus complicating the global warming and climate change mechanism.

SEE ALSO: Biogeochemical Feedbacks; Climate Feedbacks; Climate Sensitivity and Feedbacks; Evaporation and Transpiration.

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Evolution of the Atmosphere

EARTH'S ATMOSPHERE IS unique in the solar system: of all the heavenly bodies, Earth alone has an atmosphere capable of supporting life. An appreciation of this highly specialized nature of the contemporary atmosphere is vital to understanding its evolution. The atmosphere has not always been the way it is today, and the present atmosphere is almost certainly not directly related to Earth's primordial atmosphere. The contemporary atmosphere arose from thermal and geological processes occurring some time after Earth's formation, and its evolution to a life-supporting state is intimately linked to the evolution of life itself.

THE PRESENT ATMOSPHERE

The Earth's atmosphere is extraordinary; comparing the Earth to other planets in the Solar System illustrates just how extraordinary. The inner planets are often referred to as the terrestrial planets because they consist of rocky masses surrounded by gaseous atmospheres (with the exception of Mercury, whose atmosphere has long since been lost to space because of its proximity to the Sun). Venus and Mars both have substantial atmospheres and make excellent comparisons for the atmospheric evolution of Earth.

The atmospheres of Venus and Mars have evolved to consist primarily of carbon dioxide (CO_2), with some nitrogen and hardly any oxygen. Although Venus and Mars have important differences in their atmospheric chemistry, their atmospheres are essentially similar. Roughly speaking, both atmospheres consist of 95 percent CO_2 and 3 percent nitrogen. The amount of free oxygen on both planets is less than 1 percent. Earth's atmosphere may have evolved in a similar way: it was formed at roughly the same time from roughly the same material. Instead, Earth's atmosphere is markedly different. It contains hardly any CO_2 (although CO_2 plays a crucial role in regulating the planet's atmosphere and climate), consisting mainly of nitrogen, with a comparatively high oxygen content of around 21 percent. These differences result in an important chemical distinction between the atmospheres. The atmospheres of Venus and Mars are highly oxidized, containing a lot of chemically combined oxygen (mainly CO_2). In contrast, Earth's atmosphere is highly oxidizing, containing large amounts of free oxygen.

That one fifth of the Earth's atmosphere is comprised of oxygen is curious. Oxygen is a highly reactive gas, and the atmosphere and surface of the Earth contain many materials with which oxygen can react. Furthermore, the amount of time it would take for all the oxygen in the air to undergo these reactions is much shorter than the time the oxygen has been there. In short, there should not be anywhere near as much oxygen as there is in Earth's atmosphere; the atmosphere is a long way from chemical equilibrium.

From a chemical perspective, the Earth's atmosphere is like a bucket that, despite having a hole in the bottom, remains half full. It is impossible, unless water is flowing into the bucket at the same rate that it is leaking through the hole. In the same way, the composition of Earth's atmosphere is impossible, unless something is constantly adding oxygen to counteract the rate at which it is being lost through chemical reactions. The factor acting on the atmosphere to keep it in its state of chemical disequilibrium is life.

Biological activity on the planet uses energy from the Sun, during photosynthesis, to produce vast quantities of free oxygen. In the absence of life, there is no way for oxygen to have built up to the levels observed today. The evolution of the Earth's atmosphere has taken a very different path from that of Venus and Mars, and this path has led to an atmosphere that is outstanding among all the other known atmospheres. In this evolution, life has played a critical role.

FORMATION OF THE EARTH AND ATMOSPHERE

The evolution of the atmosphere begins 4–5 billion years ago with the formation of the Earth, but there is good evidence that the present atmosphere is not directly related to the Earth's original atmosphere by a continuous line of evolution.

As the Earth formed from the stellar nebula from which the Solar System was created, its rocky core acquired an atmosphere by gravitationally attracting nebula gases. This was the Earth's first, or primary, atmosphere. However, the hydrogen and helium thus trapped are likely to have escaped into space as the young Sun sprang to life, so these lightweight, primordial-nebula gases are not found in today's atmosphere. However, heavy, chemically-inert primordial gases such as neon and argon can be found. Being heavy, these gases would not have been lost to space, and their inertness would prevent them being removed from the atmosphere by chemical reactions. Therefore, their presence in the contemporary atmosphere would signal a direct line of descent from that primordial nebula to the present day atmosphere.

However, isotopic analysis shows that the neon and argon in today's atmosphere are predominantly the result of nuclear decay, rather than the remnants of that early atmosphere. It seems that at some stage soon after formation, the Earth lost its primordial atmosphere of nebula gases, and acquired a secondary atmosphere, from which the present atmosphere evolved.

The young Earth was a violent place, with radioactive decay, heavy meteor bombardment, and frictional and gravitational forces, all acting together to heat up the rocky mass of the planet. Much of the rock was molten. Under these conditions, gases were released from the planet's hot rocky core. These gases, predominantly nitrogen, CO_2, and water, had either been physically trapped within the solid Earth as it formed, or else were released by thermal decomposition of rocks and minerals. These are the gases that formed Earth's secondary atmosphere, the starting point for evolution towards the contemporary atmosphere.

In this earliest of epochs of geological history, the atmospheric CO_2 probably reacted again to form carbonate rocks, and the water eventually condensed to form the oceans. This left an atmosphere consisting predominantly of nitrogen. Trace amounts of free oxygen would be able to form in this atmosphere, as sunlight split (photolysed) molecules of water and CO_2 in the air. However, photolysis cannot result in particularly high concentrations of oxygen; a limit exists because the oxygen produced by photolysis absorbs light at the same frequency that CO_2 and water photolyse. As the concentration of oxygen builds up, it blocks the light needed to further increase its concentration. Without photosynthesis (that is, without a biological process for oxygen production), there is a natural limit on the amount of oxygen in the atmosphere. The exact concentration depends on CO_2 and water concentrations, and sunlight intensity, but no more than one-billionth of the present atmospheric level of oxygen existed before the emergence of life.

This limit to the pre-biological free oxygen concentration turns out to be critically important to the evolution of life, and, hence, to the evolution of the atmosphere. Had the atmosphere been appreciably oxidizing (containing significant levels of free oxygen), it would not have been possible for life's chemical precursors to accumulate on the planet's surface. The complex and fragile molecules of life, slowly forming and beginning to organize into proto-living systems in stagnant ponds and lakes, would have rapidly oxidized, and thus, destroyed, had the pre-biotic atmosphere been too oxidizing.

THE EMERGENCE OF LIFE AND OXYGEN

The emergence of life elegantly illustrates the intimacy of the connection between atmospheric evolution and biological evolution. The pre-biotic atmosphere, with its low concentration of free oxygen, not only provides favorable conditions for the development of biologically important molecules; the atmosphere also contains the chemicals from which life's precursor molecules themselves can be synthesized.

The famous Miller-Urey experiment in the 1950s demonstrated that a gas mixture containing methane, ammonia, hydrogen, and water subjected to simulated lightening discharges is capable of producing amino acids (essential biochemicals) within a very short time. Subsequent experiments have shown that gas mixtures more closely resembling the actual composition of the pre-biological atmosphere produce essential biomolecules under the influence of electrical discharges. Hence, laboratory experiments demonstrate that the atmospheric conditions on the early Earth were sufficient to give birth to the molecules of life.

It is unknown how life arose from this primordial mixture of chemicals, though plausible mechanisms can be postulated. There is certainly plenty of time in which rare events leading to unusually stable states could repeatedly occur; about a billion years separate Earth's formation and the dawn of life, sometime around four to five billion years ago.

The number of places on the planet's surface where life could form, however, must have been somewhat limited. The organic molecules needed for living systems are susceptible to destruction in the presence of free oxygen, and sunlight is a catalyst for this oxidation. Even though the concentration of oxygen in the early atmosphere was low, its presence would have confined the initial emergence of life to the water. Water acts as a filter, preventing the damaging ultraviolet wavelengths of light penetrating much below the surface. However, the oceans would have been unsuitable environments for early life because the turbulent vertical mixing of ocean waters would bring biomolecules and early organisms to the surface where sunlight could initiate oxidation. The first living things were, therefore, confined to the sub-surface waters of stagnant pools.

These early life forms were different from the majority of living things alive today; there was so little oxygen available that they evolved to survive without it. Relatives still survive on Earth today as the anaerobic bacteria that live in stagnant water. These early bacteria were photosynthetic, using visible wavelengths of light to make food and biomolecules from CO_2 and water. An important by-product of this activity of the first living things was oxygen.

Over the next billion years or so, these simple cells carried on a chain of life that steadily increased the oxygen concentration of the atmosphere, from its low point of less than one-billionth of today's value, to somewhere around one percent of the present concentration.

This increasing oxygen concentration was an important development, for with it the came an increase in the complexity of biochemistry available to living systems. Most importantly, the development of structural proteins that can be formed only in the presence of oxygen allowed the evolution of the cell nucleus.

With this change, biological complexity could increase rapidly by means of sexual reproduction; genetic material could be shared among members of a species. The concomitant increase in variability gave rise to simple animals and plants, as well as to more varied bacteria. Aerobic respiration became dominant, as it is today, and life was able to explore many more configurations and exist in many more niches.

All the while, photosynthesis was generating more and more free oxygen.

An important atmospheric change was occurring alongside all this biological activity; the action of sunlight on the increasing amount of oxygen in the air was generating ever-higher concentrations of ozone. As the ozone concentration increased, the intensity of damaging ultraviolet light at the surface of the waters was rapidly decreasing. Then, as now, the ozone layer served to protect life from harmful radiation from the Sun. The depth of water required to screen the Sun began to be reduced, and life could finally enter the open ocean.

This led to an explosion in the numbers of living creatures on the Earth, as life expanded into the newly available space. More life meant more photosynthesis and rapid increases in the atmospheric oxygen concentration. With increasing availability of free oxygen, even more complex biomolecules became possible, and multicellular life arose. Fossil evidence of jellyfish-like creatures from 670 million years ago gives valuable evidence of the oxygen concentration. These creatures had no lungs, and must have relied upon the ability of oxygen to diffuse across their skin. It is estimated that to support their existence, the atmospheric oxygen concentration must have been around seven percent of its present value at that time.

About 550 million years ago, fossils with strong and impervious exoskeletons suggest that the oxygen concentration had risen to 10 percent of present values (around two percent of total atmospheric composition), and the ozone concentration was approaching levels that would enable life to exist on the land, unmolested by ultraviolet radiation. Land-based life emerges in the fossil record at 420 million years ago, and by 380 million years ago the complexity of land-based life has multiplied remarkably leading to the appearance of the Carboniferous period's Great Forests (from which fossil fuels derive). The rapidly increasing oxygen and ozone levels allow ever more complex land-based life, and the forests soon find themselves home to amphibious animals, mammals, and eventually the flowering plants. With this blossoming of life, the atmosphere finally reaches present oxygen and ozone levels by 300 million years ago.

Without biological activity, the Earth's state of chemical disequilibrium, including oxygen levels, would be impossible.

RECENT CHANGES IN THE ATMOSPHERE

The evolution of the atmosphere has been intimately linked to the development of life, and there is a constant feedback between the atmosphere and the biosphere. Both CO_2 and water are greenhouse gases, and have played an important role in regulating the Earth's surface temperature during the atmosphere's evolution. Water vapor is by far the more abundant, with an average (though highly variable) concentration of one percent by volume. The equilibrium between liquid water and water vapor is crucial in controlling Earth's temperature. On Venus, the high temperature prevented liquid water from forming, which is thought to have led to that planet's runaway greenhouse effect.

Current ice-core data for atmospheric CO_2 concentration goes back 650,000 years. These data show that during this time the present ecosystem of land mammals and flowering plants have never experienced CO_2 concentrations above 300 ppmv (parts per million by volume) until very recent history. The concentration of CO_2 has risen rapidly in the last 300 years, since the beginning of the Industrial Revolution and the dramatic increase in fossil fuel use. Isotopic analysis shows that the rise in CO_2 concentration to its present value of more than 370 ppmv is largely due to human activities, chiefly fossil fuel burning.

The widely held scientific consensus is that this rise will lead to significant perturbations in the surface temperature and large scale global climate change, significantly altering the biosphere-atmosphere feedbacks. The unprecedented release of fossil carbon laid down in geological deposits during the life of the ancient Carboniferous Great Forests is perhaps the unfolding storyline in the atmosphere's continuing evolution.

SEE ALSO: Biogeochemical Feedbacks; Earth's Climate History; Gaia Hypothesis; Oxygen Cycle.

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FEEM (Italy)

THE FONDAZIONE ENI Enrico Mattei (FEEM) is a nonprofit, nonpartisan institute in Italy. The chief focus of FEEM is research in sustainable development. In July 1989, the president of Italy recognized FEEM as a research institution; FEEM has been operating since 1990 as a self-described "global network of environmental economists." There are four principle criteria that guide the research endeavors of FEEM: analysis of relevant fields of research, a focus on legitimate "real-world" issues in sustainability, utilization of multi-disciplinary and collaborative research schemes, and development and support of international networks for research and sharing of knowledge and information. FEEM has seven programs of research: Climate Change Modeling and Policy, Corporate Social Responsibility and Sustainable Management, International Energy Markets, Knowledge Technology and Human Capital, Natural Resources Management, Privatization Regulation Corporate Governance, and Sustainability Indicators and Environmental Evaluation.

FEEM scientists from Italy and abroad carry out research. Italian and international researchers can work at FEEM through fellowship options. One such international fellowship is the Marie Curie Individual Fellowship, for scientists with research experience outside of Italy. Italian scientists can apply directly for a FEEM fellowship. Scientists not fitting qualifications for these two fellowships can still work at FEEM. Culture Factories, run by the foundation, are locations for courses free to its registered users. Users are typically university students. The courses cover topics such as computer programming, graphic design, website design, preparation for the European Computer License exam, and languages.

FEEM has offices in several Italian cities, and its main headquarters are in Milan, with other locations in Genoa, Rome, Turin, and Venice. FEEM's Milan office coordinates and manages most of the research, as well as houses the administration. Additionally, the majority of FEEM research is conducted in Milan. The Genoa office opened in April 1998, as did the Culture Factory. Major activities of the Genoa office include training and research in the programs of Corporate Social Responsibility and Sustainable Management, and Natural Resource Management. The Rome office opened in 2000, and, houses a Culture Factory. FEEM opened its Turin office in January of 1998, which housed the first FEEM Culture Factory. This office carries out research in the program of Knowledge Technology and Human Capital. Finally, the Venice office has been in operation since 1996.

Here, research is conducted for the programs in Climate Change Modeling and Policy, Natural Resources Management, and Sustainability Indicators and Environmental Evaluation. This office opened its Culture Factory in 1999.

FEEM can also act as a consultant to public and private sectors with questions of economics and environmental impact. FEEM collaborates with institutions such as the Abdus Salam International Centre for Theoretical Physics, the European Union, the United Nations including the United Nations Commission of Sustainable Development, the World Bank, and other European, U.S., and global universities and institutions. The foundation is managed by a board of directors, which is overseen by a chairperson, an Audit Committee, a Scientific Advisory Board, executive director, research director, and coordinators for administration, applied research, the Culture Factory Project, international projects and relations, and publications. In 2006, FEEM published a series of books called the Fondazione Eni Enrico Mattei Series on Economics, the Environment, and Sustainable Development.

SEE ALSO: European Commission; European Union; Italy; Sustainability; United Nations; World Bank.

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Fiji

A NUMBER OF islands in the Pacific, Fiji has a land area of 7,056 sq. mi. (18,274 sq. km.), with a population of 853,445 (2006 est., and a population density of 119 people per sq. mi. (46 people per sq. km.). Some 10 percent of the country's land is arable, with another 10 percent used for pasture, mainly of cattle and goats. About 65 percent of the land is forested, with a significant timber industry, leading to rapid deforestation. Fiji has a relatively low per capita rate of carbon dioxide emissions, at 1.1 metric tons per person in 1990, and remaining relatively stable, rising slowly to 1.3 metric tons in 2003. Although there is extensive use of electricity throughout the country, 82 percent come from hydropower and only 18 percent from fossil fuels. This has the result that most carbon dioxide emissions do not come from electricity generation (solid fuels account for only 7 percent of these emissions), 87 percent of emissions come from liquid fuels, mainly from automobiles and household generators, with 6 percent from the manufacture of cement.

Fiji faces major problems from global warming and climate change, with the rising sea level threatening the flooding of many parts of the country. Some reports from around the islands show that the average shoreline has been receding at 6 in. (0.15 m.) per year since 1920. The most dramatic effects of global warming have been seen on the island of Gau, in the Lomaiviti Group, to the east of the main island Viti Levu, which has lost 656 ft. (200 m.) of coast, with threats to Beachcomber Island and Treasure Island in the Mamanuca Group to the west of Viti Levu; with Lelevia and Caqelai also likely to be affected in the next 25 years. Other places likely to be affected are Tokou village on Ovalau Island, and even some villages on low-lying land on Viti Levu, such as Culanuku and Toguvu.

Another problem has been the rise in the amount of coral reef bleaching, especially during the summer months, mainly caused by the rise in water temperature, which is expected to cause a decline in marine life living on coral reefs. There has also been a noticeable rise in tropical cyclones, from three during the 1940s, to 15 in the 1990s. The Fijian government ratified the Vienna Convention in 1989, and took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, ratifying that in 1993. They signed the Kyoto Protocol to the UN Framework Convention on Climate Change on September 17, 1998, ratifying it the same day; it took effect on February 16, 2005.

SEE ALSO: Hurricanes and Typhoons; Oceanic Changes; Sea Level, Rising.

The shoreline in Fiji may be receding at a rate of six inches per year since 1920. The rising sea level is also a threat.

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Finland

HISTORICALLY, FINLAND WAS a poor country, but in the post-World War II era, it transformed itself. Finland in the 21st century has a highly developed industrial economy and a standard of living that places it among the 10 richest nations in the European Union. More sparsely populated than most European nations, modern Finland must still confront the environmental problems that trouble all industrialized countries. Severe winters and long distances separating parts of the population increase the need for fuel. These needs added to the heavy demands of energy-intensive industries make Finland's per capita energy consumption among the world's highest.

Since the 1970s, the Finnish government has been engaged in conservation, using state-owned enterprises and price controls to encourage responsible consumption. These measures, coupled with exploiting the abundant peat lands as a fuel source, and imposing high standards for energy efficiency in home construction reduced energy use for heating by more than 30 percent within 10 years. However, Finland's need for energy continued to expand, as did the problems from dependence on fossil fuels. As a signatory to the Kyoto Protocol, the nation is committed to the reduction of greenhouse gases. As a member of the Arctic Council, Finland recognizes the greater urgency experienced by nations whose Arctic areas are face warming at twice the rate of the rest of the Earth.

Global warming in the 20th century increased temperatures in Finland by approximately 1.3 degrees F (0.7 degrees C). With further increases, Finland could experience a dramatic increase in annual precipitation. The climate changes could decrease energy demands, as warmer winters would require less fuel, and the increased rainfall could lead to increased productivity in agriculture and timber. On the other hand, changes will result in heavier flooding, which, in turn, will speed coastal erosion and pose additional threats to biodiversity. In 2007, species of butterflies and fish typically seen in warmer climes had already made their way to Finland, and environmentalists expressed concern about the effects of melting permafrost on reindeer, a crucial ingredient in the economy and the culture of the Sámi people of northern Finland.

From 2000 through 2005, the World Economic forum ranked Finland in the top position in the

Environmental Sustainability Index, and the 2006 Yale University study accorded Finland the third spot in its Environmental Performance Index. Finland has benefited from is heavily forested land (72 percent of the country) in decreasing its CO_2 levels. The country also ranks high in its use of renewable energy. Because many Finns use wood from their own forests as a secondary source of heat, and because the pulp and paper business burns its byproducts, about 20 percent of Finland's energy consumption is wood-based. Finland also uses nuclear power to cut its dependence on imported energy. The $5 billion, 1600-watt Olkiluoto 3, scheduled to begin operation in 2011, is expected to provide 15 percent of Finland's electricity. In 2006, Finland reported that greenhouse gas emissions for 2005 were below the levels targeted by the Kyoto Protocol.

SEE ALSO: European Union; Global Warming; Kyoto Protocol; Nuclear Power.

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Floods

A FLOOD IS the intrusion of water into normally dry land. While floods are a natural part of the ecological cycle and have some benefits for the health of the biosphere as a whole, flooding has always been one of the most devastating types of natural disasters for humans, responsible for thousands of deaths and billions of dollars in property damage each year. Climate change is expected to increase the risk of flooding for people around the world, both by raising global sea levels and increasing severe inland flooding events.

FLASH FLOODING

Flash flooding is most commonly caused by heavy rainfall over a short period of time, from a tropical system or an unusually heavy thunderstorm event. Less common causes include dam and levee breeches or the release of ice jams. Flash floods come on quickly and with little warning, developing in less than six hours from the initial rain or water event. They can move with great speed and strength, uprooting trees, picking up large boulders, destroying bridges, roads, and homes in a matter of moments. Flash flooding is responsible for at least 80 percent of all weather-related deaths in the United States each year, mostly due to people becoming trapped in automobiles. As little as 2 ft. (0.6 m.) of water can lift and move a full-sized commercial vehicle.

Although flash flooding is commonly associated with canyons or narrow valleys, where geography dictates the flow of excess water, or arid regions where the ground is not able to rapidly absorb large amounts of rainfall; urban areas are often affected by the phenomena. Buildings and impervious surfaces such as roadways and parking lots collect tremendous amounts of rainfall and divert it into storm drains, which can quickly be overwhelmed, sending the overflow into communities that are often unprepared for the threat.

Globally, flash floods are responsible for an average of 5,000 deaths and millions of dollars of property damage each year. Many regions do not have the forecasting or notification technology to alert vulnerable populations to oncoming flood events. Since 2006, the World Meteorological Organization (WMO) has been working to implement a system known as the Flash Flood Guidance Center with Global Coverage, which would give developing countries greater ability to mitigate loss of life in flash-flooding events.

INLAND AND RIVERINE FLOODING

Flooding within a watershed, or riverine flooding, is another common form of inland flooding. Like flash flooding, riverine flooding is generally caused by rainfall or runoff that is too heavy to be absorbed into the watershed, sending the water over the bounds of the river or stream's banks and inundating nearby flood plains. Unlike flash floods, they build slowly, over a period of many hours or days, and last for a longer period of time, often more than a week, and sometimes over a month. Flooding along the Mississippi River Valley in 1993 lasted for 45 days, with some areas still partially flooded for 183 days; a flood event in Bangladesh in 1998 lasted for 68 days before finally receding.

Riverine flooding tends not to be as deadly as flash flooding, but causes great damage to property and agricultural lands, as was seen in the Mississippi Valley floods of 1993. High water displaced 70,000 people in nine states, damaged 50,000 homes, destroyed 12,000 acres of farmland, and caused an estimated $15 billion in losses.

COASTAL FLOODING AND STORM SURGE

By 2006, an estimated 44 percent of the world's 6.5 billion inhabitants lived within 93.2 mi. (150 km.) of a seacoast. Eight of the world's 10 largest cities are coastal, including: New York, Tokyo, Shanghai, Kolkota, Sao Paulo, and Mexico City. This puts tens of millions of people at risk from coastal flooding and storm surge, with more people gravitating toward the oceans each year. As the Boxing Day Tsunami of 2004 illustrated, the impact of coastal flooding can be devastating: over 220,000 people around the Indian Ocean were killed in a single day.

A tsunami is a series of waves created by the displacement of water and is generally the result of geological events such as an undersea earthquake, a volcanic eruption, or a massive landslide. However, meteorological events are a much more common threat to coastal communities.

Coastal flooding occurs when the sea level rises above the normal tides, usually in response to an offshore storm or low-pressure system, but occasionally from significant runoff from nearby land. In its mildest forms, coastal flooding causes beach erosion, while moderate to major flooding can wash out roads and structures close to the shoreline. In coastal cities like New York, heavy coastal flooding can cause havoc by inundating the subway system and underground utilities, freezing transportation, and disrupting the power grid.

Storm surge is a phenomena tied to low-pressure systems such as tropical cyclones or hurricanes. The force of the winds inside a hurricane pushes the water up in front of it. This piling effect combines with normal tides, sometime rasing the mean water level by more than 15 ft. (4.5 m.). Wind and wave action turn this high water into a destructive force once they make landfall: 90 percent of all human deaths in hurricanes are cause by storm surge.

IMPORTANCE IN ECOSYSTEM

Flooding has long been recognized as vital part of the ecosystem. Floodwaters often carry sediment and nutrients along their path, nourishing the land wherever they are deposited. This builds valuable habitats for a variety of wildlife and vegetation, and rich alluvial soil for agricultural use. The earliest human civilizations arose on the flood plains of the Tirgis and Euphrates Rivers of Mesopotamia. For centuries, the regular flooding of the Nile River between July and September of each year deposited soils in Egypt's narrow Nile River Delta, allowing the cultivation of crops that made the growth of Egyptian civilization possible.

Worldwide, riverine flood plains cover more than 772,204 sq. mi. (2 million sq. km.) of land and coastal flood plains cover much more land. Most are considered environmentally threatened; in the United States and Europe, almost 90 percent of riverine flood plains are under cultivation, making them, in the words of one researcher, "functionally extinct." One of the main reasons for the threat is the prevalence of flood controls such as dams, levees, impoundments, and flood gates, which protect human life and property, but often destroy natural flood cycles.

HUMAN IMPACT

The desire to prevent flooding is understandable, as floods are among the deadliest of natural disasters for humans. Between 1900 and 2004, an estimated 6.8 million people were killed by flood events. About 98 percent of these deaths occurred in Asia.

Floods affect human health and safety in several different ways. A rapid rise of water, from events such as flash flooding or a tsunami, can cause immediate death from drowning or injury. As floodwaters recede, injuries are joined by a greater risk of disease from contamination of drinking water tainted by raw sewage or pollutants. Cholera and other diarrheal diseases are common in the days and weeks after floods. Standing floodwaters can become breeding grounds for vector-borne diseases like malaria; displaced rodent and reptile populations can also cause illness and injury. Critical infrastructure such as hospitals, municipal water, sanitation, and food distribution systems are often destroyed in major flood events, leaving the displaced population at even greater risk.

CLIMATE CHANGE AND SEA LEVEL RISE

Predictions regarding sea-level rise are one of the most controversial aspects in climate science, with estimates ranging from a few inches to several meters. Dramatic images of the Statute of Liberty barely peeking above the waterline aside, there is little doubt that there will be a rise in the overall sea level over the coming century.

Water will expand as ocean temperatures rise, and the melting of the polar ice caps will contribute to the overall volume of water. But the rise is not uniform across all oceans, and the mechanisms that contribute to the rise are not yet clearly understood, casting doubt on all projections.

Sea levels have climbed 400 ft. (130 m.) in the past 18,000 years. For 3,000 years, the rate of that rise was .004–.008 in. (0.1–0.2 mm.) per year. Beginning in 1900, it climbed to .04–.08 in. (1–2 mm.) per year, and in 1993 accelerated to approximately .12 in. (3 mm.) per year (although it is not yet clear if this is a cyclical variance or part of an overall trend). Were these rates to hold steady, this would correspond to a rise of 11–13 in. (280–340 mm.) by 2100. However, some climate models, particularly those who look at the partial or complete melting of the Greenland Ice Sheet, indicate a more dramatic rise of about 3 ft. (1 m.), a rise that would, among other things, swamp most of the cities along the United States' densely populated eastern seaboard.

Rising water levels put the 634 million people who live within 30 ft. (9 m.) of sea level at risk for higher storm surges, coastal erosion, loss of agricultural and aquacultural land, loss of tourism, and a decline in soil and groundwater quality. Several small islands in the Pacific and Indian oceans, most notably the island nation of Tuvalu and the Maldives, are already seeing anomalous flooding and higher tides. Residents of these islands may be the first in a long line of "climate refugees" to come.

Natual flooding is an important to the ecosystem, but is threatened by dams, levees, impoundments, and flood gates.

CLIMATE CHANGE AND FLOODING

Inland flooding will also be impacted by climate change. Rainfall patterns are expected to change over the next century, with climate models predicting more heavy-rain events, separated by prolonged periods of dry weather. Much of this will be due to the heating of the atmosphere: warmer air holds more water, raising the potential for a quick release of a large volume of water.

Air pollution will also play a role, as more particulates in the atmosphere gives this increased amount of water vapor more condensation nuclei, or seeds, around which they can coalesce. This will increase the incidence of flash flooding and landslides in many areas. So-called "100-year flood plains," literally parts of a flood plain that are only expected to flood once in a century, could expect to see flooding three to six times in a century.

Developing countries will see increased risk of loss of life in severe flood events. In summer 2007, the most intense floods seen in generations hit more than 20 African nations. Over 1.5 million people were displaced and at least 300 killed. Coming at the height of the growing season, the flooding destroyed domestic and export crops, and will exacerbate the region's already severe food insecurity crisis. Meanwhile, more developed nations are planning extensive and costly new flood control systems and sea defenses to help mitigate future flooding.

SEE ALSO: Evaporation and Transpiration; Hurricanes and Typhoons; Monsoons; Rain; Rainfall Patterns; Weather.

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Florida

THE FOURTH MOST heavily populated state, Florida is also the top travel destination in the world. In 2006, nearly one million visitors, domestic and international, poured $83 million into the state's economy, according to Visit Florida Research. Nearly $4 billion went back into state coffers as taxes. Agriculture ranks second only to tourism in Florida's economy. The state produces 75 percent of the oranges grown in the United States, and 40 percent of the world's orange juice. Both as the state with the nation's second longest coastline, more than 8,400 mi. (13,516 km.), and as the largest farm-income state in the southeastern United States, Florida is particularly vulnerable to the impact of global warming. Like most coastal states, Florida has already felt the effects of global warming, and experts warn of more severe consequences as climate changes accelerate. Florida has responded with a multitude of strategies designed to address all facets of the problem.

A 2001 study conducted by scientists at Florida's universities noted signs of coastal erosion, dying coral reefs, saltwater intrusion into inland freshwater aquifers, and increased air and sea temperatures, all generally-accepted signs of global warming. Predictions were dire. If sea levels rise the estimated 8–30 in. (20–76 cm.) over the next 100 years, seawater could advance inland as much as 400 ft. (122 m.). Not only would such an advance devastate the beaches that help to draw millions of tourists to the state, but homes and infrastructure would also be at risk, a critical concern in a state where 77 percent of the population lives in coastal cities. Salinity could become another major concern as freshwater supplies become contaminated, and potability of water supplies for the state's cities and orchards are threatened. Saltwater could also encroach on coastal wetlands, posing a particular threat to the Everglades and the more than 60 threatened or endangered species that inhabit the area, including the wood stork, the American crocodile, the West Indian manatee, and the Florida panther (with an estimated wild population of only 30 to 50 animals).

Although Floridians and their visitors depend heavily upon air conditioners and enjoy more than a million residential swimming pools that require pool pumps, Florida ranks 46th among the 50 states in total energy consumption per capita. Greenhouse gas emissions reveal a less positive picture. In 2001, 3.92 metric tons of greenhouse gases per one million Florida residents were released into the atmosphere, making the state the 13th highest emitter. Carbon dioxide accounted for around 92 percent of Florida's emissions in 2003. Between 1990 and 2003, the state's CO_2 emissions from fossil fuel combustion increased by 30 percent. The utility sector accounts for 50 percent of the emissions, and transportation for another 41 percent.

Florida has a long history of conservation. The state is the site of the nation's first wildlife refuge (Pelican Island) and the first eastern National Forest (Ocala National Forest). Concerted efforts to protect the ecosystem of the Everglades have been ongoing for nearly half a century. Since 1999, Florida's governors have pursued the most ambitious land acquisition program in the nation, acquiring nearly 2.5 million acres at the cost of more than $5 billion. The Florida Department of Environmental Protection, the state agency assigned the responsibility of managing Florida's natural resources and enforcing environmental laws since its creation in the mid-1970s, is engaged, with the South Florida Water Management District, in implementing the 30-year, $10.5 billion state-federal partnership to restore America's Everglades, the largest environmental restoration project in the history of the world.

Despite this impressive record in land management, however, Florida had been tentative in addressing global warming. Former Governor Jeb Bush signed the Florida Renewable Energy Technologies and Energy Efficiency Act in June 2006, and created the Energy Commission, a group charged with advising the state legislature on energy policies. The state followed this step by inventorying greenhouse gases, experimenting with net metering (a program to measure a customer's total electric consumption against that customer's total on-site electric production), encouraging electric power customers to use renewable sources, and adopting more environmentally-friendly building codes.

The most far-ranging action came in July 2007, when Governor Charlie Crist signed three executive orders in a single day that mandated changes in Florida's actions relating to climate change. The first order set reduction targets for greenhouse gas emission by state agencies of 10 percent below current levels by 2012, 25 percent below by 2017, and 40 percent below by 2025. It also adopted the Leadership in Energy and Environmental Design (LEED) Green Building Rating System for all state and state-funded buildings and required state vehicles to use ethanol and biofuels when these fuels were available. The second order set statewide greenhouse gas emissions targets of reaching 2000 emission levels by 2017, 1990 levels by 2025, and 80 percent below 1990 levels by 2050. Tied to these targets is the adoption of the California tailpipe emissions standards.

Additional changes included in the order are revisions in the Florida Energy Code for Building Construction to make new construction more energy efficient, a requirement that utilities produce a minimum of 20 percent of their electricity from renewable sources, and the authorization of statewide net metering. The final order created the Governor's Action Team on Energy and Climate Change, a 21-member panel of representatives from government, business, academia, and environmental groups, and charged them with recommending ways to achieve the ambitious new targets. The first phase of the group's responsibilities was to be completed before December 1, 2007. Governor Crist also signed agreements with Germany and the United Kingdom for mutual discussion of ways to reduce greenhouse gas emissions and to extend the ideas of the Kyoto Protocol.

SEE ALSO: California; Kyoto Protocol; Salinity.

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Florida International University

THE UNIVERSITY IS one of the 11 public universities that make up the Florida State University System and is located in the city of Miami. The bill providing for the establishment of Florida International University (FIU) was signed into law in 1965. In 1969, the country's youngest university president at that time, Charles E Perry, took charge at 31 years of age. The university accepted its first 5,667 students in September 1972. About 38,000 students are currently enrolled in over 280 majors. FIU has 10 academic colleges including South Florida's first public College of Medicine. The School of Hospitality is ranked among the best in the country, catering to Florida's top industry, tourism. The university is home to the National Hurricane Center. FIU is at the forefront of research on hurricane damage mitigation and the management of South Florida's unique wetlands.

The city of Miami, also known as the gateway to South America, is home to a large population of Spanish-speaking immigrants and has seen tremendous growth in housing to accommodate this influx of people. High rates of population growth and housing development in hurricane vulnerable states, such as Florida, mean increasing risk to human life and property. One of the first major storms to be recorded and measured in Florida was the Great Miami Hurricane, which swept over the center of the city in September 1926, as a Category 4 storm on the Saffir-Simpson scale, damaging every building in the downtown area and causing many deaths. On August 24, 1992, hurricane Andrew powered across the southern tip of mainland Florida as a Category 4 storm with even stronger winds gusts, and left behind over $20 billion in wind and water damage. On August 25, 2005, hurricane Katrina passed over Miami as a Category 1 storm before it gathered strength and brought devastation to New Orleans.

As part of an effort to protect the millions of dollars invested in research programs at universities, the federal government set up the Disaster Resistant University (DRU) program. In 2007, FIU became the first public university in Florida to become DRU-certified. Under this program, the Federal Emergency Management Agency has responsibility for reviewing and approving the DRU certification. When a major storm requires the evacuation of people from locations vulnerable to wind damage, storm-surge, or flooding, the university is one of the designated hurricane shelters for residents of Miami-Dade County. Also, when a Category 3 or higher hurricane threatens the Florida Keys, FIU is the officially designated shelter for people seeking sanctuary from the approaching storm.

The steady increase in societal and economic risks associated with storm events comes at a time when researchers in the United States have linked the increasing number of north Atlantic hurricanes to climate change. In 2007, the State of Florida took a step in advancing its climate research capabilities and ability to significantly reduce hurricane damage by awarding $18 million for hurricane research, including $15 million for the construction of the International Hurricane Research Center (IHRC) located at FIU. The IHRC houses a machine called the Wall of Wind powered by race car engines and capable of simulating Category 4 hurricane winds and rain, to create and test hurricane-resistant construction techniques and materials in order to improve the safety of residences and businesses.

The Florida Hurricane Alliance (FHA), coordinated by the IHRC, is a collaboration of engineers, meteorologists, biologists, epidemiologists, and others from universities across Florida. The FHA focuses on hurricane-related loss reduction by conducting research, such as studies on the effects of storm-surge along Florida's long and highly-developed coastline. IHR scientists at FIU's Laboratory for Coastal Research measure changes in shoreline and beaches in response to short-term events such as hurricanes and also over longer periods of time. At other FIU laboratories, satellite images are combined with computer animation to create simulations and interactive visuals for training and outreach. Research is also being done to develop energy-efficient equipment and solar energy powered buildings. With the price of weather and storm-related events on the increase, researchers are modeling insurance costs under different scenarios of damage, finding ways to providing incentives for people of protect their homes, and developing new wind-resistant structures for homes and businesses.

The National Hurricane Center (NHC), located on the campus of this university, is one of nine units that make up the National Centers for Environmental Prediction. The NHC is the main institution capable of analyzing and coordinating complex hazardous weather information and producing tropical cyclone forecasts for 24 countries in the Americas and the Caribbean. NHC collaborates with FIU and many other universities in activities such as the Joint Hurricane Test Bed, a multi-faceted effort to improve and expedite tropical cyclone forecasts. The mission of the NHC is to provide the best forecasts possible that will save human lives and property. In the event of a major storm, NHC's weather forecast bulletins help administrators and politicians reach important decisions that affect millions of people around the country.

The university is only 25 mi. (40 km.) from the Everglades National Park, a United Nations Educational, Scientific and Cultural Organization (UNESCO) World Heritage Site, International Biosphere Reserve, and a Wetland of International Importance. FIU is also a short drive from the open waters of the Florida Bay, the Biscayne National Park, and White Water Bay. The university is suitably positioned for conservation and management studies in marine and freshwater habitats. FIU's new program in Marine Biology seeks to take advantage of this unique environment by offering courses to university and advanced high-school students. Also at FIU, the Southeast Environmental Research Center (SERC) was established in 1993, to conduct ecological studies within South Florida's wetland environments threatened by urbanization, water diversion, and agricultural practices. Funded by the National Park Service, U.S. Environmental Protection Agency, South Florida Water Management District, National Science Foundation, among others, SERC's scientists work throughout the region using state-of-the-art laboratories and equipment to monitor the state of marine and freshwater ecosystems.

SEE ALSO: Florida; Florida State University; Hurricanes and Typhoons; National Oceanic and Atmospheric Administration (NOAA).

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LOCATED IN TALLAHASSEE, in the southern part of the state, Florida State University (FSU) has been involved in global warming and climate change research since the early 1960s. In conjunction with the geological sciences division of FSU, the Office of Polar Programs of the National Science Foundation established the Antarctic Marine Geology Research Facility (AMGRF) to serve as a curatorial and research center. The AMGRF was originally planned as a resource for analyzing deposits from the Antarctic continental shelf that had been collected by U.S. Coast Guard icebreakers as part of early deep freeze expeditions under the auspices of the U.S. Navy Hydrographic Office.

Today, the AMGRF is home to one of the largest collections of marine sediment cores in the entire world, and is the only American repository for Antarctic marine sediments, containing more than 12.4 mi. (20,000 m.) of deep-sea core sediment and more than 5,000 kg. of dredge, trawl, and grab samples. Additionally, AMGRF provides access to approximately 1.7 mi. (3,000 m.) of rotary-cored geological material obtained by Antarctic drilling programs. Ongoing projects include the Cape Roberts Project, a cooperative study of paleoenvironmental changes in the Antarctic involving the United States, Australia, Germany, Italy, the Netherlands, New Zealand, and the United Kingdom; Shaldril, a consortium of American scientists engaged in ship-based diamond coring along the continental margin of Antarctica; and Antarctic Geological Drilling (ANDRILL), a multi-national drilling project composed of scientists from the United States, Germany, Italy, New Zealand, and the United Kingdom that seeks to obtain stratigraphic records of historical paleoenvironmental changes in Antarctica.

In spring 2007, scientists at AMGRF hosted a multinational workshop to tell key researchers about mounting evidence on the connection between changes to Antarctic ice and global warming. Attendees at the conference included scientists involved in ANDRILL who were responsible for removing the core, and scientists, students, drillers, and educatiors from the United States, Germany, Italy, and New Zealand. During the event, scientists were able to study a new core that had been obtained by drilling 4,214 ft. (1,284 m.) below the sea floor located beneath the Antarctica's Ross Ice Shelf, which is the largest floating ice body anywhere in the world. The new core contained sediments dating as far back as 10 million years, offering evidence that the shelf had been engaged in an advancing and retreating cycle for the past 5 million years in response to climate changes. The Ross Ice Shelf is believed to have broken off from the larger West Antarctic Ice Sheet, which is predicted will collapse totally as a result of global warming. If such an event occurs, sea levels could rise as much as 20 ft. (6 m.), creating a worldwide catastrophe.

FSU is home to the Center for Ocean-Atmospheric Prediction Studies (COAPS), which conducts research into agricultural forecasting, air-sea interaction, ocean and coupled air-sea modeling, climate change and prediction, climate variability, and statistical studies. COAPS is also involved in predicting the social and economic consequences that arise from variations in ocean-atmospheric conditions. Funding for the COAPS program comes from a number of national government agencies, and working grants, annually total approximately $3 million. COAPS researchers are engaged in cooperative efforts with the National Oceanic and Atmospheric Administration (NOAA) Applied Research Center, the Research Vessel Data Center, the SAMOS Initiative, the Florida Climate Center, the Southeast Climate Consortium, and the HYCOM Consortium.

A number of studies that are underway at FSU have great potential for identifying the effects and consequences of global warming and climate change. Since 2006, researchers at Florida State University have been involved with the NOAA cooperative, created to study the dynamics of ecosystems within the Gulf of Mexico. Through the auspices of the newly-established Northern Gulf Institute, FSU scientists are working with those from Mississippi State University, the University of Southern Mississippi, Louisiana State University, and the Alabama Dauphin Island Sea Lab to conduct research on coastal hazards, climate change, water quality, ecosystem management, coastal wetlands, and pollution.

Also in 2006, the National Oceanic and Atmospheric Administration awarded a five-year, $6.2 million grant to FSU scientists at COAPS to develop a hurricane-prediction model that has the potential to mitigate the effects of major storms on lives and property. This prediction tool may be critical in light of the mounting evidence that climate change has caused Atlantic tropical cyclones to gain in power in recent years.

Along with scientists from the University of Minnesota, Syracuse University, the University of Maine, and the U.S. Geologic Survey, FSU scientists are engaged in a National Science Foundation study of the carbon balance in the peat lands of Lake Agazzi, Minnesota to determine the effects of climate change precipitated by global warming. Because these peat lands, which are large wastelands composed of undecomposed organic matter, have remained largely untouched, the study is expected to render valuable information on the ways in which global warming impacts the environment.

Studies of the greenhouse gases that are being emitted from melting permafrost in North Siberia have led a FSU scientist working with researchers from several other universities to determine that climate change is occurring more rapidly than previously predicted. In the study, published in the September 7, 2006, issue of *Nature*, they assert that this methane, which is 20 times more potent than carbon dioxide, is releasing carbon that has been buried for 4,000 years into the atmosphere as a result of global warming. This methane is further accelerating the pace of global warming.

SEE ALSO: Antarctic Ice Sheets; Florida; Florida International University; Hurricanes and Typhoons; Oceanic Changes.

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Food Miles

RECENT YEARS HAVE seen increasing concern about the long-term sustainability of food systems and their unintended side effects that can be imposed on the global environment and human wellness. Food miles are an appraisal of the distance a food or beverage travels from field to plate. While the cost of making things has never been cheaper, the cost of moving them around has never been as high, and it is getting higher. This is partly a consequence of outsourcing practices involving industries and retailers.

The logic is that the fewer miles foods are transported, the less fuel is used, thereby reducing the carbon footprint on the environment and improving sustainability. Some major retailers, such as Asda (Wal-Mart) in the United Kingdom, have introduced measures aimed at cutting CO_2 emissions, such as a change to bio-diesel and moving more freight by train. Direct deliveries of locally grown goods have increased as people have become more interested in provenance issues. In the United States, supermarket chains like Whole Foods and Wal-Mart announced they are reducing the transport distances of the foods they purchase. For example, in 2006, Wal-Mart announced that it would source its seafood only from fisheries certified as sustainable and well managed by the international Marine Stewardship Council.

The trade-off between minimized financial investment with high levels of automation on one hand, and intensively-used, low-cost transport on the other, needs strategic re-thinking. The attention retailers are paying to food miles demonstrates this, as they look to differentiate themselves from the competition, and, in the end, to protect the environment. Carbon footprint labels will bring the concept of food miles to bottled beverages in a way that is currently only the case with fruits and vegetables. The externalities arising from production systems indicate some important policy priorities for developed nations, particularly in North America and Europe. Some governments are taking action to reduce the environmental and social costs of food transport, particularly in the United Kingdom and New Zealand. At a broader level, the European Union has been considering the reduction of greenhouse gas emissions by 20 percent by 2020.

It is very difficult to determine the distance food travels, and by what means. Therefore, buying locally with clear provenance can make the food industry more sustainable. Purchasing seasonally helps neutralize the need for artificial heating in greenhouses. The drive to reduce food miles and reduce CO_2 could have social impacts on growers in developing countries, as global value chains are redirected. A specific tax on food miles for manufacturers and retailers reported in the companie's annual reports could also help to achieve sustainability.

Fresh and processed foods can travel large distances around the world. However, sometimes it is not easy to identify the place of origin. Also, sourcing products locally is a great initiative, but many of the products may not be available locally. Transport is only one issue of the overall environmental impact of food and beverages production and consumption. The delivery cost captured by food miles does not take into account the energy use or CO_2 emissions in the production stage. It also assumes the same level of energy efficiency, no matter where it originates. For example, New Zealand is the world's biggest exporter of dairy products. Calculating food miles does not capture other carbon costs such as the use of heated indoor milking sheds common among northern hemisphere dairy farms.

Export-oriented countries, such as New Zealand, have been taking measures to counter the food miles argument, particularly in the United Kingdom. For example, this is the case of fresh fruits and vegetables, dairy products, and wine. The distance products travel are not necessarily directly related to their carbon footprints. If the concern about food miles is global warming, then the focus should be on gas emissions and energy efficiency, not on distance.

SEE ALSO: Agriculture; Carbon Footprint; Food Production; Global Warming.

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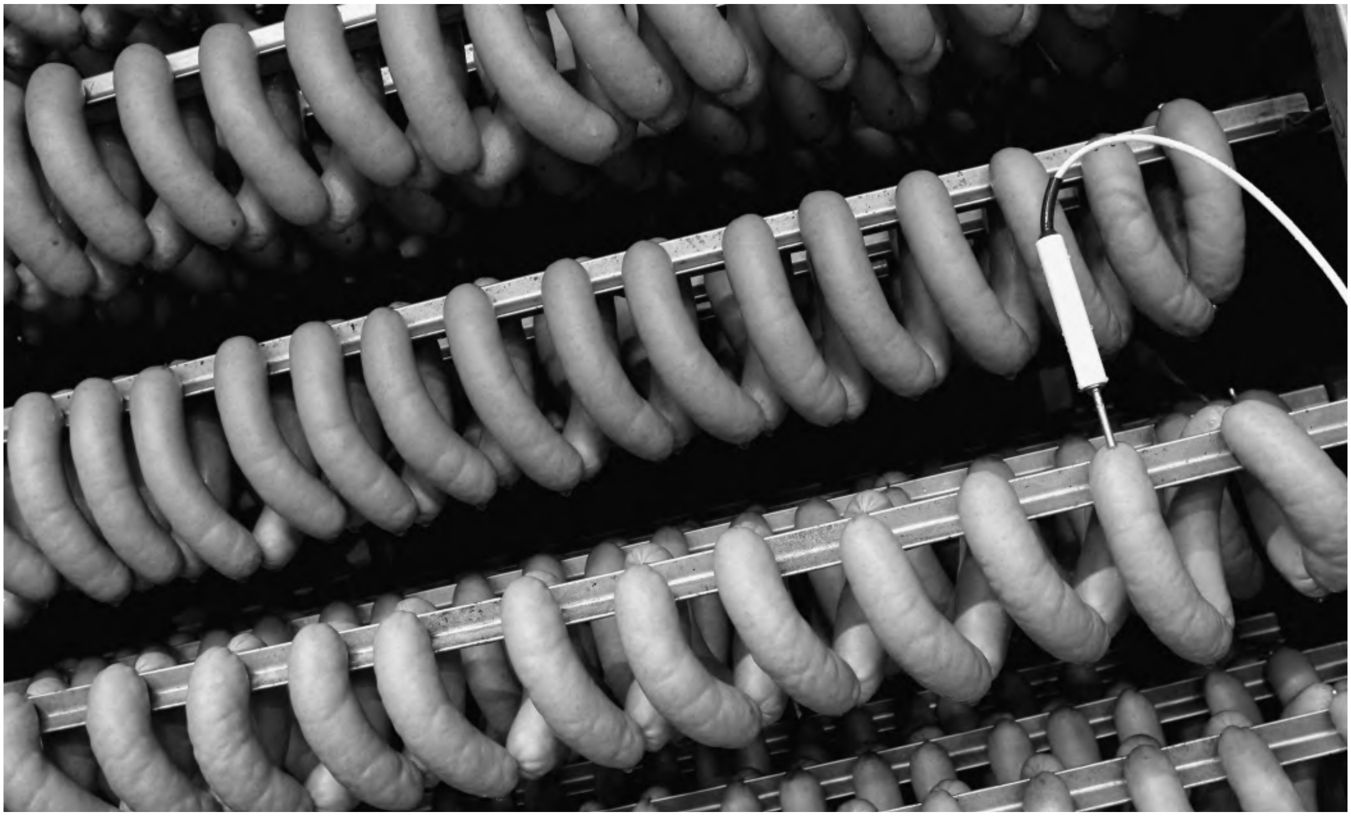
Food Production

FOOD PRODUCTION IS the growing of plant crops and animals for human consumption. It is one of the most vital activities engaged in, with food and water central to the continuation of human life. Climate change threatens to change age-old patterns of agriculture at a moment in history when there are more people alive on the planet than ever before, and may lead to a long period of global food insecurity.

Food takes many different forms, but a general description is: anything that can be metabolized by a living organism to create energy or build tissue. For humans, this means matter comprised of some combination of carbohydrates, proteins, lipids (fats), or water. Food is often grouped into the broad categories: grains, fruits, vegetables, meats, fish, legumes, and includes a separate category for the byproducts of meat and poultry production, such as milk, eggs, cheese, and yogurt.



Sausages in production: According to the United Nations, 259 million metric tons of meat were produced in 2004. Food production is the world's most common profession, with 36 percent of all workers engaged in agriculture in 2006.

Humans have been practicing agriculture since the dawn of civilization. It was the move from nomadic hunter-gatherer societies to permanent farming communities in the fertile flood plains of Mesopotamia 10,000 to 12,000 years ago that marked the beginning of historical records.

As these early agrarian societies began cultivating grain crops and domesticating animals, the outlines of society began to form. With a steady supply of food, population increased. People began to specialize in crafts to support the population around them. Social hierarchies, government, trade, written language, and slavery were just some of the structures built on the foundation of agriculture.

Today, humans cultivate about 2,000 plant species for food, with a definite preference for grains and cereals. According to the United Nations Food and Agriculture Organization (FAO), global production of cereal crops in 2004 was around 2.3 billion metric tons, compared with 886 million metric tons of vegetables, 259 million metric tons of meat, and 130 million metric tons of fish. Food production is the world's most common profession, with 36 percent of all workers engaged in agriculture in 2006. This is actually a drop from 42 percent in 1996, and reflects the shift of more and more workers to urban centers. Agricultural workers range from subsistence farmers, to owners and employees of huge industrial operations, while millions more support themselves through fishing, ranching, hunting, and foraging.

Agriculture is one of three anthropogenic causes of global warming identified by the Intergovernmental Panel on Climate Change (IPCC), after fossil fuel use and land use. The clearing of new agricultural lands creates pollution through the burning of biomass, releasing greenhouse gasses and particulate matter into the atmosphere; the loss of trees reduces the planet's natural carbon sink, the natural process whereby trees remove carbon from the air. Most modern fertilizers are petroleum-based, releasing tons of nitrous oxide and other gasses every year. Livestock are responsible for 40 percent of annual methane emissions.

Since the development of agricultural chemistry in the 19th century, there has been a steady stream of innovation, including specialized machinery, fertilizers, pesticides, fungicides, and soil amendments, advances in animal husbandry, plant breeding, hybridization, and gene manipulation. Yet, for all these technological advances, food production still relies principally on sunlight, precipitation, temperature, and soil quality. It requires predictability and stability. Farmers need to know when the growing season will begin and end, and approximately how much rain will fall between those two dates. Anomalies in the weather can have a catastrophic effect on crop yields.

CLIMATE CHANGE AND FOOD PRODUCTION

Of all the potential impacts of climate change, it is the threat to the food supply that is perhaps the most frightening. With more than six billion mouths to feed and only so much arable land on which food can be grown, the margin for crop failure is shrinking. Food abundance, the norm for the past several decades, is beginning to give way to scarcity. For example, global droughts during the 2007 growing season led to shortfalls of millions of metric tons of grains, forcing exporting powers like Australia to have to consider importing to meet internal demands. Protests have been launched against the increased price of tortillas in Mexico and pasta in Italy. The United Nation's World Food Programme (WFP) has seen operating costs jump 50 percent since 2002, and expects another 35 percent rise by 2010.

One benefit of climate change is the expansion of vineyards in the United Kingdom: the last time wine was produced on a such a wide scale in England was during the Medieval Climate Optimum of 800–1300 C.E., before the Little Ice Age of the 16th to the mid-19th centuries. Warmer temperatures are expected to expand growing seasons in regions close to the poles, opening up new land to agricultural development, particularly in the northern latitudes. Climate zones may move north by anywhere between 100–350 mi. (161–563 km.), and up 500–1,800 ft. (152–585 m.) in elevation. Some current climate zones will disappear completely, while new microclimates will be created.

Another potential benefit of global warming will be the fertilization effect of carbon dioxide (CO_2). Carbon dioxide is a plant nutrient that, under optimal conditions, can stimulate and enhance photosynthesis. It can also improve a plant's ability to use water by inhibiting transpiration, the evaporation of water out of organic material. Higher CO_2 concentrations could also mitigate the damaging effects of other environmental pollutants, such as SO_2, the main pollutant in acid rain. Over 90 percent of the world's crops could theoretically benefit from CO_2 fertilization, although some staple crops like maize, sorghum, millet, and sugar cane would not. A 1990 study estimated that it could increase crop productivity 10 to 20 percent over the next century.

Crop growth is implicitly tied to air temperature. Higher temperatures speed a plant's development, which for farmers means a shorter period between the planting and harvesting of crops. In some areas, planting will be able to begin earlier in the calendar year, and temperatures may allow multiple planting cycles in a season. But outside the northern latitudes, the impact of higher temperatures becomes a negative. Prolonged periods of 90 to 100 degree F weather causes severe damage to most crops. Heat-stressed livestock do not thrive, with high temperatures reducing, for example, milk production.

The same fertilizing effects of CO_2 seen in plants also work on weeds, which may become more invasive in a warming world. This will require heavier application of weed-controlling agents, most of which emit greenhouse gases as they break down, to protect threatened crops. Insects and pests are likely to take advantage of warmer winters and move into new regions; a longer period of summertime warmth will also allow some destructive insects, like grasshoppers, to go through several reproductive cycles in a single year, maximizing the potential damage. Bacteria and fungi will take advantage of new wind patterns and warmer, wetter conditions to bloom.

Higher temperatures also have an effect on soil quality. Warmer soil breaks down organic matter more quickly, stripping it of nutrients and requiring the use of more fertilizers to enhance soil fertility. These, like pesticides and herbicides, emit pollutants. Dried-out soil is also more prone to erosion. Precipitation patterns are expected to change dramatically over the next century. Climate scientists expect that there will be more prolonged dry spells, punctuated by brief, heavy downpours. This will have a negative impact on crop yield, because most staple crops are sensitive to drought stress. Heavy rain falling on very dry soil exacerbates soil erosion. Increased risk of flooding raises the likelihood of crop damage or outright destruction. Aside from the increased risk of drought, farmers will also have to face an overall reduction in available water for irrigation, stemming both from changes in the global hydrologic cycle and an increasing urban population.

There are a number of ways farmers could adapt to climate change, ranging from very simple techniques such as changing their sowing dates to take advantage of an earlier spring, to the more complex options including developing methane-recovery systems that sequester livestock manure into digesters and turn them into biogas. While the use of genetically modified (GM) crops remains controversial in many parts of the world, gene manipulation could create crops that are more resistant to many of the situations that might present themselves in a warming world.

SEE ALSO: Agriculture; Food Miles; Impacts of Global Warming; Plants.

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Foraminifera

FORAMINIFERA ARE MARINE eukaryotic unicellular organisms that construct a shell or test. They use chemicals from their surroundings to construct calcareous or siliceous crystals, or particulate grains to form an agglutinated test. They are heterotrophic protoctists with granular reticulopods (pseudopodial networks) exhibiting two-way streaming. Foraminifers are Linnean classified by their chemistry, mineralogy, structure of the test walls, cytology, and DNA of protoplasm.

Foraminifers can be either benthic or planktonic. Benthic foraminifers, in the shape of simple agglutinated tubes, lived in the Cambrian (500 million years ago). Planktonic foraminifers appear in the fossil record during the Jurassic (206 million years ago). Both variants provide excellent fossil records and are the most diverse group of shelled marine microorganisms on Earth. Most live in specific environments and cannot survive drastic environment changes. Most foraminifers evolve relatively quickly and only range in the geological record for a short time (approximately 10^5 years), making them useful for developing theories on evolution, origination, extinction, and biogeographic distribution of past and present environments projected into the future.

The ecological controls on foraminifers depend on if they are bathyal-abyssal open ocean, or shallow water foraminifers. Benthic foraminifers are affected by the input of organic matter and other food sources from the surface layer 328 ft. (100 m.), amount of available oxygen, sediment influx, and seafloor currents, salinity, and temperature. Benthic foraminifers are used to evaluate surface productivity in the ocean. Controls on planktonic foraminifers include salinity, temperature, upwelling, and the productivity of the surface layer. Planktonic foraminifers are used to reconstruct ocean currents, circulation, paleotemperatures, and large-scale shifts in Earth's surface thermal regime.

Stable oxygen and carbon isotopes, as well as trace elements taken up in tests of foraminifers, are used reconstruct gross past climate trends and temperature cycles. Foraminifers are sampled from marine sediment cores from around the globe. They are correlated with the magnetic stratigraphy and biostratigraphy of other microfossil groups among the Atlantic, Pacific, Indian, and Arctic oceans.

Oxygen and carbon in biogenic carbonates are determined by the mass ratios of CO_2. ^{16}O and ^{18}O for foraminifers are used for fractionation comparison. $\delta^{18}O$ in seawater is linked to the hydrologic cycle (evaporation, atmospheric vapor transport, freshwater return to the oceans by precipitation, runoff or melting of icebergs, and long-term storage in aquifers and ice sheets). Lighter isotopes evaporate first and precipitate last. Therefore, the farther the precipitation occurs from source waters, the more depleted in ^{18}O the vapor becomes. Temperature and salinity can be deduced from ^{18}O values. There are many factors that affect the fractionation of oxygen in foraminifer tests, including ontogenics, symbiotic photosynthesis, respiration, gametogenic calcite, and carbonate ion concentrations. All of these factors need to be taken into account when interpreting $\delta^{18}O$ in planktonic foraminifers and sometimes in benthic foraminifers.

Carbon isotopes are derived from organic matter and sediment carbonate reservoirs. Surface waters are enriched in ^{13}C due to the fractionation that occurs in photosynthesis. In deep water, $\delta^{13}C$ is controlled by the amount of organic decay, time of exposure at the sea floor, and rate of decay of organic matter. Change in depth of calcification of foraminifers is also recorded.

Trace elements are also used to reconstruct past oceanic conditions, providing independent validation of other proxies such as stable isotope values and ratios. The calcite test of a foraminifer is composed of 99 percent $CaCO_3$, with the remainder comprised of trace elements. The composition of a test reflects seawater composition and the biological and physical conditions of the environment. Paleotemperature proxies (Mg), seawater nutrients, carbon and carbonate levels (Cd, Ba), physical properties such as temperature and pressure (Mg, Sr, F, B), history of ocean chemistry (Li, U, V, Sr, Nd), and secondary post-depositional processes such as $CaCO_3$ and SiO_2 diagenesis (Mn) are combined for the development of paleoceanographic reconstructions.

SEE ALSO: Climatic Data, Proxy Records; Earth's Climate History; Sediment Records.

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Forced Climate Variability

STUDIES ON GLOBAL warming and climate change generally distinguish between internally generated and externally-forced climate variability. Internally generated variability is the result of processes within a system, while externally-forced variability is caused by some factors outside the system. A classic example of externally-forced climate variability is represented by the changes caused by variations in the amount and distribution of solar energy incidents on the Earth because of the differences in the solar luminosity or in the Earth's orbital parameters. The distinction between the two types of variability is not always so clear-cut, because it depends on how the boundaries of the system under examination are defined. For example, when studying or modeling the atmosphere in isolation from the rest of the climate system, changes in sea surface temperatures would be termed external forcing. Yet, in a coupled ocean/atmosphere model, variability induced in the atmosphere by variations in sea surface temperatures would be internally generated variability. There is still considerable debate concerning the extent of internal climate variability.

Internal climate variability not forced by external agents occurs on all time-scales, from weeks, to centuries and millennia. Slow climate components, such as oceans, have particularly important roles on decadal and century timescales because they complement high-frequency weather variability and work together with faster components. Thus, climate is capable of producing long timescale internal variations of considerable magnitude without any external influences. Externally-forced climate variations may be caused in changes by natural forcing factors, such as solar radiation or volcanic aerosols, or changes in anthropogenic forcing factors, such as increasing concentrations of greenhouse gases or sulfate aerosols. Therefore, the response to anthropogenic changes in climate forcing is set against the background of natural internal and externally-forced climate variability that can take place on similar temporal and spatial scales.

The action of natural climate variability means that the detection and attribution of anthropogenic climate change should demonstrate that an observed change is significantly different statistically than can be explained by natural internal variability. However, although a particular change in climate is detected, this does not necessarily mean that its causes are understood. In order to define more precisely the adaptation and mitigation strategies needed to deal with the potential impacts of expected climate change, a deeper understanding of the intrinsic and externally-forced variability of the climate system is needed to detect, attribute, and predict global and regional climate change provoked by natural and anthropogenic causes.

Examples of externally-forced climate variability include variations in solar output and volcanic eruptions that cause a general cooling of climate by injecting aerosols into the stratosphere. Human activities can also produce changes in the composition of the atmosphere. The extent of this externally-forced variability depends on the extent of the forcing and the sensitivity of the climate system to the forcing. When the forcing is gradual, as in the case of the increase in the Sun's emissions over the Earth's life span, all the different components of the system retain their equilibrium. In contrast, forcing that produces immediate changes or consists of a short-lived impulse, such as volcanic eruptions, provoke a transient reaction with multiple timescales.

The intensity of solar radiation varies over a large range of timescales and the extent of these variations depends on wavelengths. Sunspots are cool patches that break up the convective movement of cells in the photosphere. They take place in conjunction with strong magnetic fields and their lifetimes range from a day to a few months. In contrast, faculae are hot spots in the pattern of convective cells that often accompany sunspots and strong magnetic fields. Their lifetimes are comparable to those of the sunspots. Flares are intense emissions of ultraviolet and x-ray radiations and high-energy particles that the sun's outer atmosphere emanates within its active regions. Their main features are strong magnetic fields, violent motions and a lifespan of an hour. During the active phase of the 11-year solar cycle, there are numerous sunspots, faculae, and flares, appearing first at higher latitudes, and later at lower ones as well. During the quiet phase of the solar cycle very few of these disturbances occur.

The impacts on climate due to volcanic eruptions are mainly represented by the effects of sulfate aerosols formed from SO_2 emissions. Yet, traces of these aerosols remain in the troposphere for only a few weeks. Thus, only major eruptions, such as the 1991 Mt. Pinatubo eruption in the Philippines, penetrate the lower stratosphere and have a significant impact on global climate. Aerosol clouds generated by major volcanic eruptions can reduce the flux density of direct solar radiation incident on the Earth's surface. This reduction in total incident solar radiation produces lower global-mean surface air temperature following major volcanic eruptions than in the long-term average. The duration of the cooling of the Earth following major volcanic eruptions appears to be longer than the one to two-year duration of aerosols in the stratosphere. This is due to the interaction of the ocean mixed layer and its large heat capacity. An additional period of a year or two is necessary for the layer to regain the heat lost due to the air-sea temperature imbalance while the aerosols were in the atmosphere. The global-mean surface air temperature returns to its pre-eruptions level only when the equilibrium of the ocean is restored. In addition to these forcings, there are others that are associated with human-induced activities such as the burning of fossil fuels that result in a buildup of carbon dioxide in the atmosphere and the consequent greenhouse warming.

SEE ALSO: Climate Forcing; Volcanism.

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Forests

THE EARTH'S SURFACE is covered by diverse vegetation, from tropical and polar deserts, to alpine and arctic tundra, to coastal temperate and tropical rainforests. Forests cover a large fraction of the Earth's terrestrial biosphere (approximately 4 billion hectares) and differ from other vegetation types in several important ways. Forests tend to occur where soils and climate are more favorable to plant growth. As a result, forests tend to store larger quantities of carbon then other terrestrial ecosystem types. Forests are taller than non-forest vegetation types (such as grasslands), and as a result, forests more profoundly affect microclimate at the ground level through canopy shading and reduced effects of wind.

Forests tend to use more water than nonforest vegetation, which together with higher rain interception rates, results in less water entering soils and leaving forests through ground and surface channels. Forests have very different effects on soils compared to other vegetation types. Forests tend to return larger inputs of litter to the soil surface, resulting in the accumulation of a sometimes-thick organic layer, including large woody debris. There is more soil-mixing in forests when large trees fall over and root systems tip up. Disturbances such as fire or hurricanes are more intense, as larger amounts of biomass are consumed or displaced.

Forests occur across a remarkable diversity of soil types, climates, elevations, and aspects. They range from monotypic stands of pine, to highly-diverse tropical rainforests with many hundreds of tree species per hectare. Together, compositional, environmental, and physical/chemical diversity results in very wide ranges in forest productivity, with differences in species composition and productivity altering the chemical and physical properties of soils. Overall, rates of net primary production for forests can range from 200 g. or less per sq. m. per year in cold climates on infertile sites, to several kg. per sq. m. per year in warm, wet climates on fertile sites. Of particular interest to ecologists is how forest composition affects the factors that regulate forest productivity, including nutrient availability, water-holding capacity, and carbon content. For all these reasons, forests receive substantial attention from global change scientists.

FOREST CARBON STORAGE

Forests exert a disproportionately large influence on the global carbon cycle. The Earth's forests store over 1,200 Pg of carbon (1 Pg [petagram] equals 1 x 1,015 g.), which is approximately half of all organic carbon in the terrestrial biosphere. More than 80 percent of this forest carbon resides in boreal and tropical forests, with the remainder in temperate forests. Terrestrial vegetation, especially in forests, interacts strongly with the atmosphere, with impacts on carbon dioxide concentrations and fluxes. Every year, the terrestrial biosphere removes approximately 120 Pg of carbon from the atmosphere through photosynthesis, while releasing an almost identical amount of carbon back to the atmosphere as carbon dioxide through plant and soil respiration. By comparison, humans release approximately 6 Pg of carbon to the atmosphere as carbon dioxide through fossil fuel combustion. Forests also modify weather patterns and local- to regional-hydrologic cycles, and higher rates of plant productivity in forests translate to larger export of products, including biomass feedstock for paper, dimension lumber, and biofuels.

Globally, two to five times more carbon is stored in forest soils than aboveground forest biomass. Despite the large above and belowground differences in carbon storage, only 60 Pg carbon out of the 120 Pg carbon fixed annually by terrestrial vegetation through photosynthesis is allocated belowground for the construction and maintenance of root systems and mycorrhizae, the belowground symbiotic fungal partners of plants that allow plants to increase their exploration of soil for nutrients. Notably, this belowground carbon flux is the Earth's third largest biologically mediated carbon flux after oceanic photosynthesis and terrestrial photosynthesis.

From an evolutionary perspective, this flow of carbon represents the currency with which chloroplasts in leaves (photosynthetic endosymbionts) acquire nutrients, water, and structural support from mycorrhizae. Most of the carbon allocated belowground is rapidly released back to the atmosphere, with up to 80 percent released within one year of entering soil. When only net primary production is considered (that is, gross photosynthesis less plant respiration) the relative proportion of net primary production in forests that is allocated to belowground may be 20–50 percent of what is allocated to aboveground net primary production, in contrast to grassland or tundra ecosystems where the opposite pattern is found. The carbon that remains belowground takes the form of newly-formed soil organic matter or coarse roots, the two main long-lived stocks of organic carbon in soil. The roots of large trees may be extensive, for resource acquisition and to support large aboveground biomass.

Climate change, along with elevated carbon dioxide, increased nutrient deposition rates, invasive species, and land use change are likely having large, often site-specific (and sometimes opposing) effects on forest carbon budgets. Together, these changes on a global scale have the potential to drastically alter how forests interact with the atmosphere. There is great uncertainty regarding how the balance of photosynthesis and respiration will change in response to these global change variables, because many effects are opposing. Because so much organic carbon is stored belowground, accurate estimates of how belowground carbon allocation and belowground process rates in forests will respond to climate change are needed to understand how climate change will alter root growth, carbon inputs belowground, and soil organic matter formation. These, in turn, will influence biotic and abiotic properties of soil such as bulk density, cation exchange capacity, and water-holding capacity, which in turn affect plant growth.

CLIMATIC EFFECTS ON FORESTS

Increasing temperature, nutrient deposition rates, and atmospheric carbon dioxide may stimulate forest production, but these effects may saturate, or be canceled by, increased water limitations to forest productivity due to warmer or drier conditions or by increases in atmospheric plant toxins such as ozone. Warmer temperatures may drive higher respiratory process rates, which may increase carbon losses from forests. However, substrate limitations to microbial decomposition rates in soils or to biochemical processes in plants (acclimation) may limit losses of ecosystem carbon to the atmosphere. Uncertainty increases as ecosystems adapt or become modified by these global change variables.

For example, plant stress may increase with climate change, resulting in greater susceptibility to pests and pathogens. A change in nutrient availability or a warmer climate may, therefore, alter species composition by favoring the recruitment and survival of more tolerant plant species over species previously occupying sites under a cooler climate or nutrient-poor conditions. Climate change may also alter disturbance regimes. For example, in a warmer and drier world, it is anticipated that certain plant species will experience more frequent periods of drought stress and susceptibility to pest and pathogen attacks, resulting in higher mortality and fuel loads. Higher fuel loads and a changing climate will interact to increase intensity and frequency of major fire disturbances.

In already warm and dry ecosystems, warming and drying, therefore, may cause a large transfer of carbon from soils and vegetation to the atmosphere, and these changes would result in a positive feedback on global warming by accelerating the increase in atmospheric carbon dioxide concentrations. Conversely, in currently cool and wet climates, forest productivity may increase as growing season length and nutrient availability increase with warming, potentially resulting in an increase in carbon storage. This would have the opposite negative feedback effect on future warming through a net reduction in the rate at which atmospheric carbon dioxide concentrations are increasing.

Superimposed on the uncertainty of how global change variables will impact forests and forest carbon budgets is the uncertainty concerning ever-evolving patterns of human land use, especially the conversion of forest to nonforest, decisions over abandonment that result in the opposite process, as well as the magnitude and direction of changes in the amounts and distribution of total annual precipitation. The global sum of these changes is receiving tremendous scientific attention, but uncertainty of predicted outcomes from these effects and their interactions remains high.

SEE ALSO: Afforestation; Carbon Sequestration; Carbon Sinks; Deforestation.

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Foundation for International Environmental Law and Development

THE FOUNDATION FOR International Environmental Law and Development (FIELD) was established in London in 1989 by a small group of international lawyers interested in the protection of the environment and the promotion of sustainable development. The organization provides advice and assistance to governments, inter-governmental and non-governmental groups worldwide. FIELD works for the development of international legislation that defends the environment and encourages fair and sustainable development. FIELD has a charitable, nonprofit status and attempts to develop skills and abilities in the citizens of developing and transition countries. In 2005, it became a subsidiary of the International Institute for Environment and Development (IIED). FIELD remains an independent charitable organization but shares offices, core services, and a Board of Trustees with IIED. Thanks to their alliance, the two organizations can combine their strengths: FIELD's expertise in law and advocacy and IIED's experience in social, political, and economic sciences.

The foundation is interested in researching proposals for possible legislation, disseminating good practices though education and teaching, and lobbying for passing legislation for environmental protection and sustainable development. In particular, FIELD has three core programs covering biodiversity and marine resources; climate change and energy; and trade, investment, and sustainable development. The Biodiversity Program was established in 1997, and its projects are aimed to the conservation of biological diversity, the sustainable use of its components, and the equitable sharing of benefits arising from the utilization of genetic resources. In addition to these three issues, the work of the program also focuses on liability and reparation for damage caused to biodiversity. The Trade, Investment and Sustainable Development (TISD) Program focuses on how the international regulations and institutions that manage the processes of globalization impact on developing countries and sustainable development. TISD also addresses how such regulations and institutions relate to international protocols intended to protect the environment. FIELD aims to foster the political and economical empowerment of marginalized countries and communities so that they can make informed choices about trade rules and their effect on the natural environment. FIELD lawyers have monitored and influenced the law and policy of the World Trade Organization, the European Union and other regional trading blocks, the Organisation for Economic Co-operation and Development (OECD), and various environmental treaty bodies.

The foundation considers climate change as one of the most serious ecological threats facing the planet. Climate change and global warming have put the environmental, social, and economic security of many countries is at risk. FIELD has been directly involved in the development of international legislation about climate change, and continues to play an important role in its implementation. The foundation points out that climate change and global warming are already affecting the Earth's physical and biological balance. FIELD's program aims to address the threats that climate change and global warming create for developing and poorer countries. It works to strengthen international and regional legal frameworks and their application to ensure that these weaker communities are not left without help to bear the economic, health, environmental, social, and political burden of climate change effects. The main focus of FIELD's climate change work has been on providing legal assistance for the 43 members of the Alliance of Small Island States (AOSIS) in negotiating and implementing the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol. Since 1998, FIELD has also actively promoted the implementation of the UNFCCC and the Kyoto Protocol in the European Union (EU), in particular through the elaboration of the EU emission allowance trading scheme.

SEE ALSO: Global Warming; International Institute for Sustainable Development; Kyoto Protocol.

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Fourier, Joseph (1768–1830)

JOSPEH FOURIER WAS a French mathematician, also acknowledged as an Egyptologist and administrator, who greatly influenced mathematical physics through his *Théorie analytique de la chaleur* (1822; *The Analytical Theory of Heat*). He analyzed the conduction of heat in solid bodies in terms of infinite mathematical series now called the Fourier series. His work went well beyond the area of heat conduction, stimulating research in mathematical physics. Since Fourier, the discipline has been identified with the solution of boundary-value problems, focusing on many natural occurrences such as sunspots, tides, and the weather. Fourier has also contributed to the theory of functions of a real variable, one of the main branches of modern mathematics. The mathematician was one of the earliest proponents of the theory of global warming, although his many other achievements have overshadowed such contribution. In an article first published in 1824, Fourier pioneered the study of global warming, arguing that the atmosphere absorbs some of the Sun's warmth and sends it back to the Earth.

Fourier was born on March 21, 1768 in Auxerre, Bourgogne, France, the ninth of 12 children from his father's second marriage. His childhood was marked by the premature death of both his parents. His mother died when he was 9 years old and his father, a tailor, died the following year. Fourier started his education at Pallais's school, run by the music master from the cathedral. Because of the great potential that he had shown, he proceeded, in 1780 ,to the *Ecole Royale Militaire* of Auxerre where first he excelled in literature, but very soon understood that his favorite field was mathematics.

In 1787, Fourier entered the Benedictine abbey of St Benoit-sur-Loire to become a priest. His interest in mathematics continued, however, and Fourier was not completely sure that training for the priesthood was the right decision. In his correspondence with C. L. Bonard, the professor of mathematics at Auxerre, he admitted that he really wanted to make a major impact in mathematics. In the end, Fourier did not take his religious vows and left St Benoit in 1789. The following year, he found employment as a teacher at the Benedictine college, Ecole Royale Militaire of Auxerre, where he had studied. With the outbreak of the French Revolution, political commitment also entered Fourier's life, and, in 1793, the mathematician became involved in politics and joined the local Revolutionary Committee. Fourier was "enamored," as he wrote, of the ideal of equality that pervaded the Revolution at the beginning, although he was appalled by the excesses that soon characterized the Terror.

After being briefly imprisoned due to internal feuds within the Revolutionary Front, later in 1794, Fourier was accepted to study at the Ecole Normale in Paris. This institution had been established for training teachers, and was intended to serve as a model for other teacher-training schools. Fourier began teaching at the Collège de France and, thanks to his contacts with Lagrange, Laplace and Monge, who had been his teachers at the Normale, began further mathematical research. He was appointed to a position at the Ecole Centrale des Travaux Publiques. After a second arrest, in 1975, Fourier went to teach at the Ecole Polytechnique. In 1797, he succeeded Lagrange as chair of analysis and mechanics.

In 1798, Fourier joined Napoleon's army in its invasion of Egypt as scientific adviser. Fourier acted as an administrator as French style political institutions and administration were installed. In particular, he helped create educational facilities in Egypt and carried out archaeological explorations. While in Cairo, Fourier was among the founders of the Cairo Institute and was one of the 12 members of its mathematics division. He was also elected secretary to the Institute, a position he held during the French occupation of Egypt. After his return to France, Fourier was entrusted with the publication of the enormous mass of Egyptian materials collected during the expedition. This became the *Description de l'Égypte,* to which he also wrote a lengthy historical preface on the ancient civilization of Egypt. From 1802 to 1814, he was appointed administrator the Isère *département*. Because of his competent work as an administrator, in 1809, Napoleon made him a baron. Following Napoleon's downfall in 1815, Fourier was appointed director of the Statistical Bureau of the Seine. In 1817, he was elected to the Académie des Sciences, becoming its perpetual secretary in 1822. Because of his work in Egyptology he was elected, in 1826, to the Académie Française and the Académie de Médecine. He died on May 16, 1830, in Paris.

During the 1920s, Fourier began to analyze the question of how the Earth stays warm enough to maintain its diverse range of flora and fauna. He wondered why the heat generated by the Sun's rays does not get lost after striking and bouncing off the great oceans and landmasses of the planet. Fourier formulated a first hypothesis of global warming. According to Fourier's metaphor, the atmosphere is compared to an invisible domed container made of glass that absorbs some of the Sun's warmth and reradiates it onto the Earth's surface. Such a gigantic bell jar is formed out of clouds and invisible gases. Water vapor and other gases simulate a vault that conserves heat. Fourier described this hypothesis in the article "General Remarks on the Temperature of the Terrestrial Globe and Planetary Spaces," which was published in the *Annales de chimie et de physique* in 1824. The article was not well-received during Fourier's lifetime, but is now considered a first formulation of global warming.

SEE ALSO: Egypt; France; Global Warming.

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Framework Convention on Climate Change

THE UNITED NATIONS Framework Convention on Climate Change (UNFCCC or FCCC) is an international environmental treaty produced at the United Nations Conference on Environment and Development (UNCED), informally known as the Earth Summit, in Rio de Janeiro in 1992. The treaty set the goal of reducing emissions of greenhouse gas in order to combat global warming.

The original framework of the treaty did not set mandatory limits on greenhouse gas emissions for individual nations and contained no enforcement provisions; it is therefore considered legally nonbinding. Rather, the UNFCCC stated that mandatory emission limits would be established by further "protocols" that would serve as updates of the convention. The principal update is the Kyoto Protocol which, since its enforcement in 1997, has become more frequently referred to than the framework convention itself. While the FCCC was ratified by the U.S. Senate and signed by President George W. Bush in October 1992, neither the Bill Clinton administration nor the Bush administration sent the protocol to Congress for ratification. The Bush administration explicitly rejected the protocol in 2001. The Kyoto Protocol legally binds signatories to reduce greenhouse gas emissions of an average of 6–8 percent below 1990 levels between the years 2008–12, defined as the first emissions budget period. Under the Protocol, the United States would be required to reduce its total emissions an average of 7 percent below 1990 levels.

The FCCC was adopted at the United Nations Headquarters, New York on May 9, 1992. It was open for signature at the Rio de Janeiro from June 4–12, 1992, and thereafter at the United Nations Headquarters, New York, from June 20, 1992 to June 19, 1993. By that date, the Convention had received 166 signatures. The Convention took effect on March 21, 1994. Those States that have not signed the Convention may accede to it at any time. Its stated objective is "to achieve stabilization of greenhouse gas concentrations in the atmosphere at a low enough level to prevent dangerous anthropogenic interference with the climate system." Signatories of the UNFCCC must submit a national greenhouse inventory, an accounting of greenhouse gas (GHG) emissions and removals. The Convention on Climate Change sets an overall framework for intergovernmental efforts to tackle the challenge posed by climate change. It recognizes that the climate system is a global and shared resource and that emissions of carbon dioxide and other greenhouse gases can have a deep impact on its stability. The FCCC enjoys near universal membership, with 191 countries having ratified. Through the FCCC, governments are committed to gather and share information on greenhouse gas emissions, national policies, and best practices; devise national strategies for addressing greenhouse gas emissions and adapting to expected impacts; provide financial and technological support to developing countries so that they can face the challenges of climate change; and cooperate in preparing for adaptation to the impacts of climate change.

The UNFCCC treaty set the goal to reduce emissions of greenhouse gas, but set no mandatory limits on emissions.

The FCCC divides its member countries into three main groups according to differing commitments. Annex I Parties include the industrialized countries that were members of the Organisation for Economic Co-operation and Development (OECD) in 1992. In addition, countries with economies in transition (the EIT Parties), including the Russian Federation, the Baltic States, and several Central and Eastern European States, are included in this group. Annex II Parties consist of the OECD members of Annex I, but not the EIT Parties. The FCCC requires them to provide financial resources to developing countries to organize emissions reduction activities and to adapt to adverse effects of climate change. In addition, Annex II Parties have to promote the transfer of environmentally-friendly technologies to EIT Parties and developing countries. Funding provided by Annex II Parties is directed mostly through the FCCC's financial mechanism.

Finally, non-Annex I Parties are, for the most part, developing countries. Certain groups of developing countries are recognized by the FCCC as especially vulnerable to the adverse impacts of climate change, including countries with low-lying coastal areas and those affected by processes of desertification and drought. Other countries in this group have economies that rely heavily on income from fossil fuel production and commerce. These are thus recognized as particularly vulnerable to the potential economic impacts of climate change response measures. Through investment, insurance, and technology transfer, the FCCC stresses the importance of activities that will answer the special needs and concerns of these vulnerable parties. The 48 Parties, classified as least-developed countries (LDCs) by the United Nations, are given special attention under the FCCC on account of their limited capacity to respond to climate change and adapt to its adverse effects. Parties are urged to take full account of the special situation of this group of countries when considering funding and technology-transfer activities.

Several categories of observer organizations also attend sessions of the Conference of Parties and its subsidiary bodies. These include representatives of United Nations secretariat units and bodies, such as United Nations Development Program (UNDP), United Nations Environment Program (UNEP) and United Nations Conference on Trade and Development (UNCTAD), as well as its specialized agencies and related organizations, such as the Global Environmental Facility and the Intergovernmental Panel on Climate Change (IPCC). Observer organizations also include intergovernmental organizations (IGOs), such as the OECD and its International Energy Agency (IEA), along with non-governmental organizations (NGOs). Since the 11th Conference of Parties, over 750 NGOs and 56 IGOs are admitted as observers. The NGOs represent a broad spectrum of interests, and embrace representatives from business and industry, environmental groups, indigenous populations, local governments and municipal authorities, research and academic institutes, parliaments, labor unions, religious groups, women, and youth.

GREENHOUSE GAS INVENTORIES

In accordance with Articles 4 and 12 of the FCCC, and the subsequent decisions of the Conference of the Parties, Parties to the FCCC submit national greenhouse gas inventories to the Climate Change secretariat. Following Article 12 of the Convention, the Conference of the Parties has elaborated several different types of reports and related guidelines consistent with the common, but differentiated responsibilities of the Parties, relating to their Annex status. These inventory data are provided in the national communications under the Convention by Annex I and non-Annex I Parties, and in addition Annex I Parties submit national greenhouse gas inventories annually. The greenhouse gas data tables contain estimates for: Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), Perfluorocarbons (PFCs), Hydrofluorocarbons (HFCs) and Sulphur hexafluoride (SF_6). Parallel to the stress on greenhouse gas emission limitation, the FCCC also stresses the importance of adaptation to climate change. Article 4.8 of the FCCC encourages Parties to consider actions, including those related to funding, insurance, and the transfer of technology, to meet the specific needs and concerns of developing countries, particularly small island countries and countries whose economies are highly dependent on fossil fuels.

In one of its subsequent decisions, the Conference of Parties requested the Convention secretariat "to work on the synthesis and dissemination of information on environmentally sound technologies and know-how conducive to mitigating, and adapting to, climate change; for example by accelerating the development of methodologies for adaptation technologies, in particular decision tools to evaluate alternative adaptation strategies." This request aimed to assist Parties in applying the best available methods to assess the impact of, their vulnerability to climate change, and their adaptation options. The secretariat has responded positively with a number of activities. It produced a report in 1999 entitled "Compendium of Decision Tools to Evaluate Strategies for Adaptation to Climate Change" and has organized workshops and meetings of experts. In 2003, the secretariat issued a new version of the Compendium to reflect new developments. A final draft of the updated compendium, titled "Compendium of Methods and Tools to Evaluate and Adapt to Climate Change" was put on-line.

To facilitate adaptation to climate change, the FCCC and subsequent decisions of the Conference of Parties have established the National Adaptation Programs of Action (NAPAs) to provide LDCs with plans to respond to their pressing needs with regard to adaptation to climate change. The rationale for NAPAs rests on the limited ability of LDCs to adapt to the adverse effects of climate change. In order to address the urgent adaptation needs of LDCs, NAPAs stress the importance of enhancing adaptive capacity to climate variability. NAPAs start with existing concrete coping strategies in LDCs countries at the grassroots level, and develops them to identify priority activities, rather than focusing on scenario-based modeling to assess future vulnerability and long-term policy at the state level. NAPAs give prominence to community-level input as an important source of information, recognizing that grassroots communities are the main stakeholders in the process of climate change adaptation.

CONFERENCE OF PARTIES

The Conference of Parties (COP) meets annually to assess progress in dealing with climate change. The COP also carried out the task of negotiating the Kyoto Protocol in the mid-1990s to establish legally binding obligations for developed countries to reduce their greenhouse gas emissions. The COP is the highest decision-making authority of the FCCC. It is an association of all the countries that are Parties to it. The COP is responsible for managing international efforts to address climate change. It monitors the implementation of the FCCC and checks the commitments of Parties in light of the FCCC's objective, new scientific findings and experience gained in implementing climate-change policies. A key mission for the COP is to review the national communications and emission inventories submitted by Parties. Based on this information, the COP evaluates the effects of the measures taken by Parties and the progress made in achieving the ultimate objective of the FCCC. The COP meets every year, unless the Parties decide otherwise. Just as the COP Presidency rotates among the five recognized United Nations regions (Africa, Asia, Latin America and the Caribbean, Central and Eastern Europe, and Western Europe and Others), there is a tendency for the location of the COP to also shift among these groups.

SUBSIDIARY BODIES

The FCCC established two permanent subsidiary bodies: the Subsidiary Body for Scientific and Technological Advice (SBSTA) and the Subsidiary Body for Implementation (SBI). These bodies give advice to the COP and each has a specific task. They are both open to participation by any Party. Governments often select their representatives among experts in the fields of the respective bodies.

As its name suggests, the SBSTA's mission is to supply the COP with advice on scientific, technological, and methodological issues. SBSTA works in two key areas for the success of the convention: the development and transfer of environmentally-friendly technologies, and the improvement of the guidelines for preparing national communications and emission inventories.

The SBSTA also carries out methodological work in specific areas, such as the Land Use, Land Use Change and Forestry sector (LULUCF), adaptation ,and vulnerability. In addition, the SBSTA acts as the link between the scientific information provided by expert sources such as the IPCC on the one hand, and the policy-oriented needs of the COP on the other. It works closely with the IPCC, sometimes requesting specific information or reports, and also cooperates with other relevant international organizations that share the achievement of sustainable development as their main mission.

The SBI gives advice to the COP on all matters concerning the implementation of the FCCC, including budgetary and administrative issues. A particularly important task for the implementation of the FCCC is to assess the Convention's overall effectiveness through an examination of the information provided by the Parties in their national communications and emission inventories. The SBI reviews the financial assistance given to non-Annex I Parties to help them implement their Convention commitments, and provides advice to the COP on guidance to the financial mechanism operated by the Global Environmental Facility (GEF).

The SBSTA and SBI also work together on cross-cutting issues that touch on both their areas of expertise. These include capacity building, the vulnerability of developing countries to climate change and response measures, and the Kyoto Protocol mechanisms. The SBSTA and the SBI have traditionally met in parallel, at least twice a year. The meetings of the two subsidiary bodies are either held at the same location as the conference of Parties or, when they are held at different times, at the Convention's secretariat.

The UNFCCC operations are supported by its secretariat in Bonn, Germany. The secretariat has been housed in the historic Haus Carstanjen, where the Marshall Plan was signed, since August 1996. It was previously located in Geneva, Switzerland. The main tasks of the secretariat are to provide practical arrangements for sessions of the Convention and Protocol bodies; to check the implementation of the commitments under the Convention and the Protocol through collection, analysis and review of information and data provided by Parties; to aid Parties in implementing their commitments; to provide support to the compliance regime of the Kyoto Protocol; and to coordinate with the secretariats of other relevant international bodies, the GEF and its implementing agencies (UNDP, UNEP and the World Bank), the IPCC, and other relevant conventions.

Specific tasks include the preparation of official documents for the COP and subsidiary bodies, the coordination of In-Depth Reviews of Annex I Party national communications, and the compilation of greenhouse gas inventory data.

Since the adoption of the Kyoto Protocol, the work of the secretariat has grown considerably. The secretariat employs about 200 people. Its head, the Executive Secretary, is appointed by the Secretary-General of the United Nations in consultation with the COP, and has the title of Assistant-Secretary-General. The Executive Secretary is responsible to the Secretary-General through the Under-Secretary-General heading the Department of Management on administrative and financial matters, and through the Under-Secretary-General heading the Department for Economic and Social Affairs on other matters.

Every two years, the Executive Secretary proposes a budget, setting out the main goals to be pursued by the secretariat in the coming biennium and the funding needed to carry out this work. This proposal is considered in the Subsidiary Body for Implementation (SBI), which then recommends a program budget for approval by the COP. For the biennium 2006–07, the program budget adopted by COP 11 stands at about $27 million for 2006 and $26 million for 2007. The Program Budget is funded by contributions from Parties, their shares being based on the UN scale of assessment.

CONTROVERSIAL WATERS

The work of the FCCC has not always been smooth, and the COP have often been characterized by controversies between different countries that have paralyzed the body. Developing countries lament that they do not receive enough assistance from developed countries. At the 12th Conference of Parties in Nairobi, Kenya, in 2006, delegates from developing countries explicitly complained about "climate tourists," Western delegates who had attended the conference to "see Africa, take snaps of the poor, dying African children and women."

SEE ALSO: Clinton Administration; Bush (George H.W.) Administration; Bush (George W.) Administration; Kyoto Protocol; United Nations Development Programme (UNDP); United Nations Environmental Programme (UNEP).

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France

THE LARGEST AMONG the nations of Western Europe, France boasts a long history of world leadership in the arts, sciences, and industrialization. As the first decade of the 21st century nears its end, France remains an influential nation with a Gross Domestic Product of $2,124 billion, and the sixth largest economy in the world. The nation's moderate climate and its ample agricultural land have made it the European Union's largest agricultural producer, ranking second only to the United States in the world market. Its varied coastlines, mountain ranges, vineyards, and cities rich in culture and tradition make France one of the most popular tourist sites in the world. Like other wealthy Western nations, France has been confronted with the problems attending urbanization, industrialization, and the loss of open space. In 1971, France created the Ministry of the Environment to develop solutions to these problems on a national level; later, the country became a signatory to the Kyoto Protocol and to two-dozen other international efforts to address the problems on regional and world levels.

Global warming is of particular concern to France because temperatures have increased since 1950 in France at nearly twice the average rate. The French remember summer 2003 and the more than 15,000 deaths in their country, and environmentalists have warned that future summers could be much hotter. The nation's extensive coastline also renders it particularly vulnerable to the changes in sea streams that accompany global warming. More than a fifth of the French coast already shows signs of erosion. The Intergovernmental Panel for Climate Change (IPCC) set up by the World Meteorological Organization and the United Nations Environmental Program (UNEP) to assess factors connected to climate change, estimates that sea levels by 2100 could rise at a rate three times that of the 20th century. The government has built artificial reefs in an effort to contain erosion, but experts hold little hope that such measures can stem the damage over the long term.

Increases in water temperature and deforestation are among the consequences of climate changes already in progress. These changes have led to the extinction of some species of fish and the spread of the Asian Hornet. The latter, which may have arrived in France from the Far East via a shipment of Chinese pottery in 2004, pose a major threat to France's beekeepers. Experts report that it takes only a few of the hornets to destroy a nest of 30,000 bees.

Of even greater concern are the effects upon France's renowned wine industry, which contributes $13 billion to the nation's economy and is intricately linked to French culture. The immediate effects of higher temperatures were beneficial, as warming produced wines with higher sugar and alcohol levels and lower acidity. However, droughts have plagued Provence and other areas of southern France, and even the northernmost areas of Alsace and Champagne have experienced harvest seasons that have moved from the traditional October harvests to as early as August. Bernard Seguin, a French climatologist, compared a one degree increase in temperature in a vineyard to moving the vineyard 124 mi. (200 km.) south. Scientists point out that the highly detailed records maintained on wine grapes over generations along with the grapes' unusual sensitivity to climate changes make them a valuable tool for studying effects of the changes on the rest of the ecosystem.

While scientists debate the theories, France has taken practical action, including making environmental protection a part of its Constitution and formulating a Climate Plan, begun in 2004, and updated annually, that targets every area of French life that can help reach the national goal of saving 54 million tons of CO_2 by 2010. Increasing public awareness of the problems and the individual role in the solution has been an important component of the plan. An 80 percent public awareness of global warming in France suggests that the goal of informing the public has been achieved. France also made an early commitment to protecting open spaces. Nearly 30 percent of France's land area today consists of forests and woodlands. Reforestation has become a common strategy to decrease CO_2 emissions, but the French government has been subsidizing reforestation since 1947, and it earmarked tens of millions of euros to aid communities and individuals in renewing privately-owned forests 2000–10.

Perhaps the most dramatic and consequential measure France has taken to deal with the problems of global warming is to rely on nuclear power as its chief source of electricity. Energy production by wind power and biofuel have increased in France, but it is the 80 percent of its energy needs being met by nuclear power that gives France the cleanest air among industrialized nations. The energy produced by the nuclear plants is also inexpensive, making it an ideal export to other European Union (EU) nations such as Germany, Italy, and England. The 58 nuclear power plants in a nation roughly the size of Texas also account for France's 40 percent reduction in CO_2 emissions and 70 percent reduction of nitrogen oxide and sulfur dioxide emissions. France's emissions of greenhouse gases are the lowest among the EU powers, and they are still declining.

Among the major Western European nations, France is closest to fulfilling is Kyoto Protocol responsibilities. President Nicolas Sarkozy, who was elected in May 2007, promised tax reforms that include a new tax on CO_2 emissions and a tax on goods imported from countries that have not signed the Kyoto Protocol. France seems positioned not only to hit its own targets in the world response to global warming, but also to influence nations that have elected not to comply.

SEE ALSO: European Union; Intergovernmental Panel for Climate Change (IPCC); Kyoto Protocol; Nuclear Power.

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Friends of the Earth

FRIENDS OF THE Earth (FoE) is a nongovernmental organization that focuses on the relationships between human rights, social justice, and environmental issues. The vision for FoE is "of a peaceful and sustainable world based on societies living in harmony with nature." FoE implements this vision by campaigning, undertaking education and awareness-raising programs, and by building networks and collaborations from grassroots to global levels. Founded in 1961, FoE's inaugural members included France, Sweden, England, and the United States. By 1981, a small International Secretariat had been established, and by 1983, FoE had 25 members, with an Executive Committee that worked on the issues in between meetings. All new FoE groups must adhere to strict criteria, ensuring consistency across the world in FoE actions and campaigning. Today, there are over 68 Friends of the Earth member groups, both national and local, that work toward implementing the FoE vision. FoE operates as a federation of autonomous environmental organizations from all over the world, and has a membership of 1.5 million in 70 countries.

FoE has a history of initiating many campaigns across many issues. For example, during the 1970s, FoE negotiated and worked on a campaign that supported protection of various whale species, without destroying economic livelihoods. In the 1980s, FoE undertook a number of tropical rainforest campaigns that helped to highlight the changing circumstances of the world's indigenous peoples living in these areas. In Europe, FoE focused on issues such as the effect of acid rain, air pollution, packaging, and biotechnology. In these contexts, FoE has often acted as the third party in court cases, raising awareness of and trying to change outcomes of some developments. For example, in the case *Friends of the Earth Inc., et al. v Laidlaw Environmental Services (TOC), Inc. 2000,* heard in the U.S. Supreme Court, FoE filed a citizen suit against Laidlaw. FoE alleged that Laidlaw was noncompliant with a National Pollutant Discharge Elimination System (NPDES) permit granted to Laidlaw and sought declaratory and injunctive relief and an award of civil penalties.

While FoE campaigns on many issues, it is currently prioritizing climate change, which it believes is the biggest environmental threat to the planet. Initiatives have included: demanding strong national emissions reductions target; bringing lawsuits against major polluters, such as oil corporations; challenging a number of big oil projects around the world projected to accelerate climate change; and joining forces with climate-affected communities to facilitate a global movement that will redress social and economic equity issues between and within countries.

For example, in 2003, FoE launched a Climate Justice program. This program involves supporting people, and initiating legal challenges to governments, related to climate change. Challenges to date have been: against the Bush administration's export credit bodies for not doing climate change accounting when providing monies for fossil fuel projects, and, in 2004, against the German government for its lack of transparency in fossil fuel projects. FoE is also working with indigenous peoples, such as the Inuit, who are developing a petition to the Inter-American Commission on Human Rights against the United States, for violations of human rights due to climate change, especially in the areas of property, culture, and subsistence.

Finally, in 2006, FoE members from 51 groups gathered at the International Conference on Climate Change in Abuja, September 28–29, 2006, culminating in the Abuja Declaration. This document recognizes that in the context of climate change, there is a need to work toward alternative energy sources, and to pursue a different vision of an energy future. This vision incorporates the principles of abandoning the belief in export-led growth in favor of servicing local (basic) needs; restructuring the price and production of energy; developing a new approach to restructuring ownership of the energy regimes; and abandoning what FoE terms the "mistaken dichotomy" between development and environment.

The declaration calls on governments of all nations to take action on developing an alternative future. This includes calls for a global moratorium on new oil and gas exploration and development until full eco-restoration and reparations are implemented in communities already impacted by extractive industries, and for governments to develop cleaner energy sources.

SEE ALSO: Developing Countries; Nongovernmental Organizations (NGOs); Oil, Production of.

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Gabon

LOCATED IN CENTRAL Africa, the Republic of Gabon was formerly a French colony and has land borders with Cameroon, Equatorial Guinea, and the Republic of the Congo. Gabon has a land area of 103,347 sq. mi. (267,668 sq. km.), with a population of 1,384,000 (2005 est.), and a population density of 13.5 people per sq. mi. (5.2 people per sq. km.).

Some 80 percent of the country is covered in forests, with a small lumber industry operating to harvest mahogany, ebony, and walnut. Only 1 percent of the land is arable, with 18 percent used for meadows and pasture. In spite of significant oil production, 70.6 percent of the electric power in Gabon comes from hydropower, with the remainder from fossil fuels. This use of fossil fuels, largely liquid fuels or gaseous fuels, contributes to the country's carbon dioxide emissions. In 1990, Gabon generated 6.3 metric tons of carbon dioxide per capita, but it fell considerably, to only 2.9 metric tons per person in 1991, afterwards rising slightly. Emissions fell again dramatically in 1998 to 1.3 metric tons, and by 2003 were only 0.91 metric tons. Much of the remaining emissions come from use of automobiles, leading to a small level of carbon monoxide emissions. Some emissions also come from cement manufacturing, which in 1998 accounted for 9 percent of the country's total carbon emissions.

This reduction in carbon dioxide emissions remains one of the most dramatic in the world, and came through investing heavily in hydropower. The government had also built the Transgabonais railway during the oil boom, with the first trains taking passengers in 1986. There is also a good bus service covering most of the country. The French Atomic Energy Commission discovered, in 1977, a prehistoric natural "nuclear reactor," which was located in an open-pit uranium mine at Oklo in the upper Ogooué River Valley in Gabon.

The Gabonaise government of Omar Bongo took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, and two years later ratified in the Vienna Convention. Gabon was the 166th country to sign the Kyoto Protocol to the UN Framework Convention on Climate Change, which took place on December 12, 2006. The government has begun a program of establishing 13 national parks, with the plan that ecotourism could replace logging entirely as a source of income for the country.

SEE ALSO: Emissions, Cement Industry; Nuclear Power; Oil, Production of.

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Gaia Hypothesis

IN THE EARLY 1960s, scientist James Lovelock was invited by the National Aeronautics and Space Administration (NASA) to participate in a scientific research project aimed at trying to find evidence of life on Mars. His job was to design instruments capable of detecting the presence of life that could be sent on a spacecraft to Mars. This led him to think about what constitutes life, and how it can be detected. This culminated, in 1979, in the publication of his book *Gaia: A New Look at Life on Earth*. His hypothesis was that the Earth itself was a live organism. The term Gaia was borrowed from Greek mythology, where Gaia is the goddess of the Earth. Lovelock's thesis is that the Earth is self-regulating and that the physical and chemical condition of the Earth, as well as the oceans and atmosphere, are kept fit because the Earth, or Gaia, is actively regulated by life itself. The Gaia hypothesis is based on the belief that Gaia evolves according to Darwinian laws of self-selection. The Gaia hypothesis does not see the Earth as a sentient organism; rather, that Earth and all the systems on it are finely balanced and interrelated to create the conditions conducive to life on the planet.

According to the Gaia hypothesis, even if all human life on Earth is extinguished, the planet will self-regulate to maintain its own life, and possibly other forms of life within it. For example, Lovelock highlights the resilience of some species of blue-green algae, which are highly resistant to short-wave, ultraviolet radiation. Life overall is robust, even if humans are not. Lovelock identifies three crucial characteristics of Gaia. The first is the tendency to keep constant conditions for terrestrial life forms. This tendency predates the arrival of humans, and he argues that as long as the planet's natural homeostasis (equilibrium) is maintained, the planet will continue to survive as a whole. He argues that the history of the Earth's climate proves his theory that Gaia is a living organism, stating, "if the Earth were simply a solid inanimate object, its surface temperature would follow the variation in solar output."

Second, Gaia has vital organs at the core, as well as ones on the periphery. Lovelock argues that it is human interference with the vital organs that will determine whether or not the planet will survive. He believes that Earth can survive without 30 percent of its surface. However, he argues it is possible that the world's carbon sinks and microscopic creatures may be vital organs, due to the key role they play in maintaining the balance of the Earth's systems. Maintaining the balance within the oxygen-carbon cycle is vital to life. Other core regions within Gaia include the region between the latitudes 45 degrees north and 45 degrees south, which include the world's tropical forests and scrub lands. Any disruption of these areas may sustain perturbations so drastic that the planet will not survive.

Lovelock argues that the third characteristic of Gaia is the way in which the planet obeys the laws of cybernetics. Gaia's response to major changes to equilibrium will obey the laws of cybernetics, where the time constant and loop gain are important factors. Lovelock points to the fact that despite the Earth revolving around the sun, its mean temperature has never varied by more than a few degrees from its current levels. Thus, it has never been too hot or cold for some form of life to survive on the planet, despite changes to the early atmosphere and variations in the sun's output of energy. This is because the Earth has been able, through the law of cybernetics (as with all living creatures) to self-regulate, which includes instigating the processes of self-correction in the event of any imbalance. However, increasingly, the planet is facing pressure that may disrupt its ability to self-regulate and recover from factors that cause imbalance to the systems within it. Lovelock argues that the disadvantage of such systems is that while they may experience major change, the period within which they manifest that change is so long that there will be

According to the Gaia Hypothesis, the Earth has always been able to self-correct any imbalance.

lag time between the effect and action to mitigate it. In his second book, *The Death of Gaia*, Lovelock is very pessimistic about the outcome of this lag, arguing that in relation to climate change, a failure to take action before the full effects of the problem are seen will have disastrous consequences for life on Earth.

The Gaia hypothesis has attracted much interest. In relation to climate change, it provides an innovative scientific analysis of the planet's feedback, loop, and cybernetic systems to highlight that unless that balance is maintained, human impacts on that system will cause catastrophic effects, such as runaway climate change, and, as Lovelock concludes, of such magnitude that life will no longer exist.

SEE ALSO: Climate Change, Effects; Earth's Climate History; Ecosystems; Global Warming.

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Gambia

THIS WEST AFRICAN country, astride the Gambia River, is entirely surrounded, on land, by Senegal, and has a land area of 4,007 sq. mi. (10,380 sq. km.), with a population of 1,517,000 (2006 est.), and a population density of 397.6 people per sq. mi. (153.5 people per sq. km.). Some 18 percent of the land is arable, with a further 9 percent used for meadows and pasture, mainly for cattle. In addition, 28 percent of the country is forested.

The electricity production in Gambia is entirely from fossil fuels. Its main power station had the only significant failure from the Year-2000 (Y2K) computer software problem, which has since been resolved. The country has had a steady carbon dioxide emission rate per capita, at 0.2 metric tons per person 1990–2003. All the carbon emissions in the country come from liquid fuels. Because of its geography, there is little need for extensive car ownership, especially with the Gambia Public Transport Corporation providing a well-regulated bush taxi service for Banjul, the capital, and other parts of the country.

Much of the country is low-lying, and Gambia is at risk of flooding with the rising water levels from global warming and climate change, and coastal erosion. This can already be seen at the beaches around Cape St. Mary and at Kololi, where sections of what had been coastline have disappeared since the early 1990s. Dutch technology is now used to try to stem this. The Gambian government of Sir Dawda Jawara ratified the Vienna Convention in 1990, and took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992. The government of Yahya Jammeh accepted the Kyoto Protocol to the UN Framework Convention on Climate Change on June 1, 2001, with it coming into force on February 16, 2005.

SEE ALSO: Sea Level, Rising; Senegal; Transportation.

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Geography

GEOGRAPHY IS AN academic discipline that traces its roots to classical Greece. The Greek scholar Eratosthenes (275–195 B.C.E.) is usually identified as the father of geography. He coined the term geography, which is derived by combining the Greek noun for Earth (*geo*) with the Greek verb "to write" (*graphein*). Literally translated, geography means to write or describe the Earth. Based on his travels up the Nile River and his knowledge of geometry, he was able to accurately calculate the circumference of the Earth.

Since the time of the ancient Greeks, geography has evolved into a varied discipline with many research subjects and methodologies. Some scholars have attempted to impose a narrow definition on the sprawling reach of geography. However, other geographers suggest that four research traditions have evolved within the discipline, all of which examine the regional dimensions of human and/or physical processes on the surface of the Earth. These themes include: physical geography or environmental science, the primary emphasis on natural processes such as hydrology, geomorphology, meteorology, and biogeography; spatial science, using deductive mathematical models, geographic information system (GIS) and global positioning system (GPS) technologies, remote sensing, and statistical analyses to study terrestrial processes; nature-society relations, focusing on the interface between human activities and environmental changes; and regional geography, examining people, places, and regions using an array of methodologies.

There is overlap between these traditions. The organization of geographical research into these four broad themes has been affirmed by Association of American Geographers (AAG), the preeminent American organization of academic geographers, who have organized the subsections of their flagship journal, the *Annals of the AAG*, to roughly correspond to these divisions. The Royal Geographical Society (RGS), the British counterpart to the AAG, and other organizations of academic geographers largely agree with this sweeping definition of Geography. Given the broad reach and crosscutting nature of the discipline, it is appropriate to view global warming through the prism of geography.

PHYSICAL GEOGRAPHY

Physical geographers have studied the causes and consequences of global warming from different perspectives, including biogeography, the cryosphere, geomorphology, and hydrology. For example, biogeographers have studied how rising temperatures or changing precipitation regimes will affect entire plant ecosystems or biomes such as boreal forests. They have also examined how specific plant species will cope under different climate conditions. In many instances, the research predicts that warm-weather plant species will successfully migrate toward higher latitudes. On the other hand, some cool-weather plant species found at high altitudes may die out if they are not able to ascend beyond a certain elevation to avoid the heat.

Geomorphologists suggest that global climate change could have drastic impacts on river flows, coastlines, and soils. These studies of fluvial and coastal geomorphology suggest that increased precipitation will increase flooding and soil erosion. This will, in turn, affect agriculture and other human activities.

Geographers who study the cryosphere (frozen regions of the Earth) predict large changes as a result of melting permafrost and melting glaciers. Forests and other plant ecosystems that were once protected from insects and other pathogens by freezing temperatures could be at risk as temperatures rise. If there is large-scale die-off from newly-invasive pests, dying trees can become a fire hazard.

Climatologists have focused on the potential of more frequent and more intense hurricanes and other weather events. Other topics within this subgenre of geography include the likelihood of droughts in China, and the predictions of local and regional-scale temperature variations across the globe. Of course, climatologists have been at the forefront of research documenting the existence of global warming. Climatologists have used maps to study geographic variations in oceanic temperatures and to predict future changes to ocean currents such as the Gulf Stream.

SPATIAL SCIENCE: METHODS, MODELS AND GIS

Geographers have always relied on maps to display their research findings. Research on global warming is no different. In fact, computer cartography, GIS, and remote sensing are widely used by climatologists, trained in many disciplines, as a way to catalogue the evidence for climate change in the past and to organize evidence for climate change now and into the future. Geographers can construct mathematical models that incorporate many independent variables related to temperature, precipitation, topography, atmospheric gases, population growth, industrial development, and rates of deforestation, to predict how the manifestations of climate change will vary by geographic scale and region.

Some of the data needed to build these models, such as historic temperature records, can be gleaned from secondary sources. However, much of the data needed, such as land cover or atmospheric gas composition, needs to be gathered using satellite images and other remote-sensing techniques. Satellite imagery is particularly useful for detecting changes in vegetation. Vegetation stressed due to drought, disease, or human activity can be detected using infrared filters on satellite images.

Maps, the stock-in-trade of geographers, are used by every major research and policy agency on the planet, including the U.S. Environmental Protection Agency (EPA), the U.S. Department of Agriculture (USDA), the United Nations Food and Agriculture Organization (FAO), the European Space Agency (ESA), and the National Aeronautical and Space Agency (NASA) to display information related to global warming. NASA websites offer online cartographical movie clips that show future scenarios for regional impacts of climate change.

NATURE AND SOCIETY

Geographers in this subgroup are interested in the human dimensions of global change. They are interested in the human causes and consequences of global warming. Consider the issue of water resources. The uneven distribution of water resources has caused many political confrontations in the past. Water scarcity and related water diversion projects in California, the former Soviet Union, and along the Nile River have all created regional and/or international political strife. Global warming is likely to exacerbate these issues as precipitation decreases further in some places and intensifies in others. Water resource geographers attempt to understand how human behaviors affect water supplies and how policies can be crafted to increase the supply of potable water to those who need it most.

An understanding of the geography of energy production and consumption is central to understanding the causes and consequences of global warming. Energy geography will also be essential to the development of strategies to combat global warming. Energy geographers work with climatologists to identify places with good wind energy potential. Some communities actively recruit wind power development. Others are not so sanguine. Hence, energy geographers work with land-use planners to find sites for wind turbines that are energy efficient and acceptable to communities in the area.

Geographers interested in natural resource management, tourism, and recreation also have an interest in global warming. Ski resorts increasingly rely on artificial snow to extend their seasons because of declining winter precipitation. Hence, some ski resorts may be forced out of business if alternative water supplies cannot be found. Large inland bodies of water are also affected by climate change. In 2007, the water levels in Lake Superior reached record lows. Declining water levels hinder navigation and beach access for recreation and commerce. This could have dire economic consequences for many communities that depend on tourism dollars.

Coastal and marine geographers study how temperature changes could increase sea levels, the intensity of hurricanes, and the extent of beachfront erosion. Many beach communities along the Atlantic Coast spend millions of dollars replenishing beaches that have been destroyed by severe wave action. If sea levels rise and storms become more intense, these communities will have to spend even more money maintaining their coastlines.

Damage and flooding to coastlines as a result of climate change will, of course, do more than just affect tourism. There are many large cities and population centers that exist, near or even below, sea level. Examples of at-risk regions certainly include Bangladesh, islands of the Indian Ocean, such as the Maldives, but also the Netherlands, the Florida Keys, and large cities of North America and Western Europe including New Orleans, New York City, Venice, and Copenhagen.

REGIONAL GEOGRAPHY: PEOPLE, PLACE, AND REGION

Scholars from the human geography tradition examine the political, economic, demographic, and cultural implications of climate change. For centuries, explorers have attempted to find a Northwest Passage that would shorten the sailing distance between Europe and Asia. Explorers such as Henry Hudson believed that a route existed through the Arctic Ocean along Canada's northern coast. He failed to find it, as did dozens of other explorers of note. In fact, severe weather and thick pack ice proved to be an impenetrable barrier to commercial shipping through the 20th century.

However, there is evidence to suggest that rising temperatures will melt the pack ice in the Arctic Ocean, allowing the Northwest Passage to become a viable commercial navigation route. However, there are serious geopolitical issues to resolve as Canada has declared that the passage exists entirely within Canadian waters. Other countries, such as the United States and European countries, claim that the route is an international channel independent of Canadian sovereignty. While nation-states quarrel over who has sovereignty over northern seaways, the plight of Inuit cultures goes largely unnoticed. However, many of the traditional hunting rituals and life-ways depend on frozen sea ice. However, rising sea levels and a longer ice-free summer season are causing coastal erosion that is forcing indigenous communities to relocate and adapt.

Global warming will also have economic impacts that vary regionally. Panama is currently investing hundreds of millions of dollars expanding its famous canal. However, if the Northwest Passage does become commercially viable, this might undermine the ability of Panama to recoup its investments in an enlarged canal. Other cities that depend on oceanic trade, such as Singapore and Hong Kong, may suffer economically as trade is diverted away from Southeast Asia northward through the Arctic Ocean.

Global warming may have profound impacts on where people live. Rising sea levels may force millions of people to relocate to higher ground. Changing patterns of precipitation may affect the livability of inland cities such as Phoenix, Arizona; Denver, Colorado; or Las Vegas, Nevada. These are rapidly growing cities located in arid and semi-arid environments. Phoenix and Las Vegas depend on water that is diverted many hundreds of miles. If water sources decline, this will limit the economic and demographic growth of these cities.

An important aspect of understanding geographic variation is how seemingly meaningless regional differences can become a basis for deep social inequality. Hence, a geographic perspective can help to understand, and possibly remediate, the social and regional injustices that could occur from global climate change. Hurricane Katrina and the fate of the residents of New Orleans have already given us a foretaste of how regional differences get translated into social inequalities. In the case of New Orleans, the people most severely affected were poor and from minority neighborhoods. Public health will also be affected by climate change, because a changing climate will likely cause diseases to shift into new regions. It will be the wealthy people and countries that will be most able to adapt. Global climate change will likely worsen existing inequalities. This dynamic may be repeated at different scales in different regions unless a geographic perspective is used to implement policies that promote a more egalitarian policy response to climate change.

SEE ALSO: American Geophysical Union; Detection of Climate Changes; Geospatial Technology; International Geophysical Year (IGY); Land Component of Models.

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Geophysical Fluid Dynamics Laboratory

THE GEOPHYSICAL FLUID Dynamics Laboratory (GFDL) is a laboratory in the National Oceanic and Atmospheric Administration (NOAA)/Office of Oceanic and Atmospheric Research (OAR). The GFDL aims to produce reliable knowledge and assessments of natural climate variability and anthropogenic changes. It also seeks to develop the required Earth System Models. The Laboratory is housed at the Forrestall Campus of Princeton University. The GFDL has pioneered the study of global warming as it developed the first climate models to study the phenomenon. It has also contributed the first comprehensive ocean prediction codes, and the first dynamical models with significant skill in hurricane track and intensity predictions. Most of the research within the laboratory centers around the development of Earth System Models for assessment of natural and human-induced climate change

The GFDL is involved in research to expand the scientific understanding of the physical processes that govern the atmosphere and the oceans as complex fluid systems. These systems can then be modeled mathematically and can be studied by computer simulation methods. The GDLF includes 300 researchers from all over the world. It is divided into branches. The Atmospheric Physics and Chemistry unit focuses on processes that impact the vertical structure of the atmosphere, such as convection and radiation. The group is particularly interested in the role of aerosols in climate change. The Biospheric Processes unit studies interactions between the physical climate and biogeochemical systems, and is the center for the development of GFDL's Earth System Model. The Climate Diagnostics unit compares observational datasets with models, and uses models to isolate key processes that regulate inter-annual variability in the ocean and atmosphere. The Climate Dynamics and Prediction unit is the largest group in the lab and is in charge of developing numerical models for climate predictions and projections. These predictions can range from seasonal-to-centennial timescales. Major projects include the development of El Niño predictions for seasonal forecasting, and the production of Intergovernmental Panel on Climate Change- (IPCC) class climate models. The Oceans and Climate section deals with the role of oceans in the large-scale climate system and with the development of numerical codes to simulate the ocean. Finally, the Weather and Atmospheric Dynamics unit works on the dynamics of the atmosphere, with particular attention to the interactions between waves and turbulence and the large-scale flow. The group is in charge to devise the GFDL's hurricane model.

The GFDL was first established in 1955, as the General Circulation Research Sector of the U.S. Weather Bureau and American meteorologist Joseph Smagorinsky was its first director. The General Circulation Research Sector was initially based in Washington, D.C., and began to study ways to represent the circulation of the atmosphere with computer models. Due to postwar tensions, the American Government was eager to fund projects in geophysics and computers, so Smagorinsky was able to develop his Research Sector and attract important meteorologists to work there, including climate modeler Syukuro Manabe and ocean modeler Kirk Bryan. In 1959, the group slightly modified its name becoming the General Circulation Research Laboratory. It took its current name in 1963 and, five years later, moved to Princeton University. The Geophysical Fluid Dynamics Laboratory was one of the first institutions to devote its attention to the phenomenon of global warming in the late 1960s. It produced one of the first estimates of the impact of CO_2 emissions on climate.

The GFDL has continued to research the phenomenon of global warming. It has warned that the strongest hurricanes in the present climate will be replaced by even more intense ones over the next century as the Earth's climate is warmed by increasing levels of greenhouse gases in the atmosphere. The computer simulations conducted at the GFDL have shown that the warming due to increasing greenhouse gases concentration will not be uniform throughout the globe. It will be faster over land masses than over oceans. In addition, computer simulations point out that the most intense warming will take place in winter months in the areas of North America and north-central Asia. Summer warming will be accompanied by drier land in many regions. Computer models designed by the Laboratory also agree that air temperatures of the Artic surface are extremely sensitive to climate change, doubling twice as fast as the global average. Over its 50-year history, the Geophysical Fluid Dynamics Laboratory has played a leading role in the development of computer models to predict the behavior of the atmosphere and the oceans, as well as their roles in climate change.

SEE ALSO: Climate Cycles; Hurricanes and Typhoons; Weather.

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Georgia (Nation)

A SMALL COUNTRY with a population of under six million, the nation of Georgia is located at the juncture of Europe and Asia. In 1991, Georgia gained its independence from Russia. Despite inadequate sewage management that has left the Black Sea heavily polluted, experts view Georgia's environmental problems as less serious than those of more industrialized former-Soviet countries. National security and economic problems have demanded more immediate attention. Nevertheless, Georgia is party to a dozen international agreements on the environment, including the Kyoto Protocol and the Ozone Layer Protection, a United Nations agreement involving Countries with Economies in Transition (CEITs).

Ironically, the collapse of the Soviet Union led to a substantial decline in Georgia's greenhouse gas emissions. The year before Georgia declared its independence, its CO_2 emissions totaled 37 millions tons. Seven years later, in 1997, emissions had declined by nearly 10 million tons. The figure has begun to increase again in the 21st century. While industrial production is still below those of the Soviet-led era, traffic-related pollution is a substantial problem. Not only has the number of vehicles increased, but many vehicles are also old and poorly maintained. The quality of fuel they burn is often inferior, leading to concerns about lead pollution, as well as CO_2 emissions.

Another concern relevant to global warming is deforestation. Illegal logging has remained a persistent problem in a country where energy became scarce and expensive in the 1990s, and the poverty rate soared. Trees were felled for fuel in greenbelts, in parks, and even in city streets. Little effort at reforestation ensued. However, Georgia has rich potential for developing clean and renewable energy sources. It is the most mountainous country in Europe, and the Black Sea forms its western boundary, making both wind and hydropower feasible. Legislative action in the late 1990s made it clear that Georgia understood the need to develop its renewable resources, but development has been slow, due to economic conditions. Exploiting coal reserves was a cheaper solution to immediate needs, even if doing so increased emissions. The 2006 Yale University study ranked Georgia 75th among 133 nations in its overall environmental health, a ranking largely due to its failures in sustainable resources.

The peaceful Rose Revolution saw a pro-Western government assume power in Georgia. Committed to democratic reforms, the government has also opened the country's economy and intensified efforts to join the North Atlantic Treaty Organization (NATO) and to meet the criteria of the action plan inaugurated under the European Union's (EU) European Neighborhood Policy. One step in that plan calls for Georgia to implement its policies concerning sustainable resources. Georgia's expectation of joining NATO in the near future, and its long-range goal of EU membership, may increase concern about greenhouse gas emissions and other environmental issues.

SEE ALSO: Deforestation; Energy, Renewable; European Union.

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GEORGIA IS THE largest state east of the Mississippi River. Because the economy is heavily dependent on manufacturing and agriculture, the state is involved in activities that are known to negatively affect global warming and climate change. With a population increase of 29 percent 1990–2001, Georgia's carbon dioxide emissions rose by 16 percent. As a result, Georgia ranks 11th in the nation in CO_2 emissions. Overall, global warming pollution in Georgia increased 26 percent 1990–2004. Georgia ranks second in the nation in pollution produced from electric power plants because of eight coal-fired plants built before the concept of global warming was understood. Because Georgians recognize the threat that global warming and climate change pose to health, the environment, and financial prosperity, the government has joined with nongovernmental organizations and the business community to establish programs that focus on energy, agriculture, forestry, transportation, and waste management. The state is under intensive pressure to force power companies to replace the polluting facilities and develop alternative energy sources.

The Georgia Environmental Facilities Authority (GAFA) and the Georgia Department of Natural Resources share major responsibility for managing Georgia's responses to global warming and climate change. Other entities involved include the Department of Agriculture, the Forestry Commission, and the Soil and Water Conservation Commission. GAFA works with county and city governments, other state agencies, and private organizations to promote responsible environmental practices. The Environmental Protection Division (EPD) of the Department of Natural Resources administers 26 state environmental laws and works with the U.S. Environmental Protection Agency (EPA) to implement four federal laws. EPD has the authority to impose fines and shut down facilities that are not in compliance. Various divisions within EPD have direct responsibility for meeting established standards. For example, the Fuel Storage Division monitors the maintenance of fuel tanks. In 1991, Georgia created the 15-member Governor's Environmental Advisory Council to evaluate the effectiveness of the state's environmental programs and make suggestions for improvement.

Atlanta is the state capital and the center of population and industry. Composed of 13 counties, metropolitan Atlanta ranks ninth in population among American metropolitan areas. The vast majority of the people who work in Atlanta commute from other areas, presenting major pollution problems. The Hartsville-Jackson International Airport is the busiest passenger airport in the world, increasing levels of toxic emissions in the Atlanta area. Special attention is paid to eastern Georgia, which borders the Atlantic Ocean. Global warming poses a major threat to this area because of rising sea levels, potential coastal erosion, and loss of wetlands. If coastal marshes are destroyed by salt-water intrusion, the fishing industry would suffer, and the habitat for ocean life and wintering waterfowl would be greatly compromised. Controlling global warming and climate change is also essential to protecting the ecosystems of the 328 species of birds, 92 species of mammals, 83 species of reptiles, 250 species of fish, and the 77 species of amphibians that are found in Georgia. The state's forests are at particular risk from rising temperatures, which increase the threat of massive fires such as those that spread from South Georgia to Florida in 2007. Smoke from those fires blanketed much of the state, creating health and environmental problems.

In order to deal with the ongoing problem of reducing global warming and climate change, Georgians have instituted a number of programs. The Georgia Weatherization Program, for instance, provides assistance to low-income people, with preference given to the elderly, the disabled, and families with children, to make their homes more energy efficient. The program has served nearly 8 million homes since it was created in 1976, reducing CO_2 emissions approximately one metric ton per home served.

In response to high pollution levels of ozone and particulate matter in Georgia, the state has passed strict vehicle emissions standards for residents of the metropolitan Atlanta area. To encourage carpooling, vehicles carrying multiple passengers are allowed to drive in High Vehicle Occupancy lanes on downtown sections of Interstates 85, 75, and 20. Plans to extend areas covered by the Metropolitan Atlanta Rapid Transit Authorit (MARTA), Atlanta's mass transportation system, are generally viewed as one of the most effective ways of reducing metropolitan pollution. Metropolitan Atlanta leads the nation in the number of vehicle miles traveled daily, with a yearly average of more than 40 billion miles each year. Particularly during hot, humid summers, air quality has, at times, been so poor that the state has been in danger of losing federal construction funds. The smog that blankets the city during periods of heavy pollution is a major health and environmental concern.

Since 1996, the Clean Air Campaign, a nonprofit organization comprised of more than 70 groups, has been involved in raising public awareness and in exerting pressure on state and local legislators to improve air quality in the Atlanta area. Program officials work closely with the Department of Natural Resources and the Department of Transportation. Activities are largely funded through Congestion Mitigation and Air Quality grants and matching state and corporate funds. Efforts to reduce pollution in the metro area include working with the public and businesses to promote the free Ride-Matching program and encouraging telecommuting, walking, biking, and riding MARTA. The success of the Clean Air Campaign is documented by significant reductions in nitrogen oxide and CO_2 emission levels, traffic congestion, and fuel consumption.

The State of Georgia offers tax relief to companies that institute emission-reducing programs such as the Advanced Travel Center Electrification (ATE) program, which was established to provide long-haul truckers with an alternative to the practice of idling trucks while drivers rest, releasing tons of CO_2 and pounds of NO_x and CO_2 into the air each year and wasting valuable fuel. ATE offers an external system, which can be mounted on the truck to provide heat, air, power, internet access, television, and phone services while the truck is turned off. Revenues from the program are shared between ATE designer, IdleAire Technologies Corporation, and parking space property owners. The Congestion Mitigation and Air Quality Program offers some funding for the ATE system, and the state matches 20 percent of project costs.

Farming is the largest industry in Georgia. By cutting down on the use of fuel-consuming equipment, Georgia's No-Tillage Assistance Program (NTAP) works with the agricultural sector to reduce global warming. NTAP offers funding for leasing no-till equipment such as energy-efficient terrace plows, drills with small seed attachments and acreage meters, tractors and trailers that work with these plows and drills, row crop planters, hydro-seeders, and sprig spreaders. The Resource Conservation and Development Council maintains the equipment at branches throughout the state. GEFA and RC&D bear most of the cost, but farmers pay a small rental fee. More affluent farmers have purchased their own equipment. Official estimates suggest that Georgia has saved almost 3 million gallons of fuel since the program started in 1987, reducing CO_2, NO_x, and CO emissions by tens of thousands of tons.

SEE ALSO: Agriculture; Atlantic Ocean; Energy; Florida; Transportation.

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Geospatial Technology

GEOSPATIAL TECHNOLOGY INCLUDES three different technologies that are all related to mapping features on the surface of the Earth for environmental management. They are geographical information systems (GIS), global-positioning systems (GPS), and remote sensing (RS). This is also synonymous with spatial information technology. Together, the three components of geospatial technology can track, map, analyze, and disseminate environmental management information. RS technology helps survey the entire Earth with unprecedented regularity, thus any environmental change can be noticed. Global atmospheric conditions are monitored on an hourly basis by weather satellites. RS imagery provides information on drought, vegetation, flood damage, forest fires, deforestation, and other natural disasters. GIS provides the tools to accurately map this information in both global and local perspectives. GPS technology accurately tracks the position of environmental fallout.

Geospatial information technology can play a vital role in global warming research by helping to make a connection between climate change and individual people. It is best achieved by mapping the impact of climate change at the local level through the use of satellite imagery. Thus, the public will be aware of the actual impact of global warming. Through the use of Web GIS, a virtual globe can be created and presented with environmental change information such as atmospheric, societal, and ecological changes occurring around the world. Virtual globes are a new medium for conveying information; one example available to the public is through Google Earth and Map.

Geospatial technology provides resource managers, as well as general public, with the insight and ability to react to climate change. One can monitor, map, and share the effects of: El Niño Ocean warming and La Nina ocean cooling; tropical forest depletion; the melt-down of sea glaciers in Antarctica or at the poles; vegetation monitoring through detailed knowledge of soils, erosions rates, nutrient cycles, and local agricultural practices; and water resources management through weather monitoring. With GIS, the global temperature pattern is mapped and shared among users. Researchers are using geospatial technology to quantify the carbon amount in biomass and using that information in carbon sequestration. Researchers at The Massachusetts Institute of Technology (MIT) with ESRI software have developed a Carbon Management Geographic Information System for the United States in order to capture, integrate, manipulate, and interpret data relevant to CO_2 capture and sequestration. Precipitation

One way geospatial technology can help make individuals more aware of the impact of climate change is via satellite imagery.

and rainfall pattern changes are consequences of global warming. These patterns are mapped and analyzed locally and globally.

Geospatial technology helps in understanding and mapping the patterns of vulnerability with planning climate adaptation strategies. Vulnerability analysis, or the degree to which people or the environment may be harmed, requires integrating three types of information about society and environment interactions, including: patterns of exposure to hazards, sensitivity, and resilience. Sensitivity includes the amount of damage expected from a particular event such as coastal flooding, a hurricane, or an excessive heat wave; and resilience includes the capacity to recover from the vagaries of climate change. Researchers use the spatial information technology to prepare society to withstand the challenges. Hotspot identification and analysis is a prime tool of geographic information sciences. Through geospatial technology use, governments can identify factors and hotspots responsible for global warming and climate change and locate areas affected by them. Governments can then act accordingly to save vulnerable populations. Thus, the use of geospatial technology can help in mitigating global warming problems and aftereffects.

SEE ALSO: Climate Models; Computer Models; Measurement and Assessment.

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Germany

GERMANY IS LOCATED in Central Europe, and in recent years has emerged as a leader in the fight to combat global warming. A modern nation of 82.4 million people, with a stable and diversified economy, Germany has a highly developed industrial, commercial, and agricultural infrastructure, all of which will face challenges as the climate begins to change. Like the rest of Europe, Germany expects to see more extremes in its weather patterns, with milder, wetter winters and hotter, drier summers. Steady distribution of rainfall throughout the year will likely give way to long dry periods, punctuated by sudden, heavy downpours. Most models project an average temperature increase of 0.18–0.81 degrees F (0.1–0.45 degrees C) per decade, and an increase in precipitation increase of 5–10 percent by 2050.

Agriculture will at first benefit from higher atmospheric concentrations of CO_2, and researchers do not expect any problem with crop yields in the foreseeable future, except in eastern Germany, where the sandy soil is more vulnerable to precipitation shifts. Forests, which cover a third of the country, may also fare well under rising temperatures. There is some concern, however, that precipitation extremes could stress the forest ecosystem and new insects and diseases could move as their ranges expand. Prolonged dry spells could also increase the risk of forest fires. Models predict a negligible sea level rise of 0.03–.034 in. (0.09–0.88 cm.) over the next century. Since Germany currently builds coastal structures based on an assumption of a 10–12 in. (25–30 cm.) rise over a century, this modest rise will pose no real problem. The government is planning on continuing to enhance sea walls and other defenses to protect against higher storm surges.

More intense storms could also lead to increased incidence of hail, wind, and flooding rains, putting infrastructure at some risk for damage or destruction. Shipping and air transport could also be affected by more frequent or heavier storms. While the popular summer resorts along the Baltic Sea are likely to benefit from warmer summers, the ski industry will sustain losses from warmer winters and reduced snow packs. The nation's water supply is not believed to be at risk, and there is little fear of new diseases moving into the region; in this respect, Germany will fare better than many other parts of the planet. Germany has taken a number of affirmative steps to mitigate carbon emissions and develop sustainable and renewable resources.

SEE ALSO: Agriculture; European Union; Forests.

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Ghana

LOCATED IN WEST Africa, Ghana was formerly the British colony of the Gold Coast, and has a land area of 92,098 sq. mi. (238,534 sq. km.), with a population of 23 million (2005 est.), and a population density of 215 people per sq. mi. (93 people per sq. km.). The country's economy has an extensive agricultural base, with 12 percent of the land arable, and a further 22 percent used for meadows and pasture, mainly cattle, but also sheep and goats. The cattle are responsible for some of the methane emissions. Forests cover 35 percent of the country, and the timber industry is regulated.

Ghana has had a relatively low per capita carbon dioxide emission rate, with 0.2 metric tons per person in 1990, rising to 0.37 metric tons per person by 2003. Some 77 percent of this comes from liquid fuels, the vast majority from the transportation sector, which makes up 42 percent of the country's carbon emissions. The remaining 23 percent of carbon emissions comes from cement manufacturing, and a negligible amount from solid fuels. The main reason for the extremely low per capita carbon emission rate is because 69.6 percent of Ghana's electricity production comes from hydropower, with the remainder from fossil fuels. There is also an efficient train service covering Accra, Kumasi, and Takoradi; and bus service connects the major towns.

Global warming is expected to lead to an increased rate of flooding in Ghana. This may provide the possibility for further mosquito breeding, leading to higher rates of malaria and dengue fever, and may also cause the spread of bilharzia. The Ghanian government of Jerry Rawlings ratified the Vienna Convention in 1989, and took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992. Ghana accepted the Kyoto Protocol to the UN Framework Convention on Climate Change on May 30, 2003, which took effect on February 16, 2005.

SEE ALSO: Diseases; Floods; Transportation.

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Glaciers, Retreating

THERE ARE GLACIERS in all areas of the globe. Most glaciers are found in the polar regions, but many of the Earth's tallest mountains also have glaciers. Glaciers go through life cycles. They have growing years, moving years, and retreating years. For glaciers to form, very specific climatic conditions are necessary. They are usually found where there is enough snowfall for a snow pack to permanently accumulate, where summers are not warm enough for all of the snow to melt. In some regions, such as at the North Pole, the intense cold squeezes out moisture as rain or snow before it advances to the far north. This makes the Arctic region a cold desert because the cold prevents the accumulation of snow. However, in warmer areas, the greater amount of moisture combined with sufficiently low temperatures encourage snow and the possibility of glacier formation.

There are two major kinds of glaciers: continental glaciers and valley glaciers. Continental glaciers are often called ice sheets—the glaciers in Antarctica are continental ice sheets. For practical purposes, the entire continent is locked in a single combined glacier. It is also a slow growth glacier because the low level of moisture adds only small amounts of snow each year. Alpine glaciers form in high mountain areas. In Africa, Mount Kilimanjaro has a glacial field. There are many other glacial areas such as those in the mountains of western North America and South America. New Zealand's South Island has glaciers, as do the Himalayas and the Alps in Europe.

Glaciers form because every year more snow remains than there was the previous year, because not all snow melts during the summer. As the winter snow accumulates, its weight turns the snow beneath it into ice. The snow that remains is called firn. As more snow falls, it and the snow above it compress the firn into buried layers that become thickened masses of ice crystals. In the second phase of glacier life, they move or flow. The sheer weight of the ice causes continental glaciers to move outward from a central point. As the ice is deformed internally by the weight of the ice above it, a thin layer of water forms at the bottom and the glacier then follows gravity's pull down the path of least resistance. The water may be from summer melt or from the pressure.

If the mountain slopes upon which a glacier has formed are steep, its movement may be rapid. The moving ice has internal stresses that cause fracturing into cracks (crevasses) that form at the surface of the glacier. Moving glaciers also have a dramatic impact on the environment. They scour the surface beneath them and scrape the sides of the mountain where they are flowing like frozen rivers. They crush rocks into pebbles and soil. As a glacier passes, there is erosion and then deposition of the glacial debris as moraines, drumlins, and eskers. Glaciers eventually melt and leave behind rocky debris. They also leave scoured areas, valleys, and mountainsides. The causes of glacial retreat are increases in temperatures, evaporation rates, and wind scouring that promotes sublimation. In the summertime, glaciers undergo a natural retreat in the form of ablation. A glacier will grow and move as long as more snow accumulates than melts. When there is more melting than accumulation, the glacier will eventually decrease in size or disappear.

In the northern part of North America, the glacial remnants of the last ice age are visible in many places. From New York to Labrador in the east, there are scoured mountain valleys and mountaintops. In the midwestern states and provinces, the lines of moraines and other glacial debris deposits can easily be seen from the air. Farmers as far south as Iowa plow in fields that are composed of glacial soil and where composts are easily seen. The shores of the Great Lakes provide other evidence of previous glacial activity. The retreat of the glaciers since the last Ice Age has continued slowly, until recently. Today, there is evidence of rapid melting in the alpine glaciers. The snows of Mount Kilimanjaro may disappear by 2030 if the melting continues. Other alpine glaciers in North America and in many other locations are also in retreat.

The alpine glaciers seem to be melting the fastest because they are the smallest and the most exposed to the global rise in temperatures. For example, the Franz Josef Glacier in New Zealand retreated rapidly over a 15-year period during the 1950s and 1960s. Other glaciers are also in rapid retreat such as the Quelccaya, Huascaran, and Chacaltaya glaciers in the Andes. Glaciers on tropical mountaintops are among the retreating glaciers. Photographic evidence, from as recently as 10–50 years ago, provides irrefutable proof that glaciers are retreating rapidly. The retreat of glaciers threatens the world's water supplies because snowmelt from mountain glaciers will be reduced when the glaciers are gone. The loss would also mean the loss of species that have adapted to cold water. Fish and plant that are used for food would be lost as well. Also, if the continental glaciers melt, sea levels will rise.

SEE ALSO: Glaciology; Ice Ages; Ice Albedo Feedback; Ice Component of Models.

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Glaciology

GLACIOLOGY IS THE study of the formation and movement of glaciers and their response to climate change. It included studying the past positions of glacial ice, monitoring changes in present-day ice, and forecasting the future behavior of the world's glaciers and ice sheets. Because glaciers respond directly to changes in air temperature, they are one of the key indicators of climate change on the planet. Understanding the behavior of glaciers is important to understanding the effects of climate change. Although climate change is a central focus of glaciology, this discipline also incorporates aspects of geophysics, geology, climatology, hydrology, and geomorphology.

GLACIERS AS TOOLS TO RECONSTRUCT THE PAST

The landscapes left behind by retreating glaciers can be valuable tools for glaciologists to reconstruct the past positions and characteristics of glacial ice. End moraines, for example, are formed when sediment that is eroded and transported by glacial ice is deposited at the front of the glacier in piles of rock and soil. These moraines usually mark the maximum extent of the glacial terminus, or snout. Often, glacial valleys contain numerous sets of end moraines that correspond to either the last Ice Age or smaller, more recent advances, such as the Little Ice Age in that ended in the mid-1800s. Wood that is buried in these moraines can be carbon dated to help scientists determine the age of these landforms.

Glaciers also retain evidence of past climates within layers of accumulated ice. Because snow in the accumulation zone is progressively buried, glacial ice is older toward the bed of the glacier. Glaciologists drill cores through glaciers and ice sheets to sample ice of different ages. They measure the ratios of the isotopes of oxygen and hydrogen in the ice to gain information about past atmospheric temperatures. They also extract ancient air that is trapped in small bubbles deep within the ice. This can tell scientists about concentrations of greenhouse gases, such as carbon dioxide, in past climates. The levels of methane also reveal information about the level of biological productivity in the past, while traces of sulfur are indications of volcanic activity. If the time of the eruptions is known, these layers of volcanic material can be used to help date ice cores.

The oldest ice exists deep within polar ice sheets and many ice cores have been drilled in Antarctica and Greenland. The Vostok ice core from central Antarctica, for example, dates back more than half a million years and has provided a wealth of information about past atmospheric conditions. Ice cores from alpine glaciers in the world's major mountain ranges are not as old because this ice tends to flow more quickly and is much shallower than ice in polar ice sheets. These cores however, have provided glaciologists with a wealth of information about past climate change at lower latitudes (closer to the Equator). This information is invaluable because it provides proxy climate records for many centuries prior to the first recorded measurements of atmospheric conditions.

STUDYING PRESENT-DAY ICE

Glaciers are often referred to as global barometers because they respond rapidly to changes in air temperature. They are one of the most visible indicators of climate change on the planet and, thus, glaciologists can learn a lot about the world's climate changes by monitoring the way that land-based ice is growing or shrinking.

The most common way glaciologists monitor the health of a glacier is to measure the mass balance, or water budget. The mass balance of a glacier is found by measuring the rates of ablation (melting) compared to accumulation. The difference between the accumulation and ablation for a given year describes the annual net mass balance, which corresponds to the change in glacier volume. During cooler periods, the rate of accumulation usually exceeds the rate of ablation, and during warm intervals, the reverse occurs. Glaciers respond to these changing temperatures to try to attain a neutral mass balance, where accumulation equals ablation. They do this by retreating and thinning in warmer climates and advancing and thickening in colder climates. This ongoing fluctuation in glacial ice volume has a profound effect on the amount of liquid water that is available to the hydrological cycle. For this reason, mass balance measurements are a key tool for forecasting the water supply in mountainous regions.

Ground-penetrating radar is another commonly used technique to study glaciers. Glaciologists drag the radar over the ice surface to get a picture of the shape of the topography under the glacier. Because conditions under the ice play a huge role in the flow rate and behavior of glaciers, this technique is very useful for learning about the characteristics of the ice-bedrock boundary. Scientists often measure the speed of ice flow by placing markers (such as vertical stakes) in the ice and using a global positioning system (GPS) to track their movement.

Glaciologists have developed other tools to monitor ice over very large areas, such as the Greenland and Antarctic Ice Sheets. These include the use of satellite data to measure the changing surface area of the world's ice, and laser altimetry, which is used to measure changing surface elevations. Together, these tools can be used to remotely assess the mass balance of major ice sheets. While they will not completely replace ground-based observations, these techniques are effective because they allow a large amount of data to be collected in a short time. They also cost a fraction of the amount that is required to conduct field-based measurements in remote areas.

RESPONSE OF GLACIERS TO GLOBAL WARMING

Glaciologists use their knowledge of glacial dynamics to understand how the planet's ice is responding to climate change, and to predict how this response may change in the future. Because Antarctica and Greenland house a large proportion of the world's ice, these regions are a key focus for glaciological research. These glacial systems are the largest on the planet and, while they respond more slowly to changes in atmospheric temperature than alpine glaciers, the sheer volume of ice that they contain means that they could play a central role in future sea level rise. Glaciological research in polar regions focuses on large outlet glaciers that drain ice from the interior of the giant ice sheets to the coast. Scientists monitoring these glaciers have found that the flow rate has increased over the past few decades in areas such as the Siple Coast in Antarctica. This has contributed to the loss of ice sheet mass, and the collapse of ice shelves and floating glacier tongues. It has also led to concern that these glaciers may play a major role in any future collapse of the entire Antarctic ice sheet.

Although polar regions dominate the Earth's cryosphere (snow and ice), there is also a significant amount of ice stored at lower latitudes, closer to the Equator. These alpine glaciers are concentrated in the major mountain belts of the world, such as the Andes, the Rocky Mountains, the Himalayas, and the European Alps. Because these systems are smaller than those in polar regions, they respond more quickly to changes in the climate. For this reason, glaciologists also monitor these glacial systems closely and have been making mass balance measurements for more than 100 years in alpine regions. With only a few exceptions, glaciologists have found that alpine glaciers in both the northern and southern hemispheres are experiencing widespread retreat, and some have disappeared completely.

Glaciologists also use their knowledge of the physical laws that control the behavior of glaciers, along with past observations, to try to predict how glaciers will respond to different global warming scenarios. This is usually done using physical models, which incorporate natural laws. These models cannot fully represent all of the processes that occur in glacial environments, but they aim to produce a good approximation of glacial behavior. The models are tested to see if they can mimic the behavior of present day glaciers before they are used to predict future changes.

SEE ALSO: Antarctic Ice Sheets; Climatic Data, Ice Observations; Glaciers, Retreating; Greenland Ice Sheet; Ice Ages; Little Ice Age; Vostok Core.

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Global Atmospheric Research Program (GARP)

THE GLOBAL ATMOSPHERIC Research Program (GARP) was a 15-year international research program directed by the World Meteorological Organization and the International Council of Scientific Unions.

In 1962, after the successes of the 1957/58 International Geophysical Year, the General Assembly of the United Nations formally invited the International Council of the Scientific Unions to cooperate with the World Meteorological Organization in developing a program of research on atmospheric science. The Global Atmosphere Research Program (GARP) was the result of the work of a joint ICSU and WMO committee. The program was launched in 1967.

Led by Massachusetts Institute of Technology meteorologist Jule Charney, the Global Atmosphere Research Program played a crucial role in its pioneering influence in the use of satellites for continuous, global observation of the Earth and of computers for modeling global atmosphere circulation. The program produced some visionary collaborative experiments and results, notably the Atlantic Tropical Experiment, the first major experiment of GARP, whose goal was to understand the predictability of the atmosphere and extend the time range of daily weather forecasts to over two weeks. This experiment allowed to understand how tropical weather systems are organized and their connections with the overall tropical circulation. The experiment also provided insights into variations in surface temperature and other properties of the ocean. The experiment took place in the summer of 1974 in an experimental area that covered the tropical Atlantic Ocean from Africa to South America. The work had an international scope, and involved 40 research ships, 12 research aircraft, numerous buoys from 20 countries all equipped to obtain the observations specified in the scientific plan. The International Project Office located in Senegal acted as the director of operations. The Project Office was staffed by the nations involved. The Scientific Director was from the United States and the Deputy Scientific Director was from the Soviet Union. The operational plans were drawn every day taking into account the meteorological situation and each ship and aircraft carried out the plan. The data collected were analyzed by the nations participating in accordance with an overall plan and made available without restrictions to all scientists in the world. Research using these data still goes on today, more than three decades later, and it is estimated that over a thousand papers have been published based on the data collected during this short period in 1974. The experiment involved the world's best scientists, all types of engineers, technicians, pilots, ship captains, logistics specialists, computer specialists, as well as senior policy makers from science agencies and foreign ministries in a large number of countries. The experiment led on to the highly successful 1979 Global Weather Experiment which paved the way for the scientific foundation to restructure the WMO's operational World Weather Watch. Under Charney's leadership, GARP was the first truly international research program involving climate. Charney had always argued in favor of international cooperation in meteorology in spite of the divisive political climate of the Cold War years. The important goals reached by GARP did justice to his assertion that the lack of global observations and exchange between nations prevented examination of the global side of meteorology.

INTERNATIONAL RESPONSE

As a result of these efforts within GARP, in 1978, ICSU, WMO and United Nations Environment Program jointly organized an international workshop on climate issues, hosted by the International Institute for Applied System Analysis (IASA) in Vienna. This led to the first World Climate Conference in Geneva the following year. 300 scientists from all over the world analyzed the scientific evidence, and, for the first time, confirmed the long-term effects for global climate of atmospheric CO_2 levels. They also stressed the important role of the oceans as a major factor in the natural variability of climate on seasonal to inter-annual timescales. The ICSU and WMO closed the Global Atmosphere Research Program in 1980 and set up the World Climate Research in its place. The research carried out during GARP laid down the scientific basis for the achievement of global and long-range weather forecasts.

SEE ALSO: Geospatial Technology; International Council of Scientific Unions (ICSU); International Geophysical Year (IGY).

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Global Environment Facility (GEF)

GLOBAL ENVIRONMENTAL FACILITY (GEF) is an independent financial organization that provides grants to developing countries for projects that benefit the global environment and promote sustainable livelihoods in local communities (mainly in six environmental areas: biodiversity, climate change, international waters, land degradation, the ozone layer, and persistent organic pollutants). After the Rio Convention, GEF was established to finance sustainable development in developing countries with funds from developed nations.

GEF has 177 members (also known as the GEF Assembly), which includes developed and developing countries, as well as those countries with economies in transition. Each country has a GEF representative known as a Focal Point, a designated government official who coordinates matters related to GEF governance to ensure that projects meet a country's priorities. The GEF Assembly meets once every four years to review the policies and operations of GEF. The GEF chief executive officer and chairperson leads the GEF Secretariat, which coordinates the implementation all GEF projects and programs.

The GEF Council, representing 32 constituencies (14 from developed countries, 16 from developing countries, and two from countries with transitional economies), functions as an independent board of directors, with primary responsibility for developing, adopting, and evaluating GEF programs. The council meets twice each year for three days and also conducts business by mail. All decisions are by consensus and its open-door policy towards non-governmental organizations and representatives of civil society makes GEF unique among international financial institutions.

The GEF Assembly, Council, and Secretariat approve of projects and policies, but the GEF does not implement projects. The United Nations Development Program, the UN Environmental Program, and the World Bank are some of the major agencies that are responsible for implementing and managing GEF programs. Other international organizations like the African Development Bank, Asian Development Bank, European Bank for Reconstruction and Development, UN Food and Agriculture Organization, Inter-American Development Bank, International Fund for Agricultural Development, and UN Industrial Development Organization have been added to the list of organizations executing GEF projects.

GEF-SUPPORTED PROGRAMS

GEF supports a number of programs. Renewable energy is one of the most promising substitutes for fossil fuels, which are responsible for the largest share of greenhouse gas emissions. GEF helps countries remove barriers to developing markets for renewable energies wherever cost-effective. GEF funds projects which promote the use of renewable energy, such as small hydropower generating plants, and the development of cost-effective solar voltaic cells. Such opportunities can be found in on-grid and off-grid situations, as well as in heating for industrial and other applications using renewable energy sources.

Using less energy saves money, and reduces greenhouse gas emissions. GEF supports market transformation of energy-efficiency appliances and widespread adoption of energy-efficient technologies in industry and building sectors.The transportation sector is the fastest growing source of greenhouse gas emissions. GEF supports projects that promote a long-term shift towards low emission and sustainable forms of transportation. Eligible activities include things such as: public rapid transit, which encompasses bus rapid transit, light rail transit, and trolley electric buses; transport- and traffic-demand management; non-motorized transport, and better land-use planning.

The Climate Convention guidance to the GEF on adaptation has evolved through a series of staged approaches. Originally, the GEF supported initial studies, vulnerability and adaptation assessments, and capacity building. More recently, the UN Framework Convention on Climate Change has negotiated with the GEF to support pilot and demonstration projects in the field of adaptation. Under its strategic priority Piloting an Operational Approach to Adaptation, the GEF supports projects that provide real benefits and may be integrated into national policies and sustainable development planning. In addition, the GEF supports adaptation activities through the Least Developed Country Fund and the Special Climate Change Fund.

In addition to renewable energies and energy efficiency, new technologies are critical to help prevent dangerous levels of greenhouse gas emissions, while allowing for economic development. GEF provides support for such new technologies that are not yet cost effective. The current portfolio ranges from large-scale solar power plants, to distributed power generation in fuel cells, to building-integrated solar photovoltaics.

Donor countries, usually developed countries such as the United States and Japan, contribute funds to GEF. Since 1991, GEF has provided $6.8 billion and generated over $24 billion in co-financing from other sources to support over 1,900 projects that produced global environmental benefits to more than 160 developing countries and countries with economies in transition. In 2006, 32 donor countries pledged $3.13 billion to fund operations for four years.

SEE ALSO: Alternative Energy, Solar; Energy, Renewable; Framework Convention on Climate Change; Greenhouse Gases.

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Global Industrial and Social Progress Research Institute (GISPRI)

THE GLOBAL INDUSTRIAL and Social Progress Research Institute (GISPRI) is located in Tokyo, Japan. According to the Institute, "GISPRI's core purpose is to provide research and analysis in the area of global environment and natural resources, international systems, interaction between industry/economy and culture/society to deliver comprehensive policy proposals for the international community, both at home and abroad."

The Japanese Minister of International Trade and Industry established GISPRI December 1, 1988, in response to the recognition that Japan was emerging as a leading global nation and therefore had a responsibility to the international consortium. Japan aimed to increase research exchange. There are three main initiatives of GISPRI: Joint Research, Policy Proposals, and Research and Study. Joint Research encompasses collaboration between Japanese institutes and research institutes abroad, to share knowledge as well as human resources. Policy Proposals are arranged by the Global Industrial and Social Progress Policy Forum, and focus on international issues that Japan can address locally or through international cooperation. Research and Study is the main branch that is concerned with the environment; specifically, this branch examines the relations between industry and society, and how these interactions impact the global environment. Other, smaller initiatives of GISPRI include local and international symposia and the GISPRI newsletter.

The umbrella of GISPRI's Research and Study includes two chief areas. The first area is International Order, Culture, and Society (IOCS). IOCS is concerned with "sustainable social structure and its governance." The goal of those working with IOCS is to develop communication between developed and developing countries, to foster cooperation that will protect the environment as industrialization spreads. A major study of this area analyzed "Japan and Chinese Economy After its Accession to the WTO," 2002–03. An additional research focus under IOCS is the emerging relationship between industrialization and culture, especially the significance of nonprofit organizations (NPOs). In 2003, Japan's prime minister was presented with the results of research entitled "The Statement for the Cooperation between NPOs, Businesses, and Governments for Building a New Socioeconomic System."

The second area under the Research and Study umbrella is Global Environment and Resources (GER). GER research focuses on the necessity for sustainable resource management, recognizing the fact that if society continues to use up resources at an increasingly rapid rate, the cultures that depend on those resources will be faced with a shock once the resources are exhausted. To thwart such an occurrence, GISPRI, through its GER research, has organized a 2050 Sustainability Research

Committee (SRC). This committee will examine ways to align development with environmental responsibility and sustainability.

Another principle focus of the GER researchers at GISPRI is to develop ways to include the United States, currently the world's largest emitter of greenhouse gases, and other emitting nations to the path of sustainable environmentalism during economic development. The GER works to promote environmental responsibility, utilizing Kyoto Mechanisms that came from the Kyoto Protocol of 2005. GISPRI is managed by an executive director and other directors, most of whom serve on the boards of leading electric, gas, and other corporations in Japan. A chairman oversees the executive director and other directors. The Intergovernmental Panel on Climate Change released its Fourth Assessment Report in 2007, and GISPRI participated in the generation of this report.

SEE ALSO: Greenhouse Gases; Japan; Kyoto Mechanisms; Kyoto Protocol; Policy, International.

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Globalization

GLOBALIZATION'S BEGINNINGS ARE located in the theories of modernization and dependency from the 1950s and 1960s. The notion of globalization implies the internationalization of the world's communities in economic, cultural, environmental, and financial ways. Globalization can be understood as a series of processes. One of these processes is the way in which social, economic, political, and economic activities occur across national boundaries. The decisions that affect people in one part of the planet, will affect societies in other areas of the globe. Globalization is also the process of consolidation of all the networks between societies linked by global systems such as the global economy, digital technology, and culture. Global interactions are enhanced by global telecommunications systems, especially through satellite technology. Finally, globalization can be understood as a magnification of the impact of events. For example, if a hurricane hits the United States or a tsunami hits Asia, the whole world becomes aware of this crisis and its importance is amplified.

There are also many theories of globalization. One of these is the notion of hyper-globalization. Proponents of this theory believe that globalization is a political development that has emerged due to the fact that describing the world in terms of nation-states is no longer appropriate.

As all nations are subject to the vagaries of the global market, the idea of boundaries becomes defunct. Globalization has de-nationalized economies, and has made all nations participants in a global world. Hyper-globalizers believe the shift to globalization represents a fundamental divide from previous social, political, and social arrangements.

Others argue that globalization is not a new development, and that nation states still have an important role to play in international politics. They argue that nations have always been economically interdependent, and that global world trade therefore simply serves to intensify individual connections. Proponents of this perspective of globalization ultimately argue the idea of globalization as a Western construction designed to embed Western supremacy and economic dominance. Others take a transformalist position and view globalization as a powerful influence, transforming modern society economically and politically. A new world order is emerging, in which state sovereignty has to adapt to new world conditions and where global institutions such as the United Nations, European Union, or the World Trade Organisation need to be incorporated into national decision-making processes.

At a cultural level, globalization has led to what some term the homogenization of culture, that is, a diminishing of cultural diversity due to global trends being set and transmitted through technology, art, fashion, and film making. The global influence of stations such as CNN have led to a merging of many different cultures into one that is predominantly influenced and shaped by the Western world. Economically, the production of goods has become more globalized. For example, car parts are manufactured in different countries, and items such as cars and fridges are becoming transnational goods, which all societies can access with money.

While this has advantages, it also can create conditions of global uncertainty and impacts across the world if one market or another fails or stumbles. For example, if there is a housing and interest rate crisis in the United States, this will have impacts on economies in other countries such as Britain, Australia, and New Zealand. Some argue that the world is also moving towards a global political order, based on liberal democracy and with a mutual commitment to market capitalism and individual rights. Global institutions such as the United Nations already rule on many international issues, such as human rights and the environment.

GLOBALIZATION AND THE ENVIRONMENT

The impact of globalization has put added pressure on the environment. For example, World Bank figures show that deforestation for cropping accounts for up to 20 percent of the world's global carbon emissions. Increasing trade has also encouraged fishing, destruction of forestland, and the spread of pollution to previously unrecorded levels. There are serious equity issues embedded in the treatment of the impact of these environmental issues, and the distribution of the impact.

Detractors of globalization further argue that the free trade system that is a characteristic of globalization has particular impact on the environment, because it creates a demand for and a monopoly around genetically modified products. Moreover, the trend of globalization to patent and appropriate intellectual property rights within market mechanisms causes loss of species diversity, and imposes a monoculture on the world and its environment.

Climate change is an issue that affects all societies on the planet. Global warming is a result of global agricultural and industrial processes, all of which serve to meet the needs of the global marketplace. The consequences are also global, with all regions of the world predicted to experience some form of change as a result of global warming. One of the characteristics of projected climate impacts is that the effects will not be evenly distributed. For example, many developing countries such as Bangladesh that do not proportionally contribute largely to the global emissions will sustain critical problems as a result of flooding from sea level rise. Global warming has the potential to cause economic and social disruption around the globe, but the main burden of negative impacts will fall on poor developing tropical countries, while more affluent and developed countries in temperate zones will experience fewer or less severe negative impacts. Some reformers advocate a global climate agenda that ensures that global equity issues are addressed.

ADDITIONAL ENVIRONMENTAL PROBLEMS

Other examples of global environmental problems include acid rain, the dumping of wastes in international waters, and the depletion of climatic ozone. The loss of species, biodiversity, and resources will continue to have global implications. Global institutions are working to resolve environmental problems. Many of these institutions have emerged within the umbrella of the United Nations (UN) and include agencies such as the International Union for the Conservation of Nature, the UN Educational, Scientific and Cultural Organisation, and the UN Environment Program.

Some examples of joint commitments made in the interests of the global community include the Kyoto Protocol for Climate Change, the Montreal Convention (which dealt with ozone issues), The UN Law of the Sea (1972), and the Basel Convention (1989) that binds countries to agreements relating to the transport and disposal of hazardous wastes.

SEE ALSO: Ethics; Policy, International; United Nations; United Nations Development Programme (UNDP); United Nations Environment Programme (UNEP).

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Global Warming

GLOBAL WARMING IS a term that is used to refer to an increase in Earth's average surface temperature. It is due mostly to the release of greenhouse gases (GHGs) into the atmosphere by human-fuelled activities such as increased fossil fuel consumption leading to the release of carbon dioxide (CO_2), the increasing use of automobiles, the use of nitrogen base fertilizers, and rearing and breeding large methane-belching cattle. Greenhouse gases such as carbon dioxide, nitrous oxide, water vapor, halocarbons (chlorofluorocarbons and hydrofluorocarbons), methane, and ozone have the capability of absorbing infrared radiation from the Earth's surface, thereby altering the heat balance of the Earth.

The gases later warm the Earth's surface by emitting trapped energy. When GHGs absorb radiation, the stratosphere becomes warm and then re-emits infrared radiation back to the Earth's surface. This warming of the Earth's troposphere is commonly known as the greenhouse effect. Global warming potential (GWP) is usually expressed in relation to carbon dioxide, which is given a relative global warming potential of one. Methane, nitrous oxide, and hydrofluorocarbons are assigned a GWP of 23, 296, and 12,000 respectively. This means that methane is 23 times as potent a GHG as carbon dioxide, and nitrous oxide is 296 times as potent as carbon dioxide.

Many human processes ranging from industry, transportation, power stations, agriculture, fossil fuel development and usage, to residential and commercial activities have variously led to the production of high amounts of greenhouse gases, such as carbon dioxide, methane (CH_4), nitrous oxide (N_2O), water vapor, and chlorofluorocarbons (CFCs). Of these activities, agriculture contributes the largest amount of methane (40 percent) and nitrous oxide (62 percent), while the combination of industrial processes, power stations, fossil fuel processing and development, with residential and commercial activities contributing over 82 percent of the total carbon dioxide produced by the entire human activities.

CARBON DIOXIDE

Carbon dioxide is the primary driver of global warming. It is freely available in the Earth's atmosphere, released by man and other animals, and used up by plants in the processes of respiration and photosynthesis. CO_2 is a product of the combustion of carbon related compounds such as fossil fuels and organic matter; it can be produced synthetically by acidification and decomposition of metallic carbonates, among other methods of chemical reaction. However, CO_2 is produced industrially through different processes of combustion of carbonaceous fuels, decomposition of calcium carbonates, fermentation, and from gas wells. It can also result from the oxygenation of the product of the incomplete combustion of automobile and generator fuels.

It has great industrial uses in the food, oil, and chemical industries. Of all the GHGs, it occupies the center stage of the world's basic discussion on global warming and climate change because of its effect on the environment. Human activities have contributed to a significant increase in atmospheric levels of CO_2. These concentrations have increased by 33 percent, from around 280 parts per million (ppm) as recently as the late 1700s, to 316 ppm in 1959, to 373 ppm in 2002. In the stratosphere, it is highly stable and could exist in the atmosphere for more than 100 years. This stability period means it cannot be eliminated from the Earth's atmosphere, but can only be indirectly reduced by reducing the activities producing it.

Carbon dioxide's importance in greenhouse effect is based on its ability to absorb much of the electromagnetic radiation below the visible light wavelength, trapping heat radiation that attempts to escape from the Earth, thereby causing an increase in the Earth's temperature. It is reported that doubling of CO_2 produces a temperature rise between 2.7–9 degrees F (1.5–5 degrees C), leading to a warming of between 0.9–3 degrees F (0.5–1.7 degrees C). Also, it has been established that CO_2 has significant effect in increasing the global surface temperature of the Earth's atmosphere, and of the GHGs (excluding water vapor), it is the most powerful, with a radiative forcing of 1.5 $W/m.^2$.

METHANE

Carbon dioxide is not the only GHGs increasing in its stratospheric level. Methane is also increasing in concentration. Methane is considered as an important greenhouse gas. It is believed to be the second most powerful greenhouse gas (excluding water vapour), and its concentration in the stratosphere affects the Earth's heat balance, and thus temperature. Methane

Major research findings have pointed to changes in climate temperature, including widespread melting of snow and ice and rising global mean sea level. Mountain glaciers, snow cover, and Arctic sea ice levels have also fallen.

is a natural gas with a chemical compound consisting of one carbon and four hydrogen atoms bonded covalently together, the simplest alkane, relatively abundant and gaseous at normal temperature and pressure. The Earth's crust contains huge amounts of the gas, produced anaerobically by biomethanation, and also released to the atmosphere by mud volcanoes. It is colorless and odorless, a major component of fossil fuel, about 97 percent by composition, having different uses ranging from industry, power generation, to manufacturing processes. Apart from it being a major component of natural gas, it is obtained from the anaerobic digestion of organic matter, manure, sewage, and solid and biodegradable wastes.

In the Earth's atmosphere, it adds to global climate alteration. Although not as stable as CO_2, having a stability period of 10 years, it is however, 100 times stronger than CO_2 in its greenhouse effect. A ton of methane is reported to have 25 times the temperature effect of the same size of CO_2 on the environment after every 100 years, and accounts for 20 percent of the total radiative forcing of all the combined GHGs. However, the cumulative effect of CO_2 is more than that of methane because of the enormous amount of it present in the atmosphere, with methane having a large effect on the environment over a short period of 10 years in comparison to the small effect of CO_2 over a longer period of over 100 years. The effects of methane include the absorption of infrared radiation, affecting the troposheric and stratospheric ozone (O_3).

NITROUS OXIDE

Nitrous oxide is another GHGs whose atmospheric levels have continued to rise because of human activities. It is also referred to as dinitrogen monoxide and is a colorless, odorless, covalently bonded gas that can be produced synthetically and biologically. It is a by-product of feedlots, auto emissions, and modern agricultural practices, whose atmospheric levels have increased by 17 percent since the mid-16th century. It is also emitted from processes ranging from wastewater treatment, gas combustion, industrial processes, fertilization, and microorganism's reactions in soil and in the ocean. It has a stability period of 150 years, and is about 200 times as potent a greenhouse gas as CO_2.

Today, human-fuelled activities contribute 33 percent of nitrous oxide emissions into the atmosphere. Although the quantity of N_2O present in the atmosphere in comparison to CO_2 is very small, its effect as a greenhouse gas is much more potent; one molecule of N_2O has a heat absorbing ability equivalent to 200 molecules of CO_2. It is reported that while NO_x is partially responsible for increased ozone (O_3) production as part of photochemical smog production in urban areas near the Earth's surface, it also plays a role in its destruction in the stratosphere, where the O_3 would have been helpful in absorbing excessive ultraviolet radiation. N_2O is converted to NO in the atmosphere, which on reaching the stratosphere reacts with O_3 to result in its depletion. It is however noted that the gas absorbs thermal radiation at the same wavelength as methane. The concentration of oxide in the atmosphere is presently increasing above the pre-industrial level at a rate of approximately 0.25 percent per year, due largely to anthropogenic biomass burning and bacterial oxidation of fertilizer nitrogen; it absorbs light in a broad continuum from and including 260 nm to 182 nm.

WATER VAPOR

Water vapor is also considered a greenhouse gas. This is the gaseous form of liquid water, and is enormously abundant in the atmosphere, much more than other GHGs. There have been a lot of research arguments on the impact of water vapor on the atmosphere, but over the years, it has come to be known as the most important greenhouse gas. It strongly absorbs thermal radiation with wavelengths less than eight μm and greater than 18 μm.

HALOCARBON GASES

Another group of greenhouse gases, the halocarbon gases (CFCs) are synthetic-anthropogenic molecules that contain chlorine, fluorine, and carbon atoms bonded together. They add greatly to the atmosphere's heat-absorbing ability by actively absorbing radiation in the atmospheric radiative window of seven to 12 μm. They are non-soluble, inert, and have long stability period, capable of being broken up by photolysis to release chlorine, which in turn damage the ozone layer. Of all the chlorofluorocarbons, the significant CFCs are CFC-11 (trichlorofluoromethane) and CFC-12 (dichlorofluoromethane). The atmospheric residence time of CFC-12 is 102 years and its 100-year GWP relative to CO_2 is about 8,500, while CFC-11 has stability period of 50 years and a 20-years GWP of 5,000. Some countries like the United States and Sweden have taken steps to reduce the quantity of CFCs in the atmosphere in line with the Montreal protocol.

There are other gases that adversely affect the Earth's atmosphere, creating global warming concerns. Such gases include per-fluorocarbons (PFCs), sulphur hexafluoride (SF_6), and pollutants such as SO_2. SO_2, on the other hand, is a gas that emanates as a result of human activities from combustion of coal and the exhaust of cars. It acts to cool the atmosphere, contrary to other GHGs, however, its effects as a regulatory gas to the global warming effects of the GHGs is limited by its life span on the Earth's surface, which is not more than a week.

GLOBAL WARMING EFFECTS

Human-induced warming over recent decades is already affecting many physical and biological processes on a global scale. Major research findings have pointed to changes in climate temperature, including increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global mean sea level. Due to this changing climatic condition, much of the world's population is expected to face serious water shortages by the turn of the century, food production is expected to decline in low-altitude areas, and desertification will lead to food shortages. There are reported cases of increased intensity of tropical cyclones in the north Atlantic within the past 25–30 years, and storms with heavy precipitation have also increased. Mountain glaciers, snow cover, and Arctic sea ice have also fallen.

The report of the Intergovernmental Panel on Climate Change (IPCC) in April 2007 reveals that the rising temperature of the global environment may result in the altered spatial distribution of some infectious disease vectors, meaning that the rate of transmission of such disease like malaria in Africa and other parts of the world could increase. It is also reported that diseases such as those carried by insects, ticks, and other insect vectors are likely to be affected by environmental changes because these creatures are themselves very sensitive to vegetation, temperature changes, humidity, and rainfall.

There is the likelihood of continuous enhanced coastal erosion, increased farming seasons, increased plant growth, and increased flooding as currently observed in different parts of Asia, western Europe, and west Africa. There would also be more hot days and nights, and extreme variations in the amount of rainfall across the globe, where high altitude and generally wet places will tend to receive more rainfall, while tropical regions and generally dry places will probably receive less rain. This increase in rainfall will come in the form of more rainy days; in between these periods there will be longer periods of light or no rain, bringing about increasing frequency of drought. Hurricanes will also probably increase due to warmer ocean surface temperature.

Animal and plant species have begun dying off or changing sooner than predicted because of global warming. Global warming might spark the mass extinction of endangered species, eroding biodiversity. Several scientific reports have pointed to trends of animal populations moving northward as a result of alteration to their natural habitat; of species adapting slightly because of climate change; of plants blooming earlier; and of an increase in pests and parasites.

Global warming will potentially stifle life-giving microscopic plants that live in the surface layer of the marine ecosystems, thereby cutting marine food production and accelerating climate change. Phytoplankton are not only the foundation of the marine food chain, but every day they take more than 100 million tons of CO_2 out of the atmosphere. As global warming raises the surface layer of the ocean, it becomes lighter and, therefore, separated from the cooler depths from which the phytoplanktons get many of their nutrients. This reduces their assemblage, not only reducing the food in the oceans, but also reducing the amount of CO_2 they take from the air and, therefore, accelerating the climate warming process.

INDIRECT EFFECTS OF GLOBAL WARMING

Apart from the direct effects of global warming on the global climate, there is the issue of the indirect effects of it on the sociological, political, and economic climate of nations. It is reported that the social, economic, and physical infrastructural indices of a geographical region has evolved from the adaptation of all that region's society to the prevailing climate and to the hydrological conditions brought about by that climate over a finite time period. In cases, therefore, when the frequency of occurrence and magnitudes of phenomenon such as typhoons, floods, and droughts have altered the habitability of that region and affected the social and economic activities of its dwellers, there is bound to be the development of unwanted and unexpected stresses.

Due to these direct effects on the global climate, nations worst hit by some or few of the elements of global warming effects are most likely to suffer from increasing under population, as gradually, people begin to move away from areas of incessant flooding, drought, and erosion, to areas of calmness and freedom from such environmentally dictated occurrence. This would invariably lead to the overpopulation of neighboring towns, cities, and countries, creating attending situations associated with such phenomenon. Issues of over population have over the years been linked to over-use of available natural and developed resources. As the average population of a place begins to grow, higher demand would begin to be placed on living factors such as energy, water, space, food, good health facilities, shelter, and security. The result is that more waste would be produced due to increased human presence and activities.

There would also be the challenge of higher demand placed on available water resources, and serious deforestation as a result of people felling trees and clearing grounds for shelter and other human related activities. Forest reserves would be taken over by people, and wildlife would be seriously endangered. This could lead to the problem of erosion and water pollution, as particles of erosion could be washed into fresh water resources, creating an additional need for governments to clean up the water and make it safe for domestic use. In effect, this would bring about a depletion of available resources, carrying with it some environmental issues of degradation and mismanagement.

The problem of the environment would be further aggravated, creating a recycling of environmental disturbances and furthering the effects of global warming. In Africa and some other developing countries, over population has resulted in serious famine and poverty; there have also been cases of close to zero health care, with people suffering from serious curable and incurable diseases. More so, as people migrate from areas hit by global warming impacts to other places, there could be a greater instance of disease transfer. Diseases such as polio and malaria, which the world has been trying to curb, could upsurge. Human immunodeficiency virus/acquired immune deficiency syndrome (HIV/AIDS) is another human vectored disease that could increase due to huge migration of people. There could also be greater territorial wars, international disputes, and disrespect for boundary policy if the impacts of global warming are not addressed globally. Thus, global warming does not only affect the climate of nations; it also affects the sociological, political, and economic standards of nations.

SEE ALSO: Carbon Dioxide; Climate Change, Effects; Greenhouse Effect; Greenhouse Gases; Policy, International.

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Goddard Institute for Space Studies

THE GODDARD INSTITUTE for Space Studies (GISS) is part of NASA's Goddard Space Flight Center. It is one of the laboratories in the Earth Sciences Division and is a component of Columbia University's Earth Institute. The focus at GISS is the study of global climate change. Dr. Robert Jastrow established GISS in 1961 to conduct basic research in the science of space. He served there until 1981. GISS's early tasks included the study of other planetary atmospheres using data collected by space probes and images captured by earthbound telescopes. The success of these endeavors led to its development into a world-class center for atmospheric modeling of Earth's atmosphere. Today, the mission of GISS embraces the scientific study of climate change.

Dr. James Hansen currently directs the institute, with research broken up into two major areas: human influences, and natural changes in the environment across varying time frames. The second is categorized by long-term events, such as long-term ice ages, annual occurrences such as El Niño, and isolated events like volcanic explosions. Study in these areas and analysis across a wide range of timeframes fulfills key research objectives of GISS, the prediction of atmospheric changes and the impact on climate change. Tools relied upon include satellite and spacecraft observations. The data gleaned from this process defines the input to developed models used to predict oceanic, landmass, and atmospheric interactions. Coupled with previous information on Earth's changing climate and 20th century insights into the observed workings of other planetary atmospheres, GISS analysts are beginning to understand the evolution of Earth's atmosphere.

In support of this role, GISS allocates its resources across program areas, which include atmospheric chemistry, planetary atmospheres, Earth observations, radiation, climatic events, and model development. GISS resources include personnel at the Goddard Space Flight Center who coordinate with NASA colleagues at the Laboratory for Hydrospheric and Biospheric Sciences, the Laboratory for Atmospheres, and the Earth Observing System science office. Links with Maryland area universities, in particular with

Columbia University, provide almost half of the talent needed to fulfill the GISS mission of providing the critical perspective from space in the quest to monitor and predict climate change. Columbia University supports NASA through their Center for Climate Systems Research (CCSR), the Earth Institute, and the Lamont-Doherty Earth Observatory.

In May 2007, GISS publicly reinforced the fact that greenhouse gases are directly responsible for moving Earth's climate to "critical tipping points." The conclusion, derived from paleoclimate history, satellite observations, and use of predictive climate models, suggests dire consequences for Earth. GISS posits that Arctic ice, the West Antarctic ice sheet, freshwater sources, and the habitat of many species, such as the polar bear, are at risk due to global warming. The spring study determined that the 0.6 degree C rise in temperature over the past 30 years is primarily due to the corresponding increase in greenhouse gases. GISS reported that carbon dioxide concentrations in the atmosphere, for example, are rising by about two parts per million each year. The tipping point occurs when amplified effects brought on by incremental warming suddenly accelerate this steady rise. The resulting rapid rise in temperature occurs as sunlight is absorbed to a greater degree by the dark ocean waters and is not reflected back into space by the disintegrating ice sheets.

Another study published in May 2007, assists meteorologists with future temperature projections. GISS researchers predict that by the 2080s, summertime heat in the eastern United States will rise from an average in the low-to-mid-80s to one in the low-to-mid-90s. GISS notes that the past few decades have witnessed most locations in the world warming, with areas of high latitude particularly feeling the temperature rise. These warming trends are felt most in Alaska, Siberia, the Arctic Ocean, and the Antarctic. In fact, the five warmest years since the end of the 19th century are 2005, 1998, 2002, 2003, and 2006.

GISS conducts numerous other measurements and studies related to climate change. Some recent work includes investigations into how aerosol pollutants affect climate, the possibility of a massive carbon dioxide release from the ocean depths into the atmosphere, and the positive effects of dust and other pollutants blocking sunlight. The organization provides the science behind climate change to enable policy makers to enact the best legislation to mitigate the potential devastating affects of global warming.

SEE ALSO: Columbia University; Hansen, James; National Aeronautics and Space Administration (NASA).

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Gore, Albert, Jr. (1948–)

FORTY-FIFTH VICE PRESIDENT of the United States from 1993 to 2001 in the Democratic administration of President Bill Clinton, Al Gore's political career climaxed with his nomination to run as the Democratic candidate for the presidency in the 2000 election. In one of the most divisive elections in American history, Gore won the popular vote by a margin of more than 500,000 votes, but lost the Electoral College (271–266) to his Republican opponent George W. Bush.

After his failure to win the presidency, Gore, who has always been concerned with green and environmentalist issues, has devoted most of his time to ecological causes. He has focused particularly on global warming with his Academy Award-winning documentary *An Inconvenient Truth* (2006), and with the organization of the Live Earth benefit concerts in July 2007. Because of his role in bringing the problem of global warming to public attention, Gore has been nicknamed, not always flatteringly, the "Noah of Modern Times," and "The Environment Evangelist." His commitment against global warming made him a co-winner of the Nobel Prize for peace in 2007.

Gore was born on March 31, 1948, in Washington, D.C. His father was a Democratic congressman and senator from Tennessee. Gore attended St. Albans School and, in 1965, he enrolled at Harvard University, majoring in English, but later switching to government. He graduated with honors from Harvard in June 1969 with a Bachelor of Arts degree in government. Gore was then recruited into the Army and was

Albert Gore, Jr., has sometimes been called "The Noah of Modern Times," and "The Environment Evangelist."

sent to Vietnam as a military reporter. Upon his return to the United States in 1971, he started to work for the Nashville newspaper *The Tennessean*, and enrolled at Vanderbilt University to study philosophy and law.

Gore was elected to the U.S. House of Representatives starting in 1976 for three consecutive terms before winning a seat in the Senate in 1984. In 1991, he was among the 10 Democratic senators who voted in favor of American military involvement in the Persian Gulf War. The following year, Bill Clinton, the Democratic presidential nominee, chose Gore to be his running mate, and Gore became vice president following Clinton's victory against George Bush in 1992.

In 1993, Gore was instrumental in engineering the passage of the North American Free Trade Agreement. In the 1990s, Gore launched the GLOBE project, an educational scheme that made extensive use of the internet to make students aware of environmental problems. He also campaigned, although unsuccessfully, to have the Kyoto Treaty ratified by the U.S. Senate. He symbolically signed it in November 1998.

In June 1999, Gore announced his intention to run for the presidency. As a moderate Democrat, he focused his campaign on themes such as the economy, healthcare, and education. As his running mate, Gore selected Senator Joseph Lieberman, the first Jewish American to be on the presidential ticket. The election proved one of the closest in American history. During the election night, Florida became the key state as the candidate who would get the state's 25 electoral votes, would also have a narrow majority in the electoral college. Gore initially conceded defeat as the state was assigned to Bush by television networks, but, later in the same evening, he withdrew his concession, enthused that returns from Florida pointed to an increasingly slim margin for Bush.

For five weeks, the election results remained undeclared as the two candidates fought legal battles for a possible recount of the votes. Although the Florida Supreme Court passed a resolution in favor of Gore's demand for a recount, the Democratic candidate publicly conceded the election after the Supreme Court of the United States in *Bush v. Gore* ruled 5 to 4 that the Florida recount was unconstitutional and that no constitutionally valid recount could be completed by the December 12 deadline, effectively ending the recounts. Gore strongly disagreed with the court's decision, but decided to offer the concession of defeat for the sake of the American nation.

After his defeat, Gore refused to run again in the 2004 presidential election and has instead devoted his efforts to campaign for the preservation of the environment and to spread awareness about global warming.

In 2004, he launched Generation Investment Management, a firm that invests in companies taking a stand on global issues such as climate change. In June 2006, Gore founded the Climate Project (TCP), based in Nashville, Tennessee, to increase public awareness of the climate crisis at a grassroots level throughout the United States and abroad. Gore came to the forefront when he starred in the documentary *An Inconvenient Truth*, directed by Davis Guggenheim, where he argued that global warming cannot be regarded as a merely political issue, but should be treated as a moral challenge. The documentary intertwines events in Gore's life and his increasing commitment to environmentalist causes with data on the evidence of anthropogenic global warming. Released in May 2006, the film went on to become one of the highest-grossing documentaries in American history. It was well-received by both film critics and scientists, although global warming skeptics such as Reid Bryson have criticized it as an over-exaggeration. The documentary is used in science school curricula around the world. Gore also authored a companion book to the film which became a bestseller.

On July 7, 2007 Gore was one of the chief organizers of the Live Earth concerts, which took place on all seven continents to lobby individuals, governments, and corporations to take actions to solve the global warming problem. The event reached an unprecedented audience through internet and television broadcasting, but was disapprovingly dubbed as "Private Jets for Climate Change," for the amount of emission caused by the transportation of the bands and the audiences. Gore was also criticized as political opponents pointed out that the event would launch his 2008 presidential candidacy, a fact that he has vehemently denied.

SEE ALSO: *An Inconvenient Truth*; Bryson, Reid; Clinton Administration.

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Greece

OCCUPYING THE SOUTHERNMOST part of the Balkan Peninsula and more than 1,400 islands, Greece is an ancient land of great beauty and diversity. The culture of classical Greece was a shaping force in the art, literature, philosophy, and politics of the Western world. Modern Greece is a nation of 11 million people, 60 percent of whom live in urban areas. Athens alone is home to more than three million, and more than 50 percent of Greek industry is located in Athens. The population explosion into Athens and other urban areas that began in the mid-20th century has intensified concerns about air pollution and its effects on human health and the environment.

The Kyoto Protocol, to which Greece is a signatory (along with more than 20 other international environmental agreements), allowed the country to increase CO_2 emissions 25 percent 1990–2010, but Greece has already exceeded the allowed increase and is expected to generate an excess 15 million tons beyond the target of 139 million by 2010. An increase of nearly double the maximum allowed is predicted by 2020. Coal-burning thermoelectric stations produce approximately 66 percent of Greece's electricity. During a period when other nations have built nuclear power plans and/or exploiting renewable sources of energy, Greece's use of coal for electricity production has increased. The World Wildlife Fund has designated two of the nation's power stations, Agios Dimitrios and Kardia, as the dirtiest in Europe; they produce the largest number of grams of CO_2 per kilowatt-hour. These plants and others in Greece burn lignite, or brown coal, which produces higher levels of CO_2 emissions than black coal.

The European Union (EU) has challenged Greece's violation of its greenhouse gas emissions allowance and promised consequences if the goal of 20 percent energy from renewable sources by 2010 is not met. A 2006 Yale University study ranked Greece 10th among EU nations in its overall environmental health. The Greek parliament passed new laws in 2007 that provided government support for renewable energy initiatives such as wind farms, and offered incentives for private investment in renewable sources. Solar energy remains a largely untapped resource. Whether or not these new initiatives will balance the country's dependence on fossil fuels, particularly lignite, remains to be seen.

Emissions from vehicles in crowded urban centers have also increased greenhouse gas emissions in Greece. Transport consumption of energy increased by nearly 50 percent 1982–92. The country is making a concentrated effort to address this problem. The extension of the rapid transit system in Athens, with around 25 new stations to be added 2008–18, and an additional line to be added after 2018, should help to control automobile emissions within the Athens area. Thessaloniki, Greece's second largest city, began construction of a rapid transit system in 2006 that is expected to be completed in 2012.

Despite these measures, air pollution and CO_2 emissions in Greece became a greater problem in the summer of 2007 when forest fires raged between late June and late August, claiming more than 60 lives and destroying more than 470,000 acres of forests and farmland. The nation's olive crop was ravaged in the detruction. Experts estimate damages at more than $1.6 billion, or 0.6 percent of Greece's Gross Domestic Product. Living trees absorb CO_2, but burning trees release the gas into the air. Scientists say that it is too early to know how the summer fires affected emissions, but many fear deforestation will magnify the effect of greenhouse gas emissions. Because Greece is the only country in the EU without a national forest registry, any burned land can be reclassified and sold to developers. With environmentalists preducting that global warming in the Mediterranean has begun, the fear is that a hot summer, a winter drought, and strong winds may make the Greek inferno of 2007 a common occurence. While non-human sources of CO_2 are exempt from the Kyoto Protocol and, consequently, will not add to the pressure on Greece, the costs of the devastation will certainly deplete both human and economic resources.

SEE ALSO: Coal; Deforestation; European Union.

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Green Buildings

GREEN BUILDINGS REPRESENT commercial or residential buildings that are designed, constructed, maintained, and operated with energy-efficient engineering systems, responsible use of water, and recyclable materials. These buildings are becoming increasingly popular because of their environmental, economic, and social benefits due to responsible use of natural resources. As the Earth's population is increasing exponentially, the building stock that houses the population is also increasing at a similar rate. At present, in the developed countries, buildings are using approximately one-third of the primary energy and roughly two-thirds of the electricity. As a result, even modest improvements in current building practice can result in significant energy savings. Even more important is the consequent reduction of greenhouse emissions due to reduced energy consumption during the building lifecycle, which includes not only construction and operation, but also the demolition process.

Examples of green building practices include use of wind and sun for energy, ventilation, and lighting. An appropriately-oriented building, can, with its window openings, promote natural ventilation, so the use of air conditioning systems becomes unnecessary when outdoor weather is mild.

At the same time, natural lighting can reduce the need for electricity, but the window openings need to be designed to provide sufficient lighting levels without glare. The use of local materials for buildings reduces the cost of material transportation, and the use of the natural and recyclable material reduces the cost of building demolition. The building wastewater can be treated for irrigation or used as "gray water" for non-potable purposes to reduce the impact on water treatment plants.

Green roof technology has emerged as a solution that can reduce the stormwater runoff, building energy consumption, and the heat island effect in cities. A rating system from the Leadership in Energy and Environmental Design (LEED) is used for evaluation and comparison of green buildings' performance. This LEED system was developed by the U.S. Green Building Council (USGBC), and includes the following five evaluation areas: sustainable site development, water savings, energy efficiency, materials selection, and indoor environmental quality. Each of these areas has multiple evaluation criteria that potentially affect human and environmental health.

SEE ALSO: Alternative Energy, Overview; Green Cities; Green Design; Green Homes.

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Green Cities

GREEN CITIES ARE designed and operated to have a minimal environmental impact. Green cities embrace design, construction, and operation of urban environments that are environmentally friendly, less-toxic, less-wasteful, and work more with nature than conventional cities. Pedestrian-friendly green cities are built for people, bicycles, and mass transit (as compared to conventional cities often constructed to optimize automobile transportation). Green cities are powered as much as possible by a combination of renewable energy sources such as wind, geothermal, and solar energy.

Green cities can also be known as eco-cities, eco-friendly cities, earth-friendly cities, environmentally preferable cities, and sustainable cities. Although it is unlikely that any modern city has obtained true sustainability, green cities have sustainability and even restoration of the natural environment as a goal. All cities are on a green to gray continuum, where gray represents the polluted post-industrial fossil-fuel powered city and green represents the way the area was before human intervention, the green economy based on ecologically favorable practices, or a mixture of both. The location of any city on the spectrum of gray to green will soon be able to be quantified by a forthcoming rating and certification scheme for neighborhood environmental design, Leadership in Energy and Environmental Design for Neighborhood Development (LEED-ND), developed by the U.S. Green Building Council, Natural Resources Defense Council, and the Congress for the New Urbanism. LEED-ND integrates the principles of smart growth, urbanism, and green building.

Green cities often are built on new urbanism principles, also known as traditional neighborhood design, neotraditional design, and transit-oriented development. New urbanism is an American urban design movement that arose to reform all aspects of current sprawling real estate development and urban planning, from urban retrofits to suburban infill. New urbanist neighborhoods are designed to contain a diverse range of housing and jobs (mixed use), and to be walkable. This movement seeks to restore a civil realm to urban planning and a sense of place to communities. It is a tangible response to the failed modernist planning in the United States that has resulted in unchecked suburban sprawl, non-human scale, automobile dependence, and the abandonment and pollution of the urban centers of many modern cities.

The green city represents the ultimate challenge in urban and human planning. The city must be planned so that all the elements that make it up (people, technology, nature, and material byproducts) are harmonized in aesthetic, safe, and sustainable relationships. Putting urbanism and nature together provides humanity with an opportunity to create cities that are healthy, civilizing, and enriching places in which to live. Green cities are not only designed and constructed, they must be governed and operated in an environmentally conscious manner to remain green. Green city governments use environmentally preferable purchasing programs, commercial and residential green building incentives, composting and recycling services, public transit incentives, carpooling coordination, car sharing programs (public or private), and other tools to reduce the impact of the operation of the city on the environment.

There are several advantages to living in a green city. Green cities are easily navigated by people on foot and by public transport because they are designed to the scale of the pedestrian and seek to promote a symbiotic relationship between urban development and public transportation. This reduces family transportation costs, congestion, and eliminates stressful and time-wasting automobile commutes. Those living in green cities run errands and commute using their own bodies for locomotion, therefore, they benefit from improved physical wellness. Inhabitants of green cities also enjoy health benefits because of reduced air and water pollution. Reduced air pollution improves outdoor air quality, reduces air-pollution related illness and deaths, reduces smog, and smells better than conventional cities. Reduced water pollution improves drinking water, provides opportunities for outdoor water activities (such as swimming and boating) and enables local fish to be eaten. Green cities encourage green building for construction of both homes and work places, which in addition to improving indoor air quality, saves residents and owners money on operation due to improved energy and water efficiencies. Green cities support local food and regional agriculture, and many green cities even have community gardens where residents grow fresh fruits and vegetables. This fresh produce again improves the health of the residents and in general tastes better than less fresh food. Green cities are also literally green. They promote the rebuilding of essential soil and water resources, while increasing plant and animal biodiversity. This nature, which can be found within the city, improves mental health of the occupants.

These advantages make green cities very desirable places to live. This is reflected in the increased property values found in green cities and the aggressive competition to be listed among the environmental leaders by the *Green Guide* on Earth Day. The top 10 green cities are awarded for providing energy-efficient, least polluting, and healthy living spaces, and whose green achievements set the standard for others. These standards are currently of large importance due to the lack of federal direction. Cities across the United States and the rest of the world are taking environmental stewardship into their own hands and reducing their environmental impact. In relation to climate change, city mayors working to lower greenhouse gases best exemplify this: several hundred have signed the U.S. Mayors Climate Protection Agreement.

SEE ALSO: Automobiles; Green Buildings; Green Design; Green Homes.

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Green Design

GREEN DESIGN, SOMETIMES referred to as sustainable design or ecological design, is a process by which products are created to be more sustainable, and last longer. The goal is to makes changes during the design and manufacturing phases so that the end products are as environmentally benign as possible. This, in turn, will reduce the ecological footprint of those using such items. In terms of green design in building construction and land use planning, there is significant potential to reduce the amount of carbon emitted in the development process and in day-to-day operations. Those implementing green design often follow a systems approach and readily utilize several sustainable design principles. The national Leadership in Energy and Environmental Design (LEED) certification program awards architects and builders for using green design methods. On a broader scale, land use planning techniques can be followed to design environmentally sustainable communities. Finally, there are some technologies and polices that advance the goal of green design.

The systems thinking approach to product development and certain green design principles are usually incorporated into the design and manufacturing phases when creating environmentally sustainable products. The systems thinking approach, also referred to as the life cycle approach, considers the environmental impacts of the materials and procedures used to create the product, the effects of the product while in use, and then the impacts of the product as it is disposed of and decomposed.

This method promotes the use of recycled materials and nontoxic substances in production. The product should then be environmentally benign while in use and easily broken down to recyclable and innocuous components at the end of its use.

There are a variety of green design principles that can be incorporated into the planning and implementation stages of production. First, the materials used to create the product should be given careful consideration. Materials that can be easily recycled at the end of the products' life cycle are desirable. Also, components that are nontoxic should be selected. Finally, to ensure that products or buildings are sustainable, renewable materials should be utilized. In the end, material selection must be balanced with cost. While using entirely sustainable materials is environmentally sound, this practice may cause the product to be prohibitively expensive. Successful manufacturers are able to find creative ways to employ sustainable materials without significantly increasing the price of the product.

Next, the reliability should be considered when creating green designs. Products that are durable and can withstand daily use are more advantageous than those that may need to be replaced in the short term. The longevity of a product is not only useful from a green design perspective, but also it makes the best economic sense. A third principal often considered in green design is energy use. This principle is two-dimensional. First, materials should be selected that do not require a lot of energy to make. Transportation of raw materials must be taken into account. Next, the product itself should not require much electricity to function. There are several programs available to have energy efficient products labeled so that consumers can easily identify them. An example of the is the Department of Energy and Environmental Protection Agency's ENERGY STAR labeling and marketing campaign for appliances.

Finally, green design focuses on creating items with shared uses. These consist of items that can be used my many individuals over the lifespan of the product. For instance, silverware has more shared use potential than plastic ware. The shared use principle may also encourage the same user to utilize the product for many different tasks, such as vacuum that is also able to wet-wash hardwood floors. In general, using a system approach and following certain principles when engaging in product design will lead to less energy and resource consumption.

The U.S. Green Building Council (USGBC) oversees a nationally accepted green design program for commercial and residential buildings. This program is referred to as the Leadership in Energy and Environmental Design (LEED) certification program. A systems approach is used and performance must be achieved in five categories: sustainable site development, water savings, energy efficiency, materials selection, and indoor environmental quality. Buildings are rated in each of these five areas and must achieve a specific number of points for different certfications. The lowest level of certification is when a building is simply considered LEED Certified. The next level is bronze certfication, then silver certification, followed gold certification, and finally the highest level is platnium certification. In 2007, only 14 states had buildings that were platnium certified.

On a larger scale, green design methodology can be used during land-use planning. Sometimes called sustainable development, land-use planning integrates urban planning, housing development, and transportation theory with environmental understanding. This may include using energy efficient lighting for buildings and street lamps or creating neighborhoods in which all amenities are easily walkable. Wildlife corridors and green spaces are usually left intact to protect native and migratory species.

Finally, green technologies are becoming more available in all communities. Wind turbines and photovoltaic cells are more common on peoples' properties and allow individuals to live off-grid or to net-meter excess energy. Many home textiles such as carpets and furniture coverings emit less volatile organic compounds (VOCs) than before. Water-saving fixtures like faucets, toilets, and showerheads are becoming the standard. The installation of these products, however, may be more expensive than conventional products. This development is slowly changing as the market turns toward homes that value human and ecosystem health.

SEE ALSO: Green Buildings; Green Cities; Green Homes; Impacts of Global Warming.

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Green Homes

GREEN HOMES ARE designed and operated to have a minimal environmental impact. They are constructed using green building techniques, which increase the efficiency of the homes and their use of energy, water, and materials, and reduce the homes' impacts on human health and the environment, through better siting, design, construction, operation, maintenance, and eventual removal. The green attributes of green homes generally include, but are not limited to, reduced toxicity, re-usability, reduced waste, energy and water efficiency, high recycled content, intelligent design, responsible manufacturing techniques, and reduction of personal environmental hazards.

The green building techniques needed to construct green homes are sometimes called sustainable building or environmental building. A similar concept is natural building, which focuses on the use of natural materials that are available locally. Green homes may also fall under the classification of sustainable design and green architecture; however, while the initial design of a home is important in making hbba green home, the actual operation, maintenance, and ultimate disposal or deconstruction of the home also have very significant effects on home's overall environmental impact.

There are several advantages to living in a green home. First, through the use of proper materials and attention to natural ventilation, green homes reduce exposure to mold, mildew, and other indoor toxins, and thus have better indoor air quality than standard homes. Homes with high indoor air quality are more comfortable and healthier places to live, particularly for families with young children. Second, because of increased efficiency, green homes reduce operating costs by using less energy and water. Finally, green homes in the aggregate have the potential to radically reduce environmental impacts on the local and global environment by reducing both pollutants and greenhouse gas emissions.

Green building is increasingly governed and driven by standards, such as the Leadership in Energy and Environmental Design (LEED) rating system developed by the U.S. Green Building Council. LEED for Homes has been developed, which is a voluntary rating system that promotes the design and construction of green homes. LEED certification recognizes and rewards builders for meeting the highest performance standards, and gives homeowners confidence that their home is durable, healthy, and environmentally friendly.

Fortunately, the net cost of owning a green home is comparable to that of owning a conventional home. This is possible, because although some green design practices cost more than conventional design, many cost less (particularly over the lifecycle) and when all practices are aggregated in smart, integrated design, they provide the green benefits without increased costs.

DESIGN FEATURES OF A GREEN HOME

Multiple design features work in tandem to make comfortable, efficient, and economic green homes.

Conventional homes are getting larger, while the average family size/occupancy decreases. Smaller homes that use space efficiently, are well-organized, and are filled with a prudent number of possessions, can not only be beautiful and cozy, but also use much less energy to heat and cool.

A home located on existing water, sewage, and roads will have less of an environmental impact than one that is not. Ideally, a green home would also be located close to community resources and public transportation in order to minimize automobile travel. Finally, homes should be in a compact development to allow for more open, green spaces.

Landscaping of a green home is designed to minimize fertilizer, herbicide, pesticide, and water use. Trees are also planted to provide shade (passive cooling for the home). Permeable paving is used to recharge groundwater and reduce surface run off. Finally, non-toxic methods of insect and pest control should be used.

Rainwater from the roof is harvested and graywater reuse systems are installed in a green home. High efficiency fixtures (toilets, showers, and faucets) are used. In some cases, even composting toilets or living machines treat human wastes.

In order to maintain high indoor air quality, all combustion devices (space heating, fireplaces) need to have proper venting, and air systems must have a method of heat recovery (such as heat exchangers). Materials such as paints and glues used in the homes also contribute to indoor air quality; green homes use products with low VOCs (volatile organic compounds), which helps maintain healthy air quality, not only for those living in the house, but also for those working on the construction of the home. Green homes also have good air-filtering, radon protection, humidity control, and protection from vehicle emissions.

Durable materials used in the construction are sourced locally to avoid unnecessary transportation. All wood is Forest Stewardship Council certified, and products are chosen from an environmentally preferable product list, which favors recycled and recyclable materials and rapidly renewable materials. Waste during construction is minimized, and waste is recycled during construction and during use (for example, through curb-side recycling and back-yard composting).

A green home is very energy efficient and meets the requirements for an Energy Star rating for the entire home, but also contains Energy Star appliances, windows, furnace, air-conditioning, and lighting. To earn the Energy Star rating, homes must meet guidelines for energy efficiency set by the U.S. Environmental Protection Agency, which typically make them 20–30 percent more efficient than standard homes. Green homes are well-insulated, their ducts are tight, and the thermal envelope is sealed to reduce air infiltration.

A green home is run by renewable energy, utilizing orientation and window placement for passive solar heating and natural ventilation/cooling, and has a solar domestic hot-water system. In addition, the green home may have solar photovoltaic panels, wind turbines, micro-hydro, or combined heat and power systems.

The physical design of the house can also lend a great deal to a green home's efficiency. Through careful attention to sizing and placement of glazing, room layouts, and positioning of various architectural elements, a wide range of benefits can be reaped. These benefits include an increase in natural day-lighting, solar heat gain or loss (based on climate), and better cross-ventilation.

Green homes are designed, built, and operated so that by using energy, water, and building materials intelligently, modern society can live well without needlessly damaging the environment.

SEE ALSO: Green Buildings; Green Cities; Green Design; Energy Efficiency.

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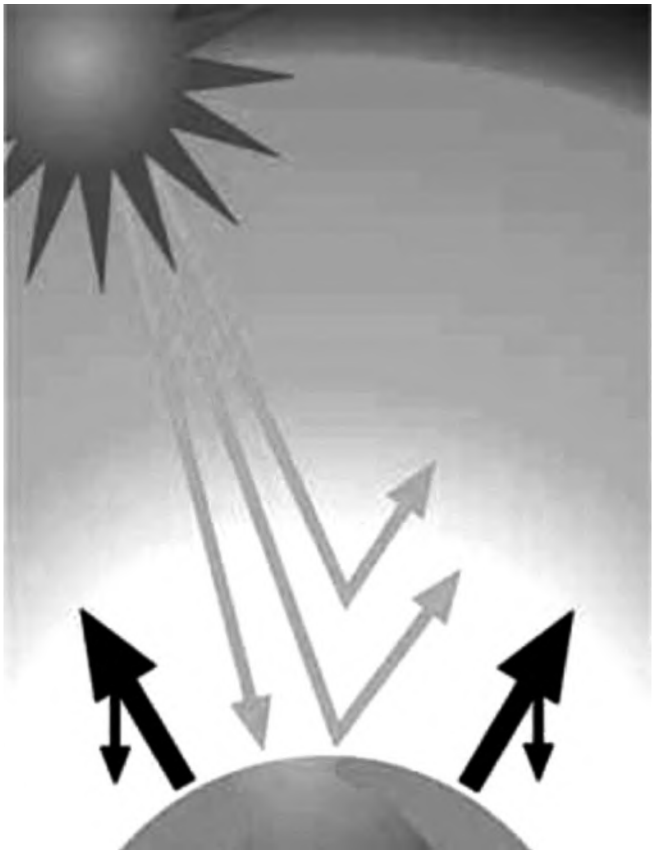
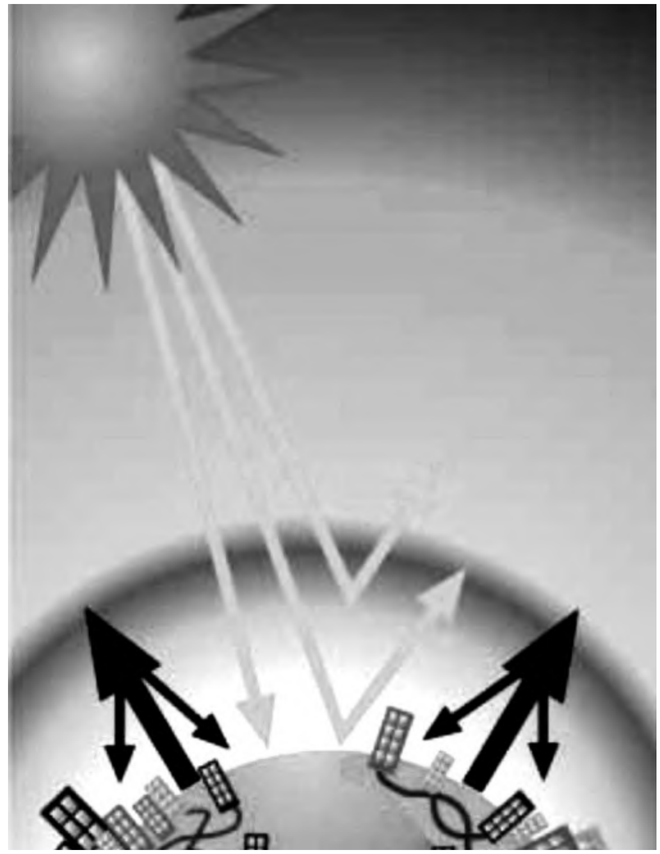
Greenhouse Effect

HUMAN ACTIVITIES CAN disrupt the balance of the natural system that regulates the temperature on



Most of Earth's heat is re-radiated toward space, but some is trapped by greenhouse gases in the atmosphere. This is a natural effect that keeps Earth's temperature at a level necessary to support life.



Human activity—particularly burning fossil fuels (coal, oil, and natural gas) and land clearing—is generating more greenhouse gases. Scientists are convinced that this will trap more heat and raise Earth's surface temperature.

Earth. This natural regulating system is known as the greenhouse effect. As human societies burn fossil fuels, and adopt it to increasingly sophisticated and mechanized lifestyles in the developed world, the amount of heat-trapping CO_2 and CH_4 in the atmosphere has increased. By increasing the amount of these heat-trapping gases in the atmosphere, humankind has enhanced the warming capability of the natural greenhouse effect.

This human influence (in addition to the natural release of these gases) on the natural warming function of the greenhouse effect has become known as the enhanced greenhouse effect. It is this human-induced enhanced greenhouse effect that causes environmental concern. This enhanced greenhouse effect has the potential to warm the planet at a rate that is unprecedented. Greenhouse gas effects due to natural phenomena have existed from the very beginning of the Earth. The rate has increased over time due to increased human activity such as industrialization, deforestation, increased fossil-fuel-based transportation, and increased agriculture to satisfy the increased population.

Another factor that is causing significant change in the atmosphere is the rising levels of carbon dioxide, due to increased burning of coal and oil, which traps more heat in the atmosphere, thus warming the Earth. This phenomenon began with the advent of the Industrial Revolution of 1800s, and has been increasing ever since. Work was done by hand and by animal power before the Industrial Revolution, but was done by fossil-fuel burning machines since the Industrial Revolution, resulting in generation of higher amounts of CO_2 and its subsequent release to the environment. It is difficult to predict the precise effects of doubling the concentration of CO_2 in the atmosphere, but doubling CO_2 should increase global temperatures.

Also, increased production of rice and growing numbers of domestic animals to feed the increasing population have resulted in increased emissions of CH_4. During the last two centuries, the concentrations of CO_2 and CH_4 (both greenhouse gases) have increased faster than at any other time in the recorded history of mankind, leading to enhanced greenhouse effect.

RESULTS OF ENHANCED GREENHOUSE EFFECT

The expected continued temperature rise due to climate change is linked to the observed build-up of greenhouse gases in the atmosphere. This will cause further warming of Earth's surface over the long term. Whether or not global warming has already begun, and if it is a direct result of the enhanced greenhouse effect, is still uncertain. The Intergovernmental Panel on Climate Change (IPCC) raised the question through the fourth report of IPCC to the United Nations (UN) in 2007. The IPCC's chairperson commented that the world still has time to reverse global warming. The decision by the Nobel Peace Prize committee to award the 2007 prize to the UN IPCC, together with former U.S. Vice President Al Gore, demonstrates that the committee considers climate change a threat to peace and that the global warming is taking place.

The enhanced greenhouse effect has already led to some severe weather patterns such as: 11 of the last 12 years (1995–2006) rank among the 12 warmest years ever recorded since global surface temperatures were measured (1850). Over the last 100 years (1906–2005), there has been an increase in surface temperature of 1.3 degrees F (0.74 degrees C), which is larger than the 1 degree F (0.6 degrees C) increase given in the Third Assessment Report for the 1901–2000 period. And the warming trend over the last 50 years (.23 degrees F, or 0.13 degrees C per decade) is nearly twice that for the last 100 years.

Temperatures in the higher atmosphere and in the oceans (to depths of at least 1.8 mi. or 3,000 m.) have also been rising, along with the water vapor content of the atmosphere. Mountain glaciers, snow cover, and ice caps have declined, on average, in both hemispheres, contributing, in part, to the rise of global sea level. The Arctic and Antarctic ice caps have also contributed to the observed rise of sea level, which amounted to a rise of 6.6 in. (17 cm.) in total over the course of the 20th century.

At continental, regional, and ocean-basin scales, numerous long-term changes in climate have been observed. These include changes in Arctic temperatures and ice, widespread changes in precipitation amounts, ocean salinity, wind patterns, and aspects of extreme weather including droughts, heavy precipitation, heatwaves, and the intensity of tropical cyclones. Some aspects of climate have not been observed to change. The difference of temperature between day and night, for example, has remained the same, since daytime and nighttime temperatures have risen by the same amount. However, even when expected natural short-term variability, such as unusually cold winters are taken into account, global temperature trends show that the Earth has warmed over the long term.

To summarize, the enhanced greenhouse effect is leading to change in atmospheric composition and climate change during the 20th century: global-average surface temperature has increased (1 degree F, or 0.6 degrees C); temperature in the lowest 8 km. increased in the past four decades, global-average sea level has risen (0.3–0.6 ft., or 0.1–0.2 m.), snow and ice extent decreased with widespread retreat of glaciers, and precipitation has increased (up to 1 percent per decade).

Since 1750, there has been an increase of: CO_2 (31 percent), CH_4 (151 percent) and N_2O (17 percent), and present CO_2 levels probably were not exceeded in the past 20,000 years.

SEE ALSO: Anthropogenic Forcing; Global Warming; Greenhouse Gases.

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Greenhouse Gases

THE IDEA THAT some gases trap thermal radiation like the glass of a greenhouse was first proposed by Jean Baptiste-Joseph Fourier in 1827. However, this analogy is not strictly correct, because greenhouses warm the air in their interior mainly by blocking convective mixing with the outside, not by trapping thermal radiation. However, in spite of this, gases that are relatively transparent to solar radiation and relatively opaque to thermal radiation are known as greenhouse gases. On Earth, water vapor (H_2O) is the most important greenhouse gas. Other important gases are carbon dioxide (CO_2), nitrous oxide (N_2O), chlorofluorocarbons (CFCs), methane (CH_4), and ozone (O_3). Anthropogenic emissions are important sources of all greenhouse gases, except water vapor. However, the atmospheric water vapor content increases with increases in surface temperature. Therefore, the atmospheric concentration of water vapor increases with anthropogenic emission of greenhouse gases. The increase in atmospheric water vapor content induced by anthropogenic emissions in responsible for a large fraction of the greenhouse effect.

CARBON DIOXIDE

Carbon dioxide (CO_2) is a colorless and odorless gas consisting of one carbon and two oxygen atoms. CO_2 is produced when carbon compounds are burned in the presence of oxygen. It is produced during forest fires and the combustion of fossil fuels. CO_2 is also produced by the decay of organic matter and volcanic eruptions. Other important sources of carbon dioxide are emission by the oceans and respiration by humans and animals. Important sinks of carbon dioxide are absorption by oceans, photosynthesis, and plankton and plant growth. Because the sources and sinks of carbon dioxide varied significantly during the Earth's history, its atmospheric concentration also varied significantly. There is evidence that the concentration of carbon dioxide was very high in the Earth's early history, then declined steadily and reached a quasi-steady value of about 280 parts per million. The concentration varied around this value with climate fluctuations.

However, the huge increase in man-made emissions of carbon dioxide that came with the Industrial Revolution has been making its concentration to increase steadily since the end of the 18th century. Today, the concentration of carbon dioxide has already exceeded 350 parts per billion and continues to increase at the rate of more than one part per million per year. The atmospheric concentration of carbon dioxide has been continuously measured at Mauna Loa, Hawaii, since 1957. It shows a clear annual cycle, resulting mainly from changes photosynthesis and a steady increase since the measurements started. The atmospheric concentration of CO_2 before this record started can be measured from bubbles of air trapped in ice cores. They show a steady increase since the beginning of the Industrial Revolution.

Human-induced emissions of carbon dioxide have increased dramatically and steadily since the end of the 18th century.

TOXIC GASES

Nitrous Oxide is a non-toxic gas consisting of one oxygen and two nitrogen atoms (N_2O). The main sources of nitrous oxide are natural processes in soils and the ocean, chemical fertilizers, and deforestation. Ice core data suggests that the atmospheric concentration of N_2O was approximately constant before the Industrial Revolution started. The annual increase in the atmospheric concentration of N_2O is estimated to be about 0.3 percent, according to the IPCC.

Chlorofluorocarbons (CFCs) are non-toxic gases composed primarily of carbon, hydrogen, chlorine, and fluorine. They are used mainly as cleaning agents, refrigerants, fire retardants, and in aerosol sprays. Since they are chemically inert in the troposphere, they have a long residence time, and reach the stratosphere where they are photodissociated by ultraviolet radiation. Then, free chlorine atoms destroy ozone catalytically. Thus, besides being important greenhouse gases, CFCs are responsible for destroying the ozone layer that protects humans from harmful ultraviolet radiation.

Methane is an odorless, non-toxic, flammable gas consisting of one carbon and four hydrogen atoms (CH_4). Mainly anaerobic or oxygen-deprived processes produce methane. It forms when the digestion of organic material by bacteria releases single carbon atoms. The main sources of methane are wetlands, the combustion of fossil fuels, animals, rice plantations, biomass burning, landfills, termites, and the oceans. Methane is removed from the atmosphere primarily by reaction with hydroxyl radicals (OH). The atmospheric concentration of methane has also been steadily increasing since the beginning of the Industrial Revolution. The atmospheric concentration of CH_4 has been increasing at the rate of about 1 percent per year.

Ozone (O_3) is formed via the dissociation of molecular oxygen by ultraviolet radiation. It is the most photochemically active greenhouse gas. Ozone is an important greenhouse gas because it strongly absorbs ultraviolet radiation. About 90 percent of the atmospheric ozone is found on the stratospheric ozone layer. However, the ozone concentration in very polluted areas can exceed the stratospheric levels.

The concentration of water vapor increases exponentially with temperature. This fact and the presence of water reservoirs such as lakes and oceans make the opacity of the atmosphere a strong function of surface temperature. Thus, global increases in temperature (global warming) produce a positive feedback in the climate system. Increases in the surface temperature causes increases in the amount of atmospheric water vapor that produce further increases in the surface temperature. This positive feedback makes the greenhouse effect increase dramatically with temperature. Above a critical value of the solar forcing, the atmospheric water vapor feedback becomes so large that equilibrium is not possible and a runaway greenhouse occurs. In fact, there is evidence that the dependence of the concentration of water vapor on temperature might lead to multiple climate equilibria.

SEE ALSO: Carbon Dioxide; Climate Feedbacks; Greenhouse Effect; Methane Cycle; Nitrous Oxide.

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Greenland Cores

GREENLAND IS THE largest island in the world. Most of Greenland is covered with an enormous ice cap that is almost three times the size of Texas. The ice cap covers about 90 percent of the island. It is so heavy that its weight has depressed the center of Greenland to about 1,000 ft. (304 m.) below sea level. The Greenland icecap contains one-eighth of the total global ice-mass. Most of the remaining ice mass is in Antarctica. Some parts of northern Greenland are ice-free because it is too cold for snow to form. In some southern parts, the area is too warm for ice to accumulate. The ice cap has been created by the accumulated weight of snowfall through hundreds of thousands of years. The shrinkage in the ice cap, since it was first measured in the 1950s, is due to global warming.

Scientists who specialize in paleoclimate research have drilled two ice core samples in the center of the Greenland ice cap. The core samples were drilled to a depth of 2 mi. (3.2 km.). The ice cores are in an area where winter snowfall has constantly added depth to the ice cap over thousands of years. The ice caps have been studied as an environmental record of the climate, regionally and globally, for the last 100 thousand years. Strictly speaking, the ice cores report what occurred climatically only where the samples were taken. However, extrapolations provide an estimate of global weather conditions, and, thus, a record of the Earth's climate through several ice ages.

Plant materials in the cores are some of the oldest plant material currently available on the Earth. The plant materials reveal that the climate of the Earth was much warmer hundreds of thousands of years ago than today. The age of the plants, as well as the insect life found, is between 500,000 and 1 million years in age. In addition, remains of boreal forests were found. The implications of the plant and insect materials in the ice cores indicate that the ice cap perhaps did not exist perhaps as long as 2.5 million years ago. However, in more recent geological ages, the ice cap did not completely disappear during interglacial periods.

As the snow accumulations have compressed over the millennia, they have also been squeezed into ice, which has trapped air bubbles. The ice cores, composed mostly of water, also contain isotopes of oxygen and hydrogen, the two elements in a water molecule. The air bubbles, the isotopes, and the organic material in the ice cores have given scientists materials that are enabling them to create a picture of the climate of the Earth over the last 1 million or more years. The heavier isotopes have a lower vapor pressure, so they condense more rapidly as temperatures cool than is the case with normal water molecules. The concentration of isotopes is an indication of the temperature at the time of the precipitation of the water molecule under study.

Concentrations of different gases in the air bubbles trapped in ice core samples record the levels of greenhouse gases in the atmosphere over a long stretch of geologic history. The concentrations of carbon dioxide, methane, and nitrous oxide reveal the greenhouse gas levels that are used to interpret the climatic changes over the last 1 million years. Some of the trace molecules in the samples were aerosols, which are indications of vast volcanic activity. Other inclusions in the ice core sample may be dust or volcanic ash, pollen, and radioactive elements. Ice core samples from Greenland can be compared with the results from ice core samples taken from Antarctica and from other major glaciers around the world. The conclusions of scientists have included inferences about solar variability, forest fires, and the water drawn from the sea through evaporation.

The depth from which an ice core sample is taken is important for stating its age. The newer parts of the core samples have thin annual layer lines, while samples from deeper depths of the ice cap are so compressed that age determination has to be made with different criteria. The ice core samples since the end of the last Ice Age, about 12,000 years ago, show variations in snowfall. This has led to the conclusion that the climate at that time was getting colder because there was less moisture in the air to fall as snow. Samples from different parts of Greenland have revealed greater differences than were expected. Evidence of volcanism that affected the climate has been found in ice core samples that have sulfate concentrations from about 9,000 years ago. The sulfate concentrations are indicators that volcanoes played a role in global cooling. However, currently, the ice cap is rapidly melting.

SEE ALSO: Climatic Data, Ice Observations; Greenland Ice Sheet; Ice Ages; Ice Component of Models.

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Greenland Ice Sheet

THE GREENLAND ICE Sheet contains about 10 percent of the world's fresh water, and is vulnerable to mass loss by climate warming; if it were to melt, it would cause a 24 ft. (7.4 m.) rise in global sea level. The ice sheet covers 82 percent of the total area of Greenland. It is a huge ice dome, with two main peaks: one at 3,220 m. at the summit (about 72 degrees N, 29 degrees W), and the other at 9,350 ft. (2,850 m.) in the south at about 64 degrees N, 44 degrees W. The ice sheet is up to 1.8 mi. (3 km.) thick in the middle, and its great weight depresses the underlying crust, which assumes the concave shape of a saucer. The ice sheet has waxed and waned in response to natural changes in solar radiation and other climatic factors over millennia: during the last Ice Age, which peaked about 20,000 years ago, it expanded to form the Laurentide Ice Sheet covering much of North America.

Various processes contribute to the accumulation (growth) and ablation (decay), and, therefore, the net mass balance, of the ice sheet. Accumulation comes mainly as precipitation (snowfall), although there is also condensation of water vapor (such as hoar frost) onto the surface. Ablation includes surface melt water runoff, iceberg calving, evaporation, and sublimation (direct conversion of solid ice to vapor). Under present climatic conditions, annual accumulation and ablation roughly balance, with about half the ablation from runoff and the other half from iceberg calving. However, iceberg calving happens only at the margins of the ice sheet, where ice streams flow outward to reach fjords and/or the sea, and can be ignored for the bulk of the ice sheet further inland. Surface mass balance is used to denote all accumulation and ablation processes, except iceberg calving. Overall (net) mass balance includes ice flow (dynamics) as well as surface mass balance processes: the ice sheet naturally deforms and flows outwards under the force of gravity. When studying Greenland Ice Sheet behavior over periods longer than about a decade, dynamical readjustment (effectively a long-term memory) of the ice sheet to changes since the last Ice Age has also to be considered.

The ice sheet is divided into an accumulation zone and an ablation zone, separated by an equilibrium line. Accumulation exceeds ablation at higher elevations (accumulation zone), and vice-versa at lower elevations (ablation zone). The much higher summer temperatures at lower elevations near the ice sheet margin explain this. The exact height of the equilibrium line varies with location according to climatic and geographic factors, ranging from about 300 m. above sea level in the north to about 1,800 m. above sea level in the south. Summer melting occurs over about half the area of the ice sheet. However, just above the equilibrium line, over more than two-thirds of the total area, the limited summer snowmelt mostly percolates into the local snow pack and refreezes, so net runoff there is negligible.

The surface mass balance of the ice-sheet margin is most sensitive to slight (several-degree) changes in summer temperatures, which substantially affect surface melt runoff. This part of the ice sheet is therefore particularly sensitive to climatic changes, such as global warming. Marginal melt rates are locally up to around 5–10 m. per year. These would be enhanced with future warming, which would radically affect the mass balance of the whole ice sheet, even though the area of significant melt covers only a relatively small fraction by area. Summer cooling in coastal southern Greenland between the late 1950s and early 1990s may explain the mid-late 20th-century re-advance of the ice sheet margin after retreats of a few km. in some places since the 19th century. This evaluation of changes in the ice margin is based on analysis of old maps, photos, and expedition reports, and cannot be expressed accurately as volume change, which can only be determined by modern altimeter surveys from aircraft and satellite.

MONITORING OF THE GREENLAND ICE SHEET

Several means have been used to assess the current state of balance of the ice sheet to effectively model its response to natural- and human-induced climatic change. Observational methods include direct meteorological and glaciological measurements at the ice-sheet surface with weather stations, ablation stakes and ice cores, and remote sensing by satellite radar, gravity surveys, and airborne laser. It is essential to establish the ice sheet's current state of mass balance and climatic sensitivity, and detect any early-warning signs that might signify its future response.

Despite much effort, the Greenland Ice Sheet is still poorly-sampled by direct glaciological measurements, although it appears that there have been relatively large fluctuations in surface mass balance over the early 21st century. However, a Greenland Climate Network of automatic weather stations and an extensive ice-core network have been established across the ice sheet in the 1990s, providing much-needed meteorological and glaciological measurements across the interior regions.

Airborne and satellite laser-altimetry data analyses indicate substantial volume losses from the ice sheet since around 1993. Various recent analyses of gravimetric (GRACE) satellite data suggest particularly high mass losses 2002–06; the largest mass losses are generally indicated from low elevations (less than 2,000 m.) and especially in southeast Greenland, with partly compensating mass gains at higher elevations (over 2,000 m.). Other altimetry data suggest that there has been substantial growth of the ice-sheet interior in the last 15 years, which may be partly attributable to increased atmospheric moisture and precipitation and/or shifting storm tracks forced by enhanced greenhouse gases. There are considerable discrepancy among these pioneering observational estimates. Moreover, most of the observational studies have data spanning less than a decade, so they have yet to provide a convincing timeframe of how the Greenland Ice Sheet might be responding to long-term climatic change, most notably the evident Arctic and global warming since the 1970s.

Outlet glaciers have typically thinned by several meters per year since the 1990s. Satellite radar interferometry reveals widespread acceleration of Greenland margin glaciers, a pattern progressing northward since 1996, with an accompanying doubling of the ice sheet's volume deficit, although it is too early to say if these changes are exceptional. Some of these margin changes are the likely response to recent climatic warming through infiltration of surface melt water and lubrication of the glacier bed, speeding up glacier flow and mass loss. Notably, several key glaciers in southern Greenland (such as Jakobshavn Isbrae, Helheim, and Kangerdlussuaq) have shown dramatic accelerations, retreats and/or breakup of their floating tongues. This thinning of the Greenland Ice Sheet margin could account for at least 10 percent of the total increase in global sea level during this period.

Studies have shown that the Greenland Ice Sheet experiences rapid changes over periods of just a few years, and some of these could be in response to climate change. Scholars are currently focusing on surface ablation and glacial dynamics in the marginal (edge) regions of the ice sheet, and their sensitivity to summer warming.

Recent relatively high summer temperatures (1995–2005) are associated with increased net ice loss over Greenland. However, recent warm summers are not unprecedented as they are similar to those experienced an early-20th-century warm period (1918–47). Nevertheless, most computer-model predictions of future climate suggest that sustained warming around the margins will lead to a negative mass balance and give a positive contribution to sea level. The latest Intergovernmental Panel on Climate Change (IPCC) prediction is for a Greenland Ice Sheet contribution to sea-level rise of 1–13 cm. during the current century. The ice sheet could respond more rapidly to continued warm temperatures via hydraulic acceleration, but at the moment, the physical response mechanisms are too poorly understood to be included in the IPCC projections.

SEE ALSO: Glaciers, Retreating; Glaciology; Greenland Cores; Ice Component of Models; Iceland.

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Greenpeace International

GREENPEACE INTERNATIONAL IS an environmental organization that uses creative confrontation, usually in the form of media spectacles, to draw attention to specific environmental problems. Abrupt climate change caused by human-induced global warming is atop the organization's list of concerns. Scientists predict that if humans continue to burn fossil fuels at present rates, global warming will have catastrophic effects on existing ecosystems, natural landscapes, plant and animal populations, and human life. Greenpeace, which is a nongovernmental organization supported by charitable grants and membership fees, is at the forefront in the struggle to convince governments, businesses, and individuals that global warming is a real threat, and in finding ways to lessen human dependence on fossil fuels. From its headquarters in Amsterdam, the Stiching Greenpeace Council gathers almost three million supporters, directs activities in 27 national and regional offices located throughout the world, and promotes local and regional actions that include media-luring confrontations that produce image bites and aggressive lobbying of politicians and businesspersons.

The problems of global warming and climate change have only recently become central targets for Greenpeace. The testing of nuclear weapons galvanized the founding of the organization in Vancouver, British Columbia, in 1972. Several American expatriates and Canadians joined hands to prevent the United States from testing nuclear bombs along the Aleutian coast of Alaska. Originally called the Don't Make a Wave Committee, after the potential tidal wave the explosions could raise in the North Pacific, the group sailed twice into the testing area of Amchitka, only to be turned away by the U.S. Navy. The U.S. government eventually discontinued the Aleutian Islands testing program as a consequence of Greenpeace's spectacular confrontations and the media attention they received. Since then, Greenpeace has been a pro-environmental force to be reckoned with, promoting greater knowledge of environmental issues including deforestation, air and water pollution, whaling, over-fishing, and genetically modified food crops.

In the late 1970s, Greenpeace International consolidated what was then an informal association of smaller groups carrying out actions in the name of Greenpeace. Headquarters were moved to Washington, D.C., and the organization refitted a fishing trawler, renaming it the *Rainbow Warrior*. The image of Greenpeace activists maneuvering their rubber dinghies in between industrial harpooner and terrific whale is representative of their purpose and determination.

Greenpeace's most famous stance came against the French nuclear testing program in the South Pacific beginning in the late 1970s, when activists sailed again into an exclusive zone, but this time encircling the Moruroa Atoll, the French test site. Again, they were rebuffed, but not so subtly. The French military rammed their yacht, the precursor to the *Rainbow Warrior*, and dished out a beating of the crew that was seen on television screens throughout the world. This raised more than a few eyebrows, and membership dollars. In 1985, Greenpeace set sail again for the atoll, but this time with the stout *Rainbow Warrior*. While docked in Auckland Harbor, New Zealand, French intelligence agents bombed the ship, killing a photojournalist. The French government of François Mitterand was humiliated and testing halted.

Greenpeace activism was significant in propelling several important international policies, furthering the goals of environmental conservation and preservation. They include the Protocol on Environmental Protection to the Antarctic Treaty (1991) that imposes a 50-year moratorium on the mining of resources on the continent; and the Comprehensive Nuclear Test Ban Treaty (1996) now signed by 177 states including the United States, China, France, and Russia. During the summer of 2007, Greenpeace began construction of another ship on Mt. Ararat, in eastern Turkey, where Noah's Ark is said to have rested after the biblical deluge. This may some day join their present fleet of five ships.

SEE ALSO: Marine Mammals; Nongovernmental Organizations (NGOs).

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Grenada

THIS CARIBBEAN ISLAND, with some much smaller islands located in the Windward Islands, has a land area of 132.8 sq. mi. (344 sq. km.), and a population of 103,000 (2005 est.). Grenada has a population density of 672.2 people per sq. mi. (259.5 people per sq. km.), making it 44th in the world in terms of population density. Some 15 percent of the land is arable, with a further 3 percent used for meadows or pasture. Unlike many other Caribbean islands, Grenada still relies heavily on agriculture; it is the second largest producer of nutmeg in the world, and agricultural output makes up some 90 percent of the exports from the country.

GOVERNMENT AND TOURISM

Since the 1990s, the Grenada government has been trying to increase the number of tourists visiting the country. Many tourists visit the coral reefs around the island, the most popular of which lie to the southwest of the main island. This has led to an increase in carbon dioxide emissions per capita, with Grenada ranking 114th in the world, with 1.2 metric tons per person in 1990, rising steadily until 1997, when it reached a peak of 2.1 metric tons per capita. After falling, this figure rose again, surpassing this level slightly in 2001. Almost all the carbon dioxide emissions in the country come from liquid fuels, with all electricity generation in the country coming from fossil fuels.

As the temperature of the seawater rises, coral bleaching occurs, threatening the tourism industry. Hurricane Ivan hit Grenada on September 7, 2004, causing widespread damage and killing 39 people. The Grenada government of Nicholas Braithwaite took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, and signed the Vienna Convention in the 1993. The government of Keith Mitchell accepted the Kyoto Protocol to the UN Framework Convention on Climate Change on August 6, 2002, with it taking effect on February 16, 2005.

SEE ALSO: Carbon Dioxide; Hurricanes and Typhoons; Tourism.

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Gross National Product

THE ECONOMIC MEASURE of countries is determined by accounting. Industrialized nations tend to use Gross Domestic Product (GDP) as their chief economic indicator to allow for easier comparison with other countries standardized accounting systems. The GDP measures the value of all within-the-country products and services, including production by foreign companies/individuals and excludes overseas income and investments. In comparison, the Gross National Product (GNP) is the total dollar value of all final products and services produced for consumption during a particular time period, including the country's global personal, industrial, and government spending and investments, with allowances factored in for depreciation and indirect business (sales and property) taxes. The GNP includes income from overseas sources that would be figured in the GDP of another country.

Climate change will affect the direct economy of a country through production, services, and resources, and will influence global trade and financial markets. The atmosphere is a global resource; it is not limited to one nation in terms of addressing greenhouse gas emissions, determining the economic consequences of climate change, but must factor in losses experienced by the economies of other countries.

In addition to disrupting weather patterns, with increased frequency of hurricanes and other extreme weather events in determining economic costs and benefits (losses in one nation may be a benefit in another nation with changing agricultural, migration and tourism, energy and heating/cooling). Economic costs must include damage associated with the impact of climate change including loss of land, loss of forested areas, loss of species, loss of water quality and supply, increased healthcare costs from heat, air quality issues, and the spread of tropical diseases. Economic benefits would factor in increased production of technology for wind, solar, and biogas energy production; and increased money flow in the construction sector for building dikes, levees, infrastructure, and buildings in previously uninhabited areas

According to estimates presented by the 2006 Stern Review, climate change could cause a 5 percent reduction in the global GNP, whereas only 1 percent of global GNP would be needed to stabilize green-

A population at risk: The economic costs of global warming include the loss of land, forested areas, species, water quality and supply; increased healthcare costs from heat; air quality issues; and the spread of disease.

house gas emissions. In general, economic models predict developing nations would experience greater economic losses (reduced GNP growth) by reducing the use of fossil fuels and substituting more expensive energy sources. A limitation of the economic models is putting a dollar amount on resources with more than a market value that cannot be assessed without difficulty and multiple value judgments of the extent of damage including social, cultural, and ecological values. To estimate these costs, economists use models that show how economic output is produced from inputs such as labor, capital, and resources.

PREVENTION AND ADAPTATION

Preventive measures for limiting the extent of global warming from the greenhouse effect include reducing emissions and enhancing carbon sequestration. Adaptive measures include construction to protect against the effects of climate change, improving water resources, and improving cultivation practices or shifting crops to the match the plants' ideal weather conditions for maximum production.

There is also a shift to previously underutilize or unused commodities like carbon taxes (levied exclusively on carbon-based fossil fuels). Such a tax would raise the price of carbon-based energy sources, giving consumers incentives to conserve energy and to shift demand to alternative sources. Demand may shift from carbon-based fuels with a higher proportion of carbon, such as coal, to those with relatively lower carbon content (such as natural gas). Other techniques include: carbon credits (with each nation allocated a certain permissible level of carbon emissions and the ability to sell leftover allocations to nations who have exceeded their allocation limits), subsidizing noncarbon-based fuel providers instead of fossil fuel providers, research and development expenditures promoting the commercialization of alternative technologies, and promoting the transfer of technology to developing nations. Any measures taken to prevent global climate change will have economic effects, both positive and negative, on gross national product (GNP), production, employment, and investment.

SEE ALSO: Carbon Permits; Economics, Cost of Affecting Climate Change; Economics, Impact from Climate Change; Policy, U.S.; Policy, International.

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Gross Primary Production

TERRESTRIAL GROSS PRIMARY productivity (GPP) is a collection of complex processes performed by photosynthetic organisms that result in the conversion of light energy and water into chemical energy and the subsequent biochemical fixation of carbon dioxide into sugars. Because the supply of organic carbon exerts a dominant control on the activity of heterotrophic organisms, from bacteria to ungulates, GPP is a central process regulating the structure and functioning of ecosystems. Further, during terrestrial photosynthesis, plants transpire large quantities of water, and so GPP impacts both water and carbon cycles, and thus local, regional, and global climate. In turn, changes in climate will impact GPP at local to global scales.

Plants are responsible for most terrestrial GPP, which on an annual basis amounts to some 120 Gt carbon (1 Gt = 10^{15} g.), or about 17 percent of all carbon in the atmosphere. About half of the assimilates derived from GPP are lost back to the atmosphere through respiration processes that support important plant functions, including: nutrient uptake from soil, reduction of nitrate to the plant-available form of ammonium, phloem loading (the active export of assimilates from leaves to the rest of the plant), and for some plant species fixation of atmospheric nitrogen into ammonium. Following export from leaves the remainder of GPP is allocated to the construction of living biomass, which is often described as net primary production (NPP, or GPP less the carbon respired for construction and maintenance purposes). This carbon is allocated to a diversity of sinks within the plant, including long-lived components (above and belowground wood growth) and short-lived components (foliage and fine root production). A large fraction of GPP is allocated belowground to support symbiotic fungi and bacteria. Ultimately, all NPP will be released as CO_2 back to the atmosphere through heterotrophic utilization of plant biomass following senescence, leaching, herbivory, or exudation from roots.

The major drivers of GPP and thus NPP include climate (temperature, water, and light availability), soil fertility, species composition, and vegetation age. Ecosystem-level plant production varies widely across the terrestrial biosphere, with the highest rates where it is warm, wet, and soils are fertile; and the lowest rates where it is cold, dry, and soils are infertile. Given the important control that climate has over GPP, it is expected that climate change will impact global patterns of plant production. Interactions among driving variables will also influence how ecosystems respond to changes in climate, with responses depending on geography. Warming in colder climates will generally result in increased plant production, while warming in already warm climates may have little, or even negative impacts on GPP. Similarly, where moisture is limiting to plant productivity, warming, even with no change in rainfall, will result in declining GPP because of increased water losses to evaporation. Warming will also impact disturbance regimes (such as fires and hurricanes) that impact GPP and NPP through drastic changes in vegetation.

SEE ALSO: Carbon Cycle; Carbon Emissions; Net Primary Production.

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Guatemala

THE NORTHERNMOST OF the Central American republics, Guatemala has a land area of 42,042 sq. mi. (108.890 sq. km.), with a population of 12,728,111 (2007 est.), and a population density of 348.6 people per sq. mi. (134.6 people per sq. km.). Some 12 percent of the country's land area is arable, with another 24 percent used for meadows and pasture, and 35 percent is covered with forests. The mainstay of the economy is coffee, the largest cash crop in the country.

Underdeveloped, Guatemala has made only a small contribution to global warming and climate change. It has an extensive public transportation system, mainly using former U.S. school buses. Guatemala has one of the lower rates of carbon dioxide emissions per capita in the world, with 0.6 metric tons per person in 1990, rising steadily to 0.89 metric tons in 2003. The vast majority of the carbon dioxide emissions from the country come from liquid fuel (92 percent), with just under 8 percent from the manufacture of cement, and a negligible amount from gaseous fuels. Most of the carbon dioxide emissions are for electricity, with 50.3 percent of the electricity production rates in the country from fossil fuels, and 44.5 percent from hydropower. Guatemala also has a high rate of carbon monoxide emissions.

Increasing sea temperatures have caused worry from conservation groups that this change might affect the beaches at Monterrico, which have extensive mangrove wetlands, and are often visited by sea turtles. Increasing sea temperatures are also likely to lead to flooding, with the possibility of increased risk of malaria and dengue fever. The Guatemalan government of President Marco Vinicio Cerezo Arévalo ratified the Vienna Convention in 1987. The government of President Jorge Serrano Elías took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, and the government of President Álvaro Arzú Irigoyen signed the Kyoto Protocol to the UN Framework Convention on Climate Change on July 10, 1998, which was ratified on October 5, 1999, and went into effect on February 16, 2005.

SEE ALSO: Diseases; Floods.

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Guinea

GUINEA IS A republic in west Africa, formerly known as French Guinea, whose capital and largest city is Conakry. Its total land area is 245,857 sq. km (94,926 sq. mi.), slightly smaller than the size of Michigan. It has 200 mi. (320 km.) of coastline. The total land border is 2,112 mi. (3,399 km.). The population of Guinea is 8.8 million (2005 est.). The name Guinea is also used for the region of most of Africa's west coast south of the Sahara desert and north of the Gulf of Guinea. The climate of Guinea is monsoon and subequatorial. Maximum daily temperature (91 degrees F, or 33 degrees C) occurs July–August. Minimum daily temperature (79 degrees F, or 26 degrees C) occurs March–April. The historical maximum/minimum temperatures were 115/ 39 degrees F (46.1/3.9 degrees C). Precipitation is highest (around 157 in., or 4,000 mm., per year) along the coastal line. Precipitation peaks in the wet season (July–August); in the dry season (March–April) it falls to around zero.

Seasonal and interannual-to-multidecadal variability of temperature and precipitation in Guinea is under control of Intertropical Convergence Zone (ITCZ) evolution, as is shown by Gennady Dvoryaninov et al. The linear trend of surface air temperature and precipitation 1920–90 is insignificant for most months because of strong superimposed interannual-to-multidecadal variations. For instance, typical magnitude of interannual-to-multidecadal variations of precipitation exceeds 20 in. (500 mm.) per year. Inter-annual variability of climate of Guinea is under the influence of El Niño/La Nina events. They impact Guinea's climate through the atmospheric bridge, resulting in a change of intensity of ITCZ and west African monsoons. Transient and early mature El Niño phases are usually accompanied by more dry conditions there. Multi-decadal variability of climate of Guinea significantly depends on Atlantic multi-decadal oscillation, in which warm phases coincides with warmer conditions in Guinea.

Guinea's territory has a curved shape, with its base at the Atlantic Ocean, inland to the east, and turning south. The base borders Guinea-Bissau and Senegal to the north, and Mali to the north and northeast; the inland part borders Côte d'Ivoire to the southeast, Liberia to the south, and Sierra Leone to the west of the southern tip. A humid and tropical country, Guinea comprises an alluvial coastal plain, the mountainous Fouta Djallon region, a savanna interior, and the forested Guinea Highlands, which rise to 5,800 ft. (1,770 m.) in the Nimba Mts. Fouta Djallon highland region in central Guinea. The Niger, Senegal, and Gambia rivers rise there. The largest rivers of Guinea, with inflows into its coastal zone, are Cogon, Fatala, and Concure. Their discharge is changeable. For example, monthly average discharge of Concure (1957–84) varied from 1770 cu. m. per second (in the wet season) to less than 20 cu. m. per second (in the dry season). There are high-amplitude inter-annual variations of Concure discharge. Its maximum is met in August, when it reaches 2,800 cu. m. per second. Sea surface temperature in the coastal zone of Guinea varies from 25.4 degrees C (in March) to 27.1 degrees C (in August). Upwelling is not typical phenomenon for the Guinean coastal zone, as opposed to that of Senegal.

SEE ALSO: Senegal; Monsoons; Upwelling, Coastal.

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Guinea-Bissau

THE FORMER COLONY of Portuguese Guinea, the Republic of Guinea-Bissau has a land area of 13,948 sq. mi. (36,125 sq. km.), with a population of 1,586,000 (2005 est.), and a population density of 114 people per sq. mi. (44 people per sq. km.). Forests cover 38 percent of the country; some 11 percent of the land is arable, and 38 percent is used for meadows and pasture. Largely because it is an undeveloped state, with many of its people living in poverty, Guinea-Bissau has one of the lowest rates of per capita carbon dioxide emissions in the world, with 0.2 metric tons per person in 1990, falling to 0.18 metric tons by 2003. All the electricity production in the country comes from fossil fuels, with all the carbon dioxide emissions in the country coming from liquid fuels.

Much of the country is low-lying, with a significant number of offshore islands, and coastline that would be flooded if global warming and climate change led to a rise in water levels. Bissau, the capital, is also liable to flooding from the Rio Géba. The government of João Bernardo Vieira took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, and the government of interim President Henrique Rosa accepted the Kyoto Protocol to the UN Framework Convention on Climate Change on November 18, 2005; it went into effect on February 16, 2005.

SEE ALSO: Developing Countries; Floods; Guinea.

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Gulf Stream

OCEAN CURRENTS AFFECT not only the temperature, but also the precipitation on land areas adjacent to the ocean. A cold ocean current near land causes the air just above the water to be cold, while the air above is warm. There is very little opportunity for convection, thus denying moisture to nearby land. Coastal deserts of the world usually border cold ocean currents. Contrary to this, warm ocean currents, such as Gulf Stream, bring moisture to the adjacent land areas.

The Gulf Stream, together with its northern extension towards Europe, the North Atlantic Drift, is a powerful, warm, and swift Atlantic Ocean current that originates in the Gulf of Mexico, exits through the strait of Florida, and follows the eastern coastlines of the United States and Newfoundland (Canadian island) before crossing the Atlantic Ocean. It carries a huge amount of warm water to northerly lands, which has enormous significance to inhabitants of those areas; without it, northern Europe would be much colder and drier.

At about 30 degrees W, 40 degrees N, it splits into two, with the northern stream crossing northern Europe, and the southern stream (Canary Current) recirculating off western Africa. The Gulf Stream influences the climate of the east coast of North America from Florida to Newfoundland, and the west coast of Europe. Warm water brought to Europe's shores raises the temperature by as much as 18 degrees F (10 degrees C) in some places.

GULF STREAM ORIGINS

The origin of the Gulf Stream is debatable. One group of scientists believes that the Gulf Stream is driven both by the rotation of the Earth and by a deep-water current called the thermohaline circulation. Another group of scientists accept the theory propounded by Henry Stomme in 1948, that the Gulf Stream is a wind-driven phenomenon. Heating and cooling affect its temperature and other properties, but not its basic existence or structure. Stomme theorized that as long

A NASA satellite image shows the Atlantic Ocean, off the shore of Georgia and the Carolinas, where the Gulf Stream current curves out to sea away from the North American continent.

as the sun heats the Earth and the Earth spins, there will be winds, and there will be a Gulf Stream.

There is some speculation that global warming could decrease or shut down thermohaline circulation, and therefore reduce the North Atlantic Drift. The time frame for this might happen is unclear; estimates range from few decades to a few hundred years. This could trigger localized cooling in the north Atlantic and lead to cooling (or lesser warming) in that region, particularly affecting areas such as the Scandinavian countries and the United Kingdom. The slowdown, which climate modelers have predicted will follow global warming, has been confirmed by the most detailed study yet of ocean flow in the Atlantic. Most alarmingly, the new research reveals that a part of the current, which is usually 60 times more powerful than the Amazon River of South America, came to a temporary halt during November 2004.

Recent research has shown that changes are occurring in the Gulf Stream. According to scientists, in the absence of the Gulf Stream and its two northern branches, the north Atlantic Drift and the Canary Current, the weather in the United Kingdom could be more like that of Siberia, which lies on the same latitude. According to Peter Wadhams of the University of Cambridge, changes are occurring in the water of the Greenland Sea. Historically, large columns of very cold, dense water in the Greenland Sea, known as chimneys, sink from the surface of the ocean to about 9,000 ft. (2,743 m.) below, to the seabed. As that water sinks, it interacts with the warm Gulf Stream current flowing from the south. However, the number of those chimneys, according to Wadhams, has decreased from about a dozen to just two. That is causing a weakening of the Gulf Stream, Wadham asserts, which could mean less heat reaching northern Europe. It is possible that the coastal areas of western Europe could be converted into deserts. However, this would require much more extensive research on changing land use patterns in coastal areas.

Harry Bryden, of the National Oceanography Centre in Southampton, presented his findings to a conference in Birmingham on rapid climate change. Bryden's research group stunned climate researchers in 2006, with data suggesting that the flow rate of the Atlantic circulation had dropped by about 6 million tons of water a second 1957–98. If the current remained that weak, Bryden predicted, it would lead to a one degree C drop in the United Kingdom in the next decade. A complete shutdown would lead to a 7–11 degree F (4–6 degree C) cooling over 20 years.

Bryden's study prompted the United Kingdom's National Environment Research Council to set up an array of 16 submerged stations spread across the Atlantic, from Florida to northern Africa, to measure the flow rate and other variables at different depths. Data from these stations confirmed the slowdown in 1998 was not a "freak observation," although the current does seem to have picked up slightly since then. Richard Seager, who presented his research to the New York Academy of Sciences on "The Gulf Stream: European Climate and Abrupt Climate Change," expressed similar views. Seager states that a slowdown of the Gulf Stream and ocean circulation in the future, induced by freshening of the waters caused by anthropogenic climate change (via melting of glaciers and increased water vapor transport into high latitudes) or simply by warming, would introduce a modest cooling tendency. This would leave the temperature contrast across the Atlantic unchanged. In fact, the cooling tendency would probably be overwhelmed by the direct radiatively driven warming from rising greenhouse gases.

SEE ALSO: Current; North Atlantic Oscillation; Ocean Component of Models; Oceanic Changes; Thermohaline Circulation.

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Guyana

GUYANA'S LOW-ELEVATION COAST hosts the majority of its population. It is predicted to become one of the world's top 10 most impacted nations from sea level rise in terms of the percentage of the population and extent of urban area implicated. Ranging from a low estimate of 16 percent to a high estimate of 103 percent, Guyana is expected to have one of the greatest losses in gross domestic product in the Caribbean as a result of climate change. One of the poorest countries in the western hemisphere, Guyana remains reliant on foreign assistance to mitigate potential consequences. Researchers have demonstrated an urgent need to update flood control. Irrigation technologies also need rehabilitation. The name Guyana is Amerindian for "Land of Water," but the country may be losing its fresh groundwater. It has been suggested that this may contribute to coastal subsidence.

The capital city Georgetown is located along Guyana's 270-mi. (434 km.) coast. Three quarters of the national population of 765,000 lives within 20 mi. (32 km.) of the sea. This same area hosts most agricultural production. Drainage is a major problem, and agricultural irrigation systems must control seawater intrusion. The centerpiece of the outdated drainage and irrigation infrastructure is the East Demerara Water Conservancy (EDWC) Dam. This structure was developed in 1880 and holds a volume of more than 100 sq. mi. (259 sq. km.) of water, but it is currently believed to over-top and seep. Defective intake contributes to dry season water shortages.

Sea level rise in Guyana is believed to be two to five times higher than global averages. It was measured at an excess of 0.3 in. (10 mm.) annually 1951–79. Research suggests that this trend has continued. Major floods in 2005 and 2006 demonstrated an inability to clear water. The impact of the flood in 2005 has been estimated at 60 percent of GDP. Many biodiverse ecosystems exist in Guyana, including mangroves in low-lying areas. Guyana hosts an extensive tropical forest that makes up a northern portion of the Amazon rainforest. In 2000, forests covered over 70 percent of the country, but multinational timber and mining concessions have accelerated deforestation.

Guyana ratified the United Nations Convention on Climate Change in 1994 and the Kyoto Protocol in 2003. The country has compiled an extensive climate change action plan. It is part of the Caribbean Planning for Adaptation to Global Climate Change Project. Georgetown hosts the administrative headquarters of the Caribbean Community (CARICOM). CARICOM is involved in climate change vulnerability assessments and adaptation programs.

As many countries in the region, including Guyana, rely heavily on fossil fuel, CARICOM oversees research on alternative energy. A bagasse cogeneration project is the first initiative in the nation under review for support from the Clean Development Mechanism.

SEE ALSO: Floods; Salinity; Sea Level, Rising.

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Hadley, George (1685–1768)

GEORGE HADLEY WAS an English lawyer, physicist, and meteorologist who first accurately theorized a hypothesis for the trade winds and the associated north-south circulation pattern now known as the Hadley Cell. This piece of information was particularly important in Hadley's times, as it helped the journeys of English vessels toward North American shores. Hadley was intrigued that winds that should have blown northward had, instead, a western course.

Hadley was born on February 12, 1685, in London, England to Katherine FitzJames and George Hadley. He was part of a family of six children and his father was the high sheriff of Hertfordshire. George was initially overshadowed by the fame of his brother John, the inventor of the octant. He studied law, but soon found out that he preferred physics to legal work. For 7 years he was in charge of the meteorological observations for the Royal Society.

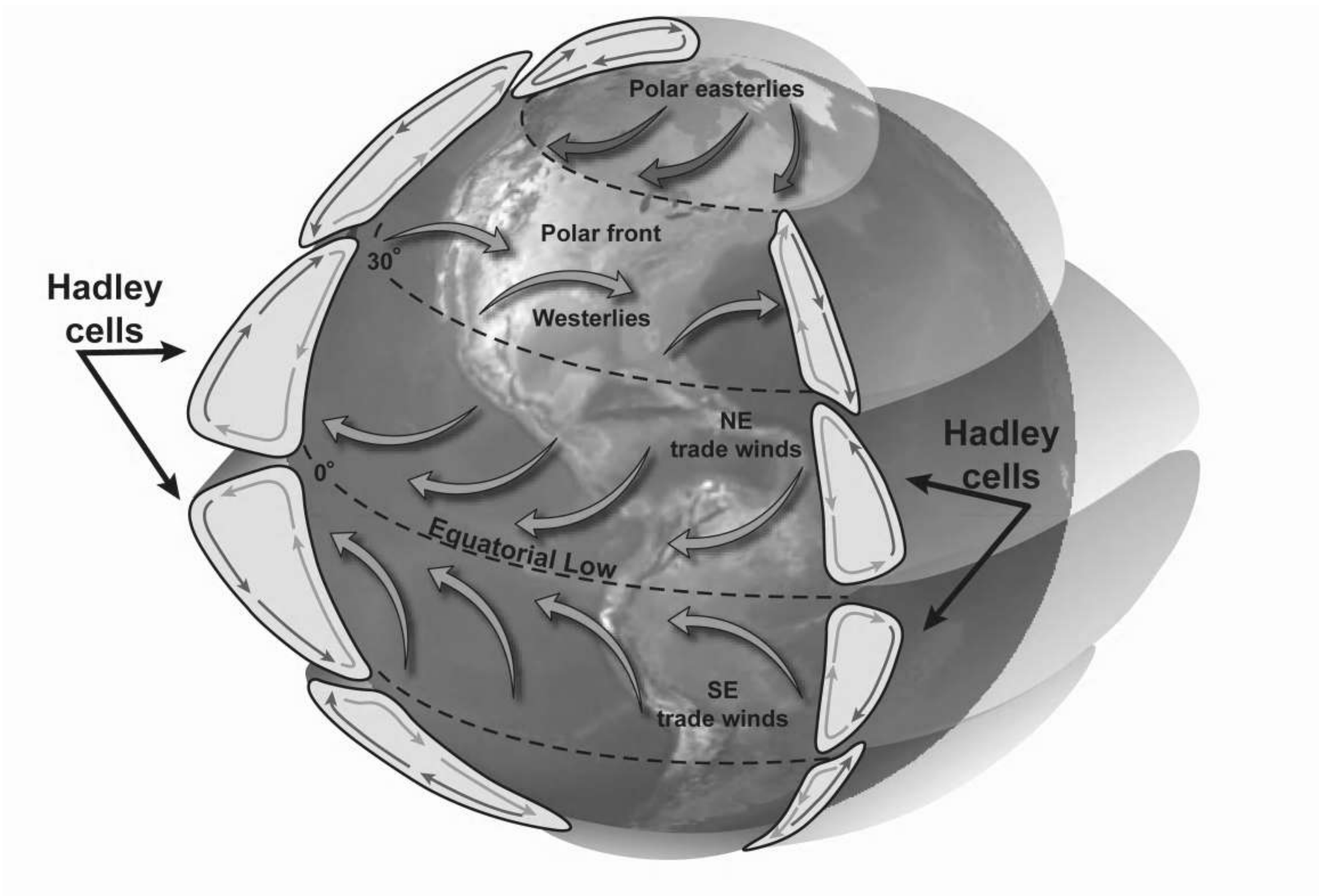
Yet, his fame rests on his work of the 1730s, when Hadley was able to complete Edmond Halley's theory of trade winds. Halley had failed to explain completely the westward component of the trades. In his famous paper "Concerning the Cause of the General Trade Winds," published in 1735, Hadley related the direction of trade winds to the rotation of the Earth.

The meteorologist started from the well-known fact that air at the equator is heated more strongly than at any other place on Earth. Air above the poles is cooler than at any other location. Therefore, it is speculated that surface air near the equator will ascend into the upper atmosphere and, above the poles, descend from the upper atmosphere to ground level. In order to balance these vertical movements of air, Hadley also assumed that air flows across the Earth's surface from each pole back to the equator and, in the upper atmosphere, from above the equator to above the poles.

This movement of air is called a convection cell, where convection describes the transfer of heat carried by a moving fluid. Yet, Hadley knew that his model was too simplified to explain the motion of the winds, which obviously do not blow from north to south in the Northern Hemisphere and from south to north in the Southern Hemisphere. He then explained that winds actually tend to blow from the east or west because of Earth's rotation.

The movement of the planet causes airflows that would otherwise be from the north or south to be diverted to the east or west. Because of his fame, Hadley was elected a Royal Fellow in 1745. He died on June 28, 1768.

A century after Hadley first proposed his theory, the French physicist Gaspard Gustave de Coriolis



Hadley Circulation provides westward windflow at the Earth's surface and eastward jet streams at higher altitudes. The circulating air patterns create convection currents in four global locations—each current is called a Hadley cell.

devised a mathematical description detailing how an object, in motion on a rotating body, follows a curved path in relation to any other body on the same rotating body.

SEE ALSO: Coriolis Force; Wind-Driven Circulation; Winds, Easterlies; Winds, Westerlies.

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Hadley Circulation

HADLEY CIRCULATION IS a type of atmospheric circulation following a stereotypical pattern in the para-equatorial region. Atmospheric circulation and ocean circulation together are the major mechanisms for global heat distribution. As ocean circulation refers to movement of waters, atmospheric circulation defines large-scale air movements around the globe. The principle tropical current known as Hadley Circulation affects jet streams, subtropical deserts, trade winds, and tropical rainbelts. Hadley Circulation provides westward windflow at the Earth's surface and eastward jet streams at higher altitudes.

The circulating air patterns create convection currents in four global locations—each current is called a

Hadley cell. The pattern of air movement is toward the Earth (prograde) at higher latitudes (in the subtropics) and backward (up from the Earth) at lower latitudes (near the equator). The movement occurs near the Earth's surface—within 6.2–9.3 mi. (10–15 km.). Its span across latitudinal markers remains within thirty degrees north or south of the equator. In this way, a Hadley cell moves heat from the equatorial region to regions within 30 degrees of latitude in either direction. Moisture is moved along with the heat.

In a Hadley cell, the air rises to the atmospheric tropopause, which is the region at the top border of the troposphere and thus the bottom border of the stratosphere. The troposphere is the lowest atmospheric region and is where all weather takes place. At the equator, it reaches up to 11 mi. (18 km.) from the earth's surface.

The next atmospheric layer is the stratosphere, extending to 31 mi. (50 km.) from the Earth's surface. This characteristic air circulation results from the Sun's rays heating the air at the level of the equator. Solar heating is strongest at the equator and weakest at the north and south poles, due to the direction of the Sun's rays, and therefore currents of atmospheric circulation due to solar heating are more prominent at the equator.

Hadley Circulation was first described by George Hadley (1685–1768) to explain the science behind the trade winds. It was to replace a flawed model that had been presented by Edmond Halley (1656–1742). George Hadley was an early 18th century meteorologist by hobby and lawyer by trade.

In fact, Hadley's theory was imperfect as well. It was corrected by American meteorologist William Ferrel (1817–91) at the end of the 19th century, but by this time Hadley's name had stuck. The Hadley Circulation is traditionally defined as resting on the equator; in fact it rests on the "thermal equator," or the Sun's zenith.

SEE ALSO: Atmospheric Boundary Layer; Atmospheric Vertical Structure; Computer Models; Current; Global Warming; Gulf Stream; Hadley, George; Ocean Component of Models; Stratosphere; Trade Winds; Tropopause; Troposphere.

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Haiti

THE REPUBLIC OF Haiti is located on the western part of the island of Hispaniola in the Caribbean. It has a land area of 10,714 sq. mi. (27,750 sq. km.), a population of 8,528,000 (2005 est.), and a population density of 758.1 people per sq. mi. (292.7 people per sq. km.). 20 percent of its land is arable, with a further 18 percent used for meadows and pasture. Haiti's farmland is divided into more than 500,000 farms, many of which are subsistence farms. Less than 4 percent of the country is still forested, a figure that is quickly declining because of the heavy demand for charcoal, and wood for construction.

Deforestation and flooding from global warming, and rising water levels have contributed to soil erosion, leading to major efforts to reduce the cutting down of trees. The Haitian Environmental Foundation has tried to replace charcoal cooking stoves with ones using briquettes of secondhand paper. U.S. aid workers are trying to replace 50,000 wood stoves with oil-fired burners each year.

Also badly affected by hurricanes, deforestation, and pollution, Haiti remains heavily underdeveloped, and, as a result, has one of the lowest rates of carbon dioxide emissions per capita in the world. Currently, Haiti ranks 181st, with 0.21 metric tons per person emitted in 2003, which is double the level achieved in 1990. Much of this rise has been accounted for by the rising level of prosperity among the middle class of the country, leading to increased use of private cars instead of reliance on the taptaps, the brightly colored pickup trucks still used for public transport in rural areas. There has also been a rise in the demand for electricity, much of it either for general household use or for air conditioning. Fossil fuels provide 68.9 percent of the electricity production in Haiti, and 31 percent comes from hydropower.

The Haitian government of the provisional president Joseph Nérette took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, and the government of René Préval ratified the Vienna Convention in 2000. The provisional government of Boniface Alexandre accepted the Kyoto Protocol to the UN Framework Convention on Climate Change on July 6, 2005, which took effect on October 4, 2005.

SEE ALSO: Agriculture; Deforestation; Hurricanes and Typhoons.

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Hansen, James (1941–)

DIRECTOR OF THE National Aeronautics and Space Administration (NASA) Goddard Institute for Space Studies in New York and adjunct professor in the Department of Earth and Environmental Studies at Columbia University, James Hansen has come to the public attention in contemporary debates about global warming for his harsh critique of the environmental policies pursued by the George W. Bush Administration. He has also unequivocally stated that, because of such criticism, it is increasingly difficult for him to speak freely about the emission of greenhouse gases and global warming. In 2005 and 2006, Hansen claimed, in several interviews with the *Washington Post* and the *New York Times*, that officials at NASA headquarters were ordering the public affairs staff to review his coming lectures, papers, postings on his mailing lists and website, and requested interviews from journalists. This was due to his critical statements made during a lecture at the American Geophysical Union in San Francisco in December 2005. In Al Gore's Academy Award-winning documentary, *An Inconvenient Truth* (2006), Hansen has repeated the charge of having been manipulated. Since the late 1980s, Hansen has been issuing public statements about the long-term threats deriving from heat-trapping emissions, dominated by carbon dioxide. To Hansen, these are an unavoidable byproduct of burning coal, oil and other fossil fuels.

Born on March 29, 1941, in Denison, Iowa, Hansen was educated at the University of Iowa where he obtained a B.A. in Physics and Mathematics with highest distinction in 1963, an M.S. in Astronomy, in 1965, and a Ph.D. in Physics, in 1967. He took part in the NASA graduate traineeship program from 1962 to 1966 and, at the same time, between 1965 and 1966, he was a visiting student at the Institute of Astrophysics at the University of Kyoto and in the Department of Astronomy at the University of Tokyo. After serving as a Postdoctoral Fellow at the Leiden Observatory in the Netherlands, in 1969, and as a Research Associate at Columbia University, from 1969 to 1972, Hansen joined the Goddard Institute for Space Studies. He has directed the Institute since 1981, and has worked as an adjunct professor at Columbia since 1985. As a college student, Hansen was first attracted to the James Van Allen Space Science Program, but later focused on planetary research dealing with climate change on Earth resulting from anthropogenic changes of the atmospheric composition.

One of Hansen's main research interests is radiative transfer in planetary atmospheres, especially interpreting remote sounding of the Earth's atmosphere and surface from satellites. Analyses of such data could constitute one of the most effective ways to monitor and study global change on the Earth. Hansen is also interested in the development and application of global numerical models for the purpose of understanding current climate trends and assessing potential human impacts on climate.

In the 1980s, Hansen was one of the first scientists to point out that the process of global warming was already taking place and that its effects would be visible beginning in the 1990s, not 2020, as most of his colleagues argued at the time. He suggested in his paper, "Global Warming in the Twenty-First Century" (2000), an "alternative scenario" for global warming and its possible solution. In it, Hansen claims that we should focus on non-CO_2 gases and black carbon in the short run, giving more time to make reductions in fossil fuel emissions. According to his alternative scenario, the current warming up of temperatures is largely due to non-CO_2 gases. Hansen stresses the role of climate-cooling aerosols emitted with fossil fuel burning in offsetting CO_2 warming and he points out that non-CO_2 gases, taken together, are responsible for roughly 50 percent of greenhouse gas warming. In "Defusing the Global Warming Time Bomb" (2003), Hansen has further developed his ideas on climate change, reaching the conclusion that human actions now far surpass the impact of natural elements in changing the climate. He has pleaded for an urgent and unprecedented international cooperation to control climate change. Hansen has predicted that 2016 will be the global tipping point (also known as the runaway effect) for global warming, if the human population is unable to reduce greenhouse gases.

Although he describes himself as a "middle-of-the-road" conservative, Hansen publicly endorsed John Kerry in the 2004 Presidential Election. This decision was motivated by his disillusion with the environmental policies pursued by the Goerge W. Bush Administration. Hansen is also particularly critical of the U.S. responsibility for the global warming phenomenon. He has repeatedly stressed that determining responsibility for climate change should not be limited to current emissions. The effect of greenhouse gas emissions on climate is determined by accumulated emissions over the lifetime of greenhouse gases in the atmosphere.

If we take into account past emissions, the United States can be described as the largest single cause of climate change, even after its current emissions are surpassed by China and other developing countries. According to Hansen, there are concerted efforts to mislead the public about issues of climate change and to dismiss the problem of global warming as a hoax. On the contrary, he points out that the phenomenon is very real, and that changes needed to keep it in check do not require hardship or reduction in the quality of life, but will also allow an improvement of life conditions such as cleaner air and water, and the growth of high-tech industries.

SEE ALSO: *An Inconvenient Truth*; Carbon Dioxide; Goddard Institute for Space Studies.

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Harvard University

HARVARD UNIVERSITY, IN Cambridge, Massachusetts, is the oldest school of higher education in the United States. Founded in 1636, in the Massachusetts Bay Colony, the school was named Harvard College in honor of John Harvard, a clergy member who left half his fortune and his library to the college. Harvard University remains a private school governed by a corporation, the president, and fellows of Harvard College. Harvard offers undergraduate, graduate, and professional study in many academic disciplines (such as law, medicine, business, and education) in several schools and centers.

EARTH SYSTEMS STUDIES

The approach to teaching and research related to Earth systems, including climate, is integrated throughout the departments and inclusive of all disciplines. Many academic courses related to climate studies or atmospheric sciences are taught by the Faculty of Arts and Sciences (FAS), founded in 1890 by the merger of the College Faculty (also Faculty of the Graduate School) and the Scientific School Faculty. The FAS includes Harvard College (undergraduate), the Graduate School of Arts and Sciences, School of Engineering and Applied Sciences, and Division of Continuing Education, including Harvard Extension School. Environmental courses are offered to undergraduates and graduates across numerous schools and departments and with neighboring schools, Massachusetts Institute of Technology (MIT) and Tufts University, including the various sciences, economics, business, philosophy, religion, literature, and law.

The options for graduate students include combining science and engineering. Those interested in life science have opportunities to work with chemists, physicists, and computer scientists to study and simulate biological processes. Engineers and physical scientists observe and apply natural principles and processes to create human-made materials and products. The Graduate School of Arts and Sciences offers a Master of Science, Master of Engineering in Applied Mathematics, Applied Physics, Computer Science, and Engineering Sciences, and a Doctor of Philosophy in Science, Technology, and Management (with Harvard Business School). Instead of traditional academic departments and degrees by specific research area, these graduate programs rely on the convergence of engineering, applied sciences, and technology, and allow for specialization, including studies in Environmental Sciences and Engineering.

HOLISTIC MODEL

The Department of Earth and Planetary Sciences relies on a holistic model of the Earth, incorporating physics, chemistry, astronomy, and biology to study the intimate link between human life and the Earth and its systems. In addition to bringing together a variety of disciplines for scientific discovery, the department incorporates colleagues in social sciences and humanities to address societal issues pertaining to the human/Earth interrelationship.

The facilities include laboratories with instruments for a wide range of analyses, libraries, and lecture rooms of the Department of Earth and Planetary Sciences in the University Museum and in the David and Arnold Hoffman Laboratory of Experimental Geology. A variety of external research facilities and sites are available to students for research, including the seismograph station at the George R. Agassiz Station of the Astronomical Observatory in Harvard, Massachusetts, about 25 mi. (40 km.) west of Cambridge. Harvard also has reciprocal instructional and credit-granting arrangements with MIT and the Woods Hole Oceanographic Institution for graduate students.

Examples of research conducted by the Department of Earth and Planetary Sciences are showcased by the ecological measurements taken at Prospect Hill in Harvard Forest in Petersham, Massachusetts and on a privately owned site adjacent to Prospect Hill. On specifically sized (10 m. radius) plots, scientists record tree growth, woody debris, litter-fall, leaf litter decomposition, leaf-area increment, foliar nitrogen content, soil respiration, and soil moisture. Also at the Harvard Forest is the Fisher Museum, open to the public. The exhibit includes dioramas on central New England forests' history, conservation, and management. The museum also has self-guided interpretive trails. These trails connect the museum to the research forest.

MILLIONS OF YEARS

The goal of study in atmosphere, ocean, and climate dynamics at Harvard is to understand the Earth's weather and climate, over timescales of days to million years, by studying the systems controlling the circulation of both the atmosphere and the ocean. Of special interest is finding sources of variability (such as irregularity of El Niño, periods of ice ages, and precipitation patterns). Ongoing research includes programs for improving weather prediction and El Niño prediction.

A variety of research projects at Harvard Forest include measuring nitrogen oxide concentrations at Harvard Forest, a study of carbon and nitrogen in the soil, along with soil temperature and moisture; and soil respiration with soil temperature and moisture. In relation to climate science, a study by one research group working at the Harvard Forest includes collection of data on greenhouse gas concentration and flux, and carbon storage. Another group has measured ozone-depleting and/or greenhouse gases above the forest canopy at Harvard Forest since 1996. In the experimental and theoretical laboratory, researchers perform work on ozone chemistry in the stratosphere/troposphere.

Atmospheric and climate dynamics research topics include the study of past and present weather, and processes for creating climate models, global atmospheric and oceanic circulations, atmosphere-ocean exchange of energy and water, as well as studies on exchange of carbon dioxide and reactive gases with the biosphere, life-cycles of aerosol particles, and the effects of changes in atmospheric composition on climate. Additional opportunities for students include the Atmospheric Chemistry Journal Club to bring together the various groups in atmospheric chemistry for discussion and collaboration on atmospheric science topics. Past topics have covered "Scientific Consensus on Climate Change" and "Saturation of the Southern Ocean CO_2 Sink due to Recent Climate Change".

RESEARCH INSTITUTES

Some of the many research institutes at Harvard focus on modeling to better understand life systems and the universe, including climate. At the Kavli Institute for Bionano Science and Technology, technology meets life and biology. The institute harnesses a variety of academic disciplines to address behavior and function of biological systems. FAS began the Center for Imaging and Mesoscale Structures in 1999, the center was renamed the Center for Nanoscale Systems and became part of the larger National Nanotechnology Infrastructure Network in 2004, for availability to researchers on a local and national basis. The focus of CNS is to integrate nanoscale components into large and complex interacting systems to study how small structure behavior varies from the larger system and objects.

At the Harvard University Center for the Environment (HUCE), the complexities of environmental dynamics requires an integrative approach. To meet this need, HUCE brings together faculty members and students from a wide range of academic disciplines (the sciences, engineering, public health, government, business, economics, and law) to research complex environmental problems with the potential for global impact. In addition, the center sponsors symposia, public lectures, and informal student convocations to connect everyone with an interest in the environment.

Edwin Land founded the Rowland Institute for Science in the early 1980s. In 2002, the institute merged with Harvard University. The institute focuses on experimental science over a wide range of academic disciplines (current research includes physics, chemistry, and biology). The facility support includes a laboratory, a precision machine-shop including a welding facility, an electronics engineering lab to fabricate custom instrumentation, and a library/information center.

In 1998, the Harvard Institute for International Development and the Kennedy School of Government established the Center for International Development (CID) at the Kennedy School. The goal of CID is to support sustainable international development research, by bringing together academics and researchers from across Harvard's schools and with international colleagues. The complex issues (including managing climate change and environmental issues) related to global development require input from a variety of views. The Sustainability Science Program presents the dynamics of human-environment systems to encourage practical application through research, innovation, policy, and management. The center offers a Master in Public Administration in International Development degree to prepare students.

The Harvard Green Campus Initiative (HGCI) started in 2000 to focus on making Harvard an example of sustainability. HGCI staff and students develop services for money-saving and environmentally-friendly results, including building upgrades, construction, and design; greenhouse gas reduction; procurement; renewable energy; reduced waste and recycling; and environmental training and education. Using a business model, HGCI seeks challenging solutions to complex problems within time, economy, and social policy. Strategy is based on value to assure that each program is financially and organizationally viable and makes a difference in improving the environment.

A few examples of the success of HGCI include construction (green building projects with energy performance 30 to 50 percent above code and 90 percent recycling of construction waste); Green Living programs (a 40 percent increase in recycling and 10 to 15 percent reduction in energy use); campus-wide green cleaning service; the use of biodiesel in Harvard buses; Waste Management and Recycling Service achieving 45 percent recycling rate; and a Commuter Choice Program to encourage use of public transport and bicycling. The goal of HGCI and working partners is to continue to demonstrate the viable approach of sustainability within the context of business and economy. As part of an extensive cooperation, an International Students' Committee (ISC) office at Harvard University connects Harvard students with St. Gallen University in Switzerland to support the St. Gallen team members planning and participation in the St. Gallen Symposium.

SEE ALSO: Massachusetts Institute of Technology; National Oceanic and Atmospheric Administration (NOAA); Sustainability; University of St. Gallen; Woods Hole Oceanographic Institute.

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Hawaii

AN AMERICAN STATE in the central Pacific, Hawaii consists of eight large islands and hundreds of islets stretching more than 1,500 mi. (2,414 km.). Located about 2,500 mi. (4,023 km.) from the mainland of the United States, this 50th state is unique in composition. Less than 6,500 sq. mi. (16,835 sq. km.) of total land area is divided 48 percent for conservation and 47 percent for agriculture. The division reflects the two largest industries of the state, tourism and food processing, with tourism contributing substantially more to the state's economy. In 2006, more than 7.5 million visitors spent $12.4 billion in Hawaii. Tourism generates more than 25 percent of the state's tax revenues. The economic crisis that Hawaii faced after 9/11, a crisis categorized as the most severe in Hawaii's history, made clear how dependent the state is on tourism, and tourism is dependent upon the island paradise that Hawaii's image promises. Hawaii has begun to take steps to preserve that image.

Changes, many of them attributed to global warming, are already threatening the paradise. In Honolulu, the average temperature has increased by 4.4 degrees F (2.5 degrees C) over the last century, and precipitation has decreased some 20 percent in the last 90 years. The Intergovernmental Panel on Climate Change projects increases in temperature by 3 degrees F (1.6 degrees C) or more by the beginning of the next century. Such warming would likely lead to an increased number of extremely hot days, and could also lead to increases in the intensity of thunderstorms.

The rising sea levels that accompany warmer temperatures create additional problems. The sea level is already increasing by 6–14 in. (15.2–35.5 cm.) per century. Erosion has been an ongoing problem for the islands for half a century. Some sources say that as much as 2 percent of the state's coastline is critically eroding, with losses ranging from 0.5–1 ft. (0.15–0.3 m.) per year. Nearly 25 percent of Hawaiian beaches have been significantly degraded. In the mid-1990s, Whale-Skate Island, a primary breeding ground for monk seals, started eroding. By 1998, the island had disappeared completely, placing this species in jeopardy.

Researchers note that most of Hawaii's plant and animal species are found only in the islands. The remote, unpopulated islands are home to some of the largest seabird colonies in the world. The state is also the world's leading site for extinct and endangered species. Approximately 70 percent of U.S. extinctions have happened in Hawaii, and more endangered species per square mile can be found in Hawaii than in any other place on the planet. While some experts are cautious about attributing such changes to global warming, others argue that climate change is at least a contributing factor.

HAWAII'S UNIQUE ENERGY PROFILE

Hawaii's isolation from the mainland United States and its non-energy intensive economy make the state's energy profile distinctive. Per capita energy consumption is among the lowest in the nation, and the state ranks 51st in its carbon dioxide production. However, the state's energy needs are growing; they increased by 18 percent 2003–04. Over one half of the state's energy consumption can be attributed to the transportation sector, particularly the jet fuel consumed by military and commercial flights. Only Alaska consumes more jet fuel. Hawaii burns very little coal (only 14 percent of its energy), but it is the most oil-dependent of the 50 states. Nearly 90 percent of the state's petroleum is imported.

Hawaii began to address the problems of climate change actively in 1989, when the state legislature voted to create the nation's first energy performance contracting program designed to foster the development of public-private partnerships that would increase the use of more energy-efficient technologies. In 2004, Hawaii enacted a law that required the state's public utilities to provide 8 percent of their electricity from renewable sources by December 31, 2005. The act required an increase of 10 percent renewable sources by 2010, with an annual increase of 1 percent until a 20 percent increase is attained in 2020. The act also mandated that the Department of Land and Natural Resources and the Department of Business, Economic Development, and Tourism foster development of renewable energy projects within the private sector. According to the U.S. Department of Energy, Hawaii ranks 5th among the 50 states in the use of non-hydro renewable energy.

In 2006, Hawaii Governor Linda Lingle signed into law four bills that were part of the Energy for Tomorrow program. The first law raised the income tax credit for certain renewable energy technologies, making this tax credit permanent, and provided incentives to support the production of biodiesel and cellulosic ethanol. It also created the Hawaii Renewable Hydrogen Program to move the state toward a renewable hydrogen economy. Other laws included in the package appropriated funds for solar power systems in public schools, required 20 percent of the state's new vehicles to be hybrids or alternative fuel vehicles, with the percentage increasing in subsequent years, established a public benefits fund for energy efficiency programs, and authorized the state's Public Utility Commission (PUC) to set penalties for failing to meet the state Renewable Portfolio Standard (RPS). A final act appropriated monies to reauthorize the Hawaii Energy Policy Forum and charged that reconvened group with developing an action plan.

The state's most ambitious move came in 2007 when Hawaii, following California's example, became the second state in the nation to place a statewide, enforceable limit on greenhouse gas pollution. A task force was given until the end of 2009 to develop the regulations that will allow the state to reduce greenhouse gas emissions to 1990 levels by 2020. The state Department of Health and Department of Business, Economic Development, and Tourism will assist the task force. Critics point to the exclusion of emissions from air transportation, despite that sector's high contribution to CO_2 emissions.

SEE ALSO: Alaska; California; Tourism; Transportation.

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Health

GLOBAL WARMING AND climate change may produce a wide variety of harmful impacts on human health. Although the magnitude and timing of climate change and the effects of human adaptation are not known with certainty, some inferences have been drawn from existing models. These models attempt to use historical scientific data and current global or regional trends to estimate a range of possible future outcomes. There remains significant disagreement in both scientific and political circles regarding trends in global warming, potential threats posed by change, and the need for mitigation effort. Five major potential outcomes of global warming and climate change associated with significant health consequences include increases in ambient temperature, weather extremes, shifts in infectious disease patterns, changes in air quality, and resource pressures associated with migration and adaptation.

BACKGROUND

Public health practitioners and medical researchers in government, academia, and other agencies around the world are studying possible health impacts of global warming and associated climate change. There is a growing body of literature used to help understand current trends and extrapolate future trends, representing the work of experts from many disciplines, working to understand health effects. Increasingly, this research takes place through collaborative partnerships or organizations comprised of experts from across the globe. Two examples of these types of collaborative efforts are research conducted by the World Health Organization (WHO) and the Intergovernmental Panel on Climate Change (IPCC).

Both direct and indirect health effects can occur from transient heat increases, extreme weather events, water availability and quality, changes in air quality and atmospheric protection, infectious diseases, and the interplay of these factors. Although some impacts may be positive, such as the possibility that increased winter temperatures may result in lower seasonal morbidity and mortality in some areas, the overall impact of global warming and climate change on human health is expected to be negative. This imbalance is partly attributed to the likelihood that climate changes over the next several centuries will outpace local and regional capacity for adaptation in many areas.

There are many uncertainties and challenges in accurately predicting the health effects of global warming and climate change. Partly, this is because the overall outcomes depend extensively on other factors that impact human health and compound their effects. These factors include population expansion, energy production, pollution or misuse of land and water resources, deforestation, and urbanization. Another complication in predicting the health effects are the many ways in which health impacts may be offset by continuing scientific advances in medical care, pharmacology, and public health. This may prove especially important with improved access and resources in developing countries.

Effects of global warming and climate change are expected to vary by population socio-demographic characteristics and by geographic area. People in developing countries are particularly vulnerable, in part, because of the reduced resources for planning and responding to changes, often due to geographic location. People who live in areas that are prone to extreme weather events, such as coastlands and lowlands, are more likely to be adversely affected. In many areas, people who contribute the least to global warming and climate change (through energy consumption and waste production) will be the most vulnerable to its effects. In both developed and developing countries, the poor, elderly, very young, and chronically ill are more vulnerable than healthier or more affluent people. Finally, there are many areas that are currently only sparsely populated, due to marginal water and food resources. With relatively small changes in average annual temperature or shifts in rainfall patterns, many of these areas will no longer support sustained human activity. Other areas that are currently too cold or arid may become more hospitable, but migration requires tremendous amounts of resources, and often requires travel across semi-permeable political (or cultural) boundaries.

TEMPERATURE INCREASES AND EXTREMES

Average temperature has increased globally over the past few decades and is expected to increase between 2.5–10.4 degrees F (1.4–5.8 degrees C) by the end of the 21st. century. An increase in mean temperature occurs in the context of fluctuating local, regional, seasonal, and other patterns. This translates to higher temperatures at the extreme, which in turn, are directly related to short-term human illness and death. For context, the estimated average temperature for the most recent ice age was approximately 7.2–9 degrees F (4–5 degrees C) below the mean temperature over the subsequent 10,000 years to the present. Research in this area has been especially controversial because of evidence of historic variation in temperature and difficulty establishing valid associations, in the context of global environmental complexity. Increasing mean temperature may be the most direct and measurable component of global warming and climate change, and health effects may be more related to extremes (both hot and cold) than to overall increased temperature.

Many scientists have proposed that the most significant impact of increasing mean temperatures will be the related disruption of regional and global weather patterns, driven, in part, by alterations in oceanic and atmospheric temperatures and currents. Relatively minor shifts in major currents, such as the Gulf Stream and El Niño, produce significant changes in the frequency and intensity of local storms and rainfall patterns.

It is expected that there will be both direct (or more immediate) impacts, as well as indirect impacts, of temperature changes and extremes. The most direct and observable effects are heat strokes and deaths related to heat extremes. Indirect effects are more debatable and difficult to attribute to any one cause, but one possibility is decreased health related to decreased physical activity, and more time spent indoors in air-conditioned environments. Some research has also shown associations between higher temperatures and violence in urban areas.

In summer 2003, a two-week heat wave in Europe killed tens of thousands of people. It was estimated that summer temperatures averaged 6.3 degrees F (3.5 degrees C) above baseline, perhaps the hottest season in several hundred years. Lessons learned include highlighting the vulnerability of elderly and health-impaired individuals, and the disparate impact of temperature extremes on poor people and resource-poor communities. This event was particularly important for future planning, because it highlighted the continuing inadequacy of mitigation plans and available resources in developed countries. Another compounding factor is the increased ambient temperature of urban areas, which can result in a significant contribution to morbidity and mortality during peak heat events.

Increases in average ambient temperature are also expected to contribute to melting of ice caps and glaciers, which currently reflect large amounts of incident radiation (albedo), potentially leading to further global warming and climate change that may negatively impact health at regional and global levels.

EXTREME WEATHER EVENTS

Flooding, drought, and environmental degradation associated with climate change may lead to population displacement and more environmental refugees. Sea-level rise is likely to affect low-lying coastal populations, especially in countries where economic means do not allow construction of sea defenses and other counter-measures. Human populations have tended to concentrate in major cities over the past 150 years, and many of the largest population centers are located on low-lying oceanfront terrain, often with an associated major river delta.

As with heat changes and extremes, there are expected to be both direct and indirect health effects of extreme weather events. Direct health impacts include injury and mortality associated with these events. There are potentially many more indirect effects, such as increases in vector-borne diseases associated with flood waters, the spread of infectious diseases in sewage runoff and poor drinking water in the aftermath of these events, and increases in mental illnesses due to community displacement, loss of property or lives, or anxiety. In late August 2005, hurricane Katrina formed over the Bahamas and

While some inferences have been drawn from existing models, more studies are needed for a better understanding of the health impacts related to global warming and climate change. Very little is known about its long-term consequences on health.

crossed the Gulf of Mexico, where it strengthened before reaching landfall along the Gulf Coast, including the New Orleans metropolitan area. Because New Orleans had been built in low-lying areas (in some cases below sea level) at the Mississippi delta, it was particularly vulnerable to the breaching of its protective levees. Nearly all of the city levees broke in at least one place, flooding large parts of the city and completely disrupting the community support system. It is estimated that over 1,800 people died, and over one million were displaced by the storm. Two years later, it was estimated that approximately one-third of the population had not returned to the area and both public and private services to remaining citizens had not returned to pre-hurricane levels.

Regarding drought, changing water patterns may put severe strain on human populations that do not have access to resources for diversion of rivers or development of major reservoirs. In areas that do have resources, the environmental impact of drought may be significantly exacerbated by human activity.

INFECTIOUS DISEASES

Perhaps the earliest measurable changes in human population health related to climate change are relatively rapid shifting of patterns in bacterial, viral, fungal, and parasitic diseases. As living organisms strive to adapt to changes in temperature and weather over time, pursuing both immediate survival and longer-term access to resources, shifts occur in the geographic range of plants, animals dependent on plants, animals dependent on animals, and associated disease patterns. For example, vector-borne diseases are caused by microorganisms that are transmitted by spending part of their life cycle in an animal that then interacts with humans. Diseases may appear in previously unaffected areas in one of several ways, including migration of the vector to newly-warmer or wetter ecosystems.

In its quest for a meal, the mosquito must penetrate the skin of animals and access blood, in the process providing access to organisms harbored in its mouthparts. Malaria (*Plasmodium* genus, *Anopheles* genus mosquito) and dengue fever (dengue virus, *Aedes* genus mosquito) are two major diseases transmitted in this way. Malaria is endemic to tropical areas, largely because the lifecycle of the *Anopheles* mosquito depends on warm, humid climate and pools of warm standing water for maturation of eggs; the malarial parasite itself does not reproduce in colder temperatures. Global and regional rises in average temperature are expected to extend the range into higher altitudes and more northern latitudes. In Central and South America, researchers have documented an increase in malaria associated with warmer temperatures that occur during El Niño affected periods.

Challenges in measuring regional and global infectious disease changes as they relate to temperature and climate alterations are compounded by many other (sometimes interrelated) human activities. For example, diseases with rapid human-to-human transmission may quickly jump large geographic obstacles such as oceans and mountain ranges through rapid transport capability and increases in overall mobility (travel) of human sub-populations.

Water-borne (especially diarrheal) infectious diseases could increase due to changes in temperature and rainfall patterns. Increasing coastal water temperatures may give rise to more frequent toxic algal blooms. Food-borne diseases, such as salmonellosis, also increase in incidence in warmer months, and may have a significant impact in many areas.

AIR QUALITY

Weather and climate changes can affect the mix and level of contaminants in the air. This has important consequences for health, according to a growing body of research showing associations between poor air quality and adverse health effects. In particular, cardiovascular conditions such as cardiac arrhythmia, and respiratory conditions, such as asthma, have been associated with poor air quality. For asthma, temperature increases can affect the levels of aeroallergens, such as pollen and mold, which can exacerbate symptoms in allergy and asthma sufferers. The combination of heat and urban pollutants interact to form the urban heat island effect. This refers to the increase in temperatures in urban areas, compared to surrounding rural areas, as a result of less tree coverage, and more use of heat-absorbing materials, such as rooftops and roadways in urban areas. Increases in temperature cause an increase in ground level ozone, a principal component of urban smog.

Atlanta, Georgia is a comparatively well-studied example of a large urban area affected by ground-level ozone and smog pollution. The increases in congestion, vehicle traffic, drought, and development of the built environment over the past several decades have interacted to increase temperatures, ozone, and smog in the city. In the summer months, Atlanta often exceeds air quality standards for ozone and particulate matter set by the U.S. Environmental Protection Agency. The Georgia Environmental Protection Division reports daily air quality levels in metro Atlanta and issues Smog Alert warnings for days when measured pollutants are projected to exceed a certain level. The purpose of alerts is to warn people with respiratory conditions and other vulnerabilities to limit exposure. In 2006, metropolitan Atlanta was issued 42 smog alert days, as well as 236 days of moderate-risk air pollution warnings for vulnerable groups.

ADAPTATION AND MITIGATION

Although it is difficult to determine the extent of the health impacts of global warming and climate change, both currently and in the future, there are several adaptation and mitigation measures that can be taken to lessen potential impacts. On the adaptation side, these include improved design of homes, buildings, and other land and water structures to withstand extreme weather events. In some cases, relocation of populations away from low-lying flood plains and other geographic areas that are especially susceptible to extreme weather events should also be considered.

On the mitigation side, more health studies are needed for a better understanding of the health impacts of global warming and climate change. Although research on health effects has increased in the 21st century, very little is known about the contribution to global warming and climate change to ill health beyond immediate and observable impacts. A related need is for better disease and environmental surveillance data on an ongoing basis, particularly in developing countries. Many developing countries lack even basic environmental-monitoring capabilities or disease-tracking systems. Another need is for the implementation or improvement of disaster response planning, including educational intervention and outreach. Each of these efforts requires financial resources. Finally, research and innovation on ways to reduce the human contributions to global warming will play an important role in adaptation and mitigation strategies. A notable area is the reduction of fossil fuel use and increasing the availability and use of renewable energy technologies. The relationship between the human population and the environment is dynamic, so if there is a change in the environment, it will require an adaptation across a broad and diverse range of resources and local and environmental challenges.

SEE ALSO: Diseases; Impacts of Global Warming; Intergovernmental Panel on Climate Change (IPCC); Pew Center for Global Climate Change; Pollution, Air; Preparedness; Rain; Social Ecology; Ultraviolet Radiation; Weather; World Health Organization.

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Heat, Latent

LATENT HEAT IS energy in the form of heat released or absorbed by a substance during a phase change of the substance. The amount of latent heat involved with condensation/evaporation and freezing/melting are different under different temperatures and pressures. As temperature increases, latent heat of vaporization decreases, but that of fusion increases. Water is not the only substance that has three different phases at a normal temperature range in the universe, but it is the most abundant substance like this on Earth. A larger amount of latent heat is involved with the phase change of water. Through this transfer of latent heat, the water cycle determines surface and atmospheric conditions, as well as atmospheric circulation. Evaporative cooling and condensation heating moderate the surface temperature. Without this cooling and heating, daily temperature range would be significant, much like that of planets such as Mars or Venus, or of blacktop asphalt in summer.

The atmosphere is a dynamic heat system designed to transfer heat from one place to another. Latent heat involved in the phase change of water plays essential roles in the transfer of heat. Just as much latent heat is released in the atmosphere through a phase change as the latent heat is absorbed at the Earth's surface. The latent heat fluxes and the transfer of sensible heat between the equator and the poles are major components of the energy balance of the Earth. The latent heat flux in the atmosphere is huge. Latent heat flux involved in the phase change of water drives the atmospheric circulation and plays essential roles in global climate.

Latent heat is also an important factor to better comprehend weather systems, because it is a primary source of energy that develops, promotes, and sustains severe weather systems, such as thunderstorms and tropical cyclones. Latent heat supplies weather energy. As water condenses, latent heat from the water molecule is released into the air, heats the air, makes it lighter, and makes it rise fast. As the air rises, more air flows in and promotes storms. In this process, some latent heat is changed into the kinetic energy that accelerates the speed of water molecules and powers up severe weather systems. Recent global warming increases the ability to evaporate and hold moisture in the atmosphere. As a greater amount of water vapor exists in the hot air, more latent energy is available to be released into severe storms. Another critical aspect of global warming is that it will increase variability of extreme weather, although the overall average of the atmospheric condition changes little. Thus rare, but extreme weather, often much beyond what we experience today, will be more common.

Controversy exists concerning if latent heat adds to global warming, increasing it, or tends to act as negative feedback for global warming, slowing it down. A small change in atmospheric composition and chemistry can induce considerable climate alteration. The proponents of global warming argue that water vapor absorbs more infrared radiation than any other atmospheric gas and induces the largest greenhouse effect of the global climate. Growing latent heat flux in the atmosphere increases the amount of clouds, helping retain more heat, which would lead to more evaporation of water and the addition of more water vapor into the atmosphere, which leads to more heat in the atmosphere, and so on, in a positive feedback cycle. Opponents of global warming argue that a growing amount of clouds would increase the Earth's albedo, which would decrease the amount of solar radiation that reaches the Earth's surface. A decrease of solar radiation received would cool the Earth's surface, instead of heating it, in a negative feedback cycle.

Clouds contribute approximately 50 percent of Earth's planetary albedo. Change in latent heat flux in the atmosphere not only determines weather, but also induces global climate change. Aside from the climate change, latent heat is also responsible for the atmospheric humidity that affects human comfort. Despite uncertainties in the understanding the global climatic system, there is evidence that indicates that the Earth's atmosphere and overall environment are warming, such as sea-level rise, polar ice caps receding, increasing weather extremes, and more severe storms. Neither positive nor negative feedback cloud forcing has reached the point where it can offset the warming or cooling effects.

SEE ALSO: Cloud Feedback; Heat, Sensible; Weather.

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Heat, Sensible

IF THE MOVEMENT of energy to or from a substance can be sensed (for example, with a thermometer) as a rise or fall in temperature, then it is referred to as sensible heat. By contrast, if the movement of energy to or from a substance has a different result, such as evaporation, there will be no change in temperature. In this case, the energy is held dormant in the substance for release should the substance revert to its initial state (for example, via condensation). For this reason it is called latent heat. Changes in the sensible heat content of a substance (such as air) result in temperature changes, but latent heat movements (such as by evaporation) do not. The rate of sensible heat flow (sensible heat flux) is often referred to as dry heat flux, whereas the rate of latent heat flow is often referred to as evaporative heat flux. Climate is characterized by how available energy at the Earth's surface is distributed between sensible and latent heat.

Energy that drives global climate originates from the Sun as shortwave radiation. Some of it is absorbed by the Earth and heats the surface. The surface, in turn, radiates this energy as longwave (infrared) radiation to the atmosphere. Greenhouse gases in the atmosphere absorb some of this energy and radiate it back to the surface. The net result, or net allwave (long and short) radiation at the surface, is energy available to heat the air via the sensible heat flux, or to be used to evaporate water via the latent heat flux (which includes the transpiration from the leaves of plants). For example, in summer at mid-latitudes, or year round at low latitudes, more solar energy is absorbed at the surface during the day than is lost by longwave radiation. Surplus energy is transported as both sensible and latent heat from the surface to the atmosphere by eddies of air (convection).

A rise in the concentration of greenhouse gases in the atmosphere leads to more energy retained at the surface of the Earth. This additional energy could be used either to heat the atmosphere by way of the sensible heat flux (increased warming), or evaporate additional water via the latent heat flux (increased humidity). If moisture is freely available at the surface, the latent heat flux will always be larger than the sensible heat flux, meaning that energy otherwise available to heat the atmosphere is used to evaporate moisture. The resulting warming of the atmosphere would be less, in this case, than if all the additional available energy was accounted for by the sensible heat flux alone.

The heating of air by the sensible heat flux at the Earth's surface causes the air to become buoyant and, as a result, rise and mix with the cooler air aloft. Moisture, as well as sensible heat from the surface, is entrained in this convectional mixing of air. As a result, the mean annual global climate impact of increased energy available from an enhanced greenhouse effect will manifest itself both as an increased sensible heat flux (warming) and increased evapotranspiration via the latent heat flux. The latter is hidden heat energy that can be transported great distances by wind and over time without loss. The impact on climate may occur in regions far from its source. This hidden heat energy does not radiate back to space until condensation occurs and returns the heat to the air.

SEE ALSO: Atmospheric Boundary Layer; Convection; Greenhouse Effect; Heat, Latent.

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Heinz Center

FOUNDED IN 1995, in honor of late Republican Senator H. John Heinz, III (1938-1991), the Heinz Center is a nonprofit institution dedicated to improving the scientific and economic foundation for environmental policy through collaboration in different sectors among industry, government, academia, and environmental organizations.

Senator Heinz was always active as a politician in initiatives to preserve the environment and to understand the impact of human actions on it. By the mid-1980s, Heinz claimed that human actions were damaging the environment and, with Democratic Senator Tim Wirth, he set up Project 88. The Project contributed to the landmark legislation Clean Air Act Reauthorization passed by the Senate in 1990. Heinz also introduced bills to encourage the recycling of newspapers, motor oil, and other hazardous wastes.

The Senate version of the Clean Air Act reauthorization bill included a Heinz amendment protecting the right of local communities to fix strict limits on radionuclide emissions from nuclear facilities. Heinz was one of the main supporters of legislation to require banks to encourage sustainable growth in developing nations by considering the environmental implications of projects they finance. Heinz also proposed legislation to protect groundwater and ensure proper maintenance of above-ground storage tanks, and cosponsored a bill to curtail global warming. Heinz was a firm believer that many environmental problems went beyond national borders, so he was a founding member of GLOBE (Global Legislators Organization for a Balanced Environment) International, created in 1989 as a forum for the world's policy-makers to exchange environmental ideas and concerns. He also chaired GLOBE-US. Heinz served in the U.S. delegation to the Interparliamentary Conference on the Global Environment in 1989. In his capacity as a member of the national board for Earth Day, Heinz sponsored a variety of organizations with educational missions. He co-chaired the Alliance to Save Energy, served as a board member to the Environment and Energy Study Institute, and, along with Senator and future Vice-President Al Gore, supported EarthTech 90, a fair of environment-friendly technology on the National Mall in 1990.

To carry out the environmentalist legacy of Senator Heinz, the center focuses on issues that confront policymakers regarding the environment. The diverse membership of the center's board of trustees, its steering committees, and all its committees and working groups, mirror its guiding philosophy that aims to involve all relevant parties to offer solutions to the complex issues surrounding environmental policymaking. Industry, environmental organizations, academia, and government are the four components that the center attempts to involve in each of its program areas and projects. All four sectors are actively involved in all aspects of environmental policymaking, from the identification of a problem, through the suggestions of recommendations, to implementation of a policy. The cooperation between these four sectors produces solutions to the environmental challenges that face the United States and the world. The center, thus, gathers leading policymakers and practitioners from government, industry, environmental organizations, and universities to work together to identify pressing environmental challenges and to agree upon ways of meeting those challenges.

THREE PROBLEM AREAS

The center has identified three program areas: the state of the nation's ecosystems, global change, and the sustainable oceans, coasts and waterways. The report on the state of the nation's ecosystems is the most comprehensive document on the condition of U.S. lands, waters, and living resources. The report supplies business leaders and the general public with essential information concerning local, state, and national environmental policy. It provides decision-makers a scientific basis to decide on the best course of action, without putting forth prescriptive recommendations. The focus of the project is on ecosystem indicators, agreed upon by hundreds of experts from universities, government agencies, corporations, and environmental organizations. Funded by the federal government, foundations, and corporations, the report also emphasizes key gaps in data that must be filled to allow a complete picture of ecosystem conditions. One of these missing data has been identified through a national "carbon storage" indicator. Also, as part of the report, the center has formed an air quality working group that has the task of identifying the suite of chemicals that pose the greatest risks to human and ecosystem health.

The Global Change Program stems from the consideration that global changes in climate pose challenges to policy-makers in both developed and developing countries. The Global Change team analyzes policy responses to global environmental changes, both in terms of limiting change and in terms of adapting to it. The Global Change program includes domestic and international collaborators. Both its present and past projects have tackled issues that are relevant for global warming. For example, the "Evaluation of Technology Policies to Help Lower Emissions of Greenhouse Gas" (1999) assessed the effectiveness of policies to accelerate the development and adoption of new technologies for lowering emissions of greenhouse gases. The "Lowering Emission of Greenhouse Gases Through Emission Trading" (1988) examined alternative plans to include emissions trading into a potential U.S. program for lowering emissions of greenhouse gases such as carbon dioxide. Researchers analyzed how different potential trading systems worked under realistic conditions, and provided advice to Congress and the Administration on the cost-effectiveness of the major options. The Heinz Center plays a major role in the international Global Energy Assessment (GEA) project, an effort to provide essential information for global energy policy development and future energy strategies. GEA is structured around four main areas of analysis: major global issues and energy, energy resources and technological options, possible sustainable futures, and policies advancing energy for sustainable development.

A major project of the Global Change Program is the Eco-thresholds initiative, which was established to explore the subject of defining acceptable levels of greenhouse gas concentrations and to determine how to anticipate and deal with rapid changes in ecosystems. Started in 2005, Eco-thresholds is the result of the cooperation of the Heinz Center with The Nature Conservancy and the Joint Global Change Research Institute. The project has gathered members of the scientific and policy communities to explore the science behind thresholds and their implications for decision-making. The Eco-thresholds project aims to enhance collaboration among government, business, academia, and environmental nongovernmental organizations to define key issues caused by abrupt changes in ecological systems. The project also intends to promote long-term cooperation among the sectors and stakeholders to cope with threshold changes in natural, managed, and socioeconomic systems. Finally, the participants will discuss acceptable levels of greenhouse gases necessary to limit those threshold changes that cannot be dealt with through management actions. In addition to the Eco-thresholds initiative, the center sponsors the program "Methane 2100" to document the global distributions and concentrations of methane, a greenhouse gas, in the atmosphere, by sensors aboard a polar retrograde orbiting satellite. The third area of intervention by the center is the Sustainable Oceans, Coasts and Waterways Program to devise policies to stop the decline in quality and sustainability in these vital areas.

SEE ALSO: Energy; Greenhouse Gases; Methane Cycle.

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Historical Development of Climate Models

CLIMATE MODELS ARE computational tools used to study the dynamics of the climate system and predict future climate changes. Climate models have developed historically through the growth of mathematical techniques, computational capacity of computers, data of present and past climates, and theories of component climate processes. Climate models have progressed from very simple models for regional weather prediction, to sophisticated general circulation models that simulate interactions of the atmosphere, oceans, land surfaces, ice, and biosphere. Climate models are of great relevance because they examine the effects of increased atmospheric CO_2 on the Earth's average temperature. As such, climate models have been the primary source of data used by scientific communities and government organizations to draw conclusions about global warming.

EARLY MODELS

As developed in the early 1920s, the first proper model of climate-related events was a mathematical technique used for numerical weather prediction. This model treated a local weather area as a grid of cells. Using a set of basic equations, the model could, in principle, calculate how differences in pressure between adjacent cells determined wind speed and direction across the represented weather area. Lewis Fry Richardson, a pioneer of numerical weather prediction, attempted to apply the model to actual weather conditions. Richardson's attempt was unsuccessful because he was unable to perform calculations faster than the weather occurred.

During the late 1940s and early 1950s, computers were developed that could reliably perform complex calculations much faster than human beings. American meteorologists used computers to build models of weather simulation, one of the earliest of which was run on a computer named ENIAC. This particular model divided North America into a grid of cells. Taking the known weather conditions for each grid, the model calculated how air should move across the cells. When compared to the real weather that emerged, the model proved partially accurate, though the applicability of the model was limited by computational capacity and scientific knowledge of weather and climate processes.

As scientists developed more successful weather models, scientific focus expanded during the 1950s and early 1960s to include the development of simple climate models. In the earliest of these models designers analyzed the effects of geography and topography of mountain ranges on airflow across North America. They also simulated how energy and momentum moved through the atmosphere, and were able to predict wind patterns with some accuracy. Additionally, simple models began to represent equilibrium in the atmosphere by incorporating calculations for balancing incoming solar radiation with outgoing radiation reflected from the Earth. By the mid-1960s, these developments gave some degree of credibility to climate modeling; models could now simulate coarse processes of the Earth's atmosphere.

GENERAL CIRCULATION MODELS

In the late 1960s and early 1970s, computers advanced to the point of performing complex calculations in short timescales. Better observational data and measurements were made available through satellites and ground measurements. These conditions facilitated the emergence of three-dimensional atmospheric general circulation models, which represented climate as a comprehensive system. As they developed, general circulation models treated the atmosphere as layers and incorporated processes of convection, evaporation, and rainfall. The models could simulate the transfer of radiation vertically through the atmosphere, the reflectivity of sunlight from snow and ice, and basic seasonal changes. During this period, oceans were represented in models and coupled with the atmosphere, though these early models treated the ocean as a slab, without any unique dynamics of its own. General circulation models permitted analysis of how the movement of radiation through the atmosphere was affected by water vapor and CO_2.

Throughout the 1970s, Syukuro Manabe built and enhanced a climate model to analyze the relationship between CO_2 changes and climate change, a concept known as climate sensitivity. Specifically, the model investigated how a doubling of atmospheric CO_2 concentration would change temperature. The first estimates indicated that temperature would increase by approximately 3.6 degrees F (2 degrees C). In this way, models raised awareness among the scientific community that rising CO_2 in the atmosphere could lead to increases in the Earth's temperature, a phenomenon known as greenhouse warming.

By the 1980s, atmospheric general circulation models permitted analysis of climate component processes occurring on smaller spatial and temporal scales. Also, models of this period coupled the atmosphere and oceans in a complex way by simulating the exchange of heat between both components. Coupled models could simulate changes in sea ice, as well as the emergence of deserts and rainfall areas. As the use of coupled models advanced, research into atmospheric changes in CO_2 revealed serious consequences for the processes driving the overturning of ocean waters, which could potentially cease with higher levels of CO_2.

MODELS AND CLIMATE CHANGE ANALYSIS

Models provided information that ultimately increased public concern about the Earth's climate. As a result, the validity of models themselves became an issue of increasing importance. By the 1990s, projects were initiated in which models were systematically compared to one another, in relation to a growing and uniformed body of climate data. Such projects provided the science of climate modeling with a form of quality control and a standard of reproducibility of results. Using data about conditions during the most recent ice age (which were gained primarily from ice-core measurements), one way of testing the validity of models was to see how well they could simulate the climatic and oceanic conditions characteristic of glacial periods. An additional test of validity involved using models to predict consequences of unique, real-time events, such as climatic responses to volcanic eruptions. Models were successful in these various tests. Models gained further credibility as they served as the primary source of data for the newly-formed Intergovernmental Panel on Climate

Change (IPCC). In the mid-1990s, the IPCC used climate model data to draw its conclusion that a human influence on climate had been detected.

Models that have developed over the past several years are extremely complex. Relative to the simple models that emerged in the 1950s, current models can carry out simulations in much shorter time periods and represent many component processes simultaneously, including the atmosphere, oceans, glaciers and ice sheets, land surfaces, and biological and chemical activities linked with human economic life. Models now inform understanding of a range of possible future climatic changes and their impacts. Current models that simulate the present climate and account for CO_2 show a severe risk of future global warming. Based on these data, the broadly accepted view among scientists, policymakers, and the public is that rising CO_2 levels are warming the Earth.

The success of complex models has not eliminated the need for simple models. The latter models still provide valuable information about independent processes and climatic changes occurring on small spatial and temporal scales. Thus, they serve to develop basic theoretical understanding that enables complex models to simulate broader interactions between the atmosphere, oceans, biosphere, and other component processes. Along with models of intermediate complexity, such as those used to study long time-series corresponding to glacial processes, simple models are regarded as part of a hierarchy of models upon which complex models are based.

In the future, models will continue to generate highly-complex, detailed three-dimensional representations of climate dynamics. Nevertheless, challenges remain that prevent models from providing a perfect simulation of real climate. Scientific understanding of many of the key process that control climate sensitivity (such as clouds, vegetation, and ocean convection) is incomplete. Consequently, these processes cannot be represented in detail in climate models. Additionally, the predictive capabilities of climate models are linked to their performance in reproducing the historical record, which is largely limited to geological data and relatively recent global temperature observations. Processes could exist on a longer temporal scale that even the highly-complex models of today cannot take into consideration. For example, the presence of non-linear processes could potentially change the behavior of climate abruptly. Future progress of climate modeling will depend on the continued commitment to developing improved mathematical and computational techniques, more data, and better theoretical understanding of climate dynamics.

SEE ALSO: Climate Models; Climatic Data, Historical Records; Computer Models; History of Climatology.

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History of Climatology

CLIMATOLOGY IS THE branch of atmospheric science dedicated to the description and analysis of the Earth's climate and its biospheric interactions over extended periods of time. Climatology began as the observation and description of weather on subcontinental and continental levels. The Ancient Greeks believed that climates were nothing more than temperature gradients varying along latitude belts. Climatology was primarily observational speculation prior to the dawning of the scientific age, when devices for measuring and studying weather were invented, and the keeping of systematic weather records began.

EARLY ATTEMPTS TO UNDERSTAND THE CLIMATE

The scientific roots of climatology, a subdiscipline of meteorology until the late 20th century, were planted in the work of Edmund Halley's 1686 mapping of the trade winds and his assertion of a relationship between solar heating and atmospheric change. His work introduced the idea of weather and climate systems interacting with the physical features of the Earth. It was not until the early 20th century that the understanding of this interaction moved beyond observation to analysis and synthesis. Prior to the mid-20th century, climatology was divided into two subdisciplines: regional climatology, studying subcontinental and continental weather and climates; and physical climatology, gathering and analyzing the statistical data related to weather and climates. Climatology sought to describe and understand normal climates, but there was little understanding of the timescale or breadth of climate change, save for the ice age or of climate as a global system of interrelated climates forming a whole that is more than its parts.

Vilhelm Bjerknes's pre-1920s work on mid-altitude cyclones led him to create a model of atmospheric change based on hydrodynamics and thermodynamics. Bjerknes's work and Lewis Fry Richardson's 1920s equation-based weather predictions led to a rudimentary three-dimensional atmospheric model.

However, the complexity of the equations and magnitude of the calculations made the understanding of climate systems nearly impossible, until the availability of high-speed computers in the 1950s made numerical modeling of climate systems possible. This expansion led to the formation of the new subdisciplines of dynamic meteorology and dynamic climatology.

The second major impetus for change in climatology in the 20th century was World War II. World War II demonstrated the advantage to modern warfare of predictive meteorology when, for example, it was used to forecast the weather for June 6, 1944, the day of the invasion by the Allies of Nazi-occupied France. These conventional military applications, along with the need to understand weather patterns and climates as they related to the possibility of nuclear war and the expanding agricultural, industrial, communication, and transportation technologies, led to increased funding for training, research, and education in climatology.

CLIMATOLOGY PIONEERS

Several key figures emerged in the academic world as the regard for meteorology and climatology increased. Carl-Gustav Rossby created the Department of Meteorology at the University of Chicago in 1942, and there, with a team of researchers, developed the first physical climate models that viewed the entire planet as an integrated physical whole, or system. Reid Bryson, a World War II military meteorologist, left the geography department at the University of Wisconsin, Madison to form a meteorology department there, and then established, in 1962, a climate research center at Madison, after receiving National Science Foundation funding. Massachusetts Institute of Technology mathematician and meteorologist Edward N. Lorenz, also a World War II military meteorologist, began applying chaos theory to the atmosphere in the 1960s, and his theories were integrated into the increasingly-complex atmospheric-modeling relegated to computers. Despite these advances, the U.S. Weather Bureau continued to view climatology only as a tool for forecasting.

Concurrent with this growth of meteorology and climatology as academic disciples, was the development of geophysics, the physics of the Earth and its environment. When the International Union of Geodesy and Geophysics was founded in 1919, geophysics encompassed such disparate fields as geology, geodesy, meteorology, oceanography, seismology, and terrestrial magnetism. Though interdisciplinary in the breadth of the fields of study, geophysics was not interdisciplinary in the integration of the knowledge bases into a coherent whole.

The weapons of World War II, such as the atomic bomb, demonstrated the need for the collaboration of various scientific disciplines. This led to the creation (in 1946) of interdisciplinary projects, such as the U.S. Air Force's Cambridge Research Center Geophysics Research Directorate and the Air Force Cambridge Research Laboratories.

This interdisciplinary spirit was boosted 1957–58, when the International Geophysical Year encouraged the interdisciplinary collaboration on subjects such as climatology. The creation (in 1970) of the National Oceanic and Atmospheric Administration (NOAA), integrating oceanographic and meteorological studies was in recognition of the growing need for interdisciplinary science in the study of climate. The National Aeronautics and Space Administration (NASA) followed suit and orbited satellites designed to enhance these interdisciplinary studies by creating an Earth system science.

INTERDISCIPLINARY COLLABORATION

This new emphasis on scientific interdisciplinarianism was demonstrated with the 1977 founding of the journal, *Climatic Change*. This end of knowledge fragmentation and the increased collaboration among disparate fields helped fuel the growth of climatology as a scientific discipline. System interrelatedness was obvious by the mid-1970s, and the symbiosis of meteorology, mathematics, computer science, geophysics, chemistry, biology, and other relevant sciences evolved into an all-encompassing discipline under the academic rubric of Earth sciences.

This systems emphasis and interdisciplinary collaboration, augmented by advances in computer technology, expanded climatology from a restrictive, predominantly statistically-based descriptive applied climatology, to include a physical-mathematical modeling discipline with predictive global capability. The International Geosphere-Biosphere Program (IGBP), founded in 1986 and based at the Royal Swedish Academy of Sciences, sought to bring international interdisciplinary cooperation to the study of the global environment.

An important result of this system-based analysis was that the old concept of a normal climatic period gave way to the idea that the climate is dynamic and always changing. During the 1960s, J. Murray Mitchell Jr., a climatologist with various federal agencies and then with NOAA, asserted that human (androgenic) actions influence climate positively and negatively and warned that the negative human influence was apparent in what he determined to be statistically significant global warming. Though it was initially unclear to Mitchell if human atmospheric pollution, particularly carbon dioxide (CO_2), might lead to drastic global warming or cooling, it was clear to him that this pollution was radically affecting the global climate and that technological and sociological intervention where necessary to avert a disaster. By the mid-1970s, Mitchell and other scientists became convinced that the real danger was global warning, and not global warming.

The history of climatology was dominated by the global warming debate during the last 30 years of the 20th century. By the beginning of the 21st century, climatology was dominated by computer modeling, and by the assumption that the proper way to understand global warming, as well as regional climates and weather patterns, was by understanding the climate system of the whole planet. This change was reflected in the emergence of the new subdisciplines of climatology: climate change, bioclimatology, paleoclimatology, and applied climatology.

SEE ALSO: Bryson, Reid; Climate; Climate Cycles; Computer Models; Historical Development of Climate Models; Lorenz, Edward.

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History of Meteorology

METEOROLOGY IS THE subdiscipline of atmospheric science that studies weather and climate using physics, chemistry, and other sciences. The term meteorology is derived from Aristotle's *Meteorologica* (350 B.C.E.). The first official regular weather reports were seen in China (1060 B.C.E.) with the first regular European weather observations in 500 B.C.E. The Ancient Greeks were the first to divide the world into temperature zones, and Aristotle was the first to articulate the hydrologic cycle, describing the circulation and conservation of the Earth's water using the evaporation and condensation cycle.

SCIENTIFIC MEASUREMENT

It was not until Rene Descartes's *Les Meteores* (1637 C.E.) that an attempt was made to establish the scientific basis of meteorology. Meteorology was nothing more than observational speculation prior to the scientific age, when devices for measuring and studying weather were invented, and the keeping of systematic weather records began. Galileo Galilei invented the water thermometer for measuring absolute temperatures in 1593, and may have constructed the first thermoscope for measuring temperature changes in 1607. Evangelista Torricelli invented (1643) the mercury barometer that detected atmospheric pressure changes, making possible the observation that drops in pressure substantially correlate with the advent of storms (in 1644). Blaise Pascal noted, in 1648, that atmospheric pressure decreased with increasing altitude, deducing a vacuum above the Earth's atmosphere, and, in 1667, Robert Hooke invented the anemometer for measuring wind speed.

Gabriel Daniel Fahrenheit created the mercury thermometer with his temperature scale in 1714, followed by Anders Celsius's alternative temperature scale in 1735, which was adopted in Napoleon's empire in the early 1800s. The daily observation of basic changes in air pressure, moisture, and the direction and speed of the wind was instituted by Laurent Lavoisie in 1765. Horace de Saussure's hair hygrometer (1780) for determining humidity provided the last major instrumentation, and one of the final measuring standards necessary to move meteorology from observation into research and theorization. Luke Howard's cloud classification system (1802) and Francis Beaufort's wind speed scale (1806) provided additional observational tools.

INTERPRETATION OF THE DATA

The scientific roots of climatology, a subdiscipline of meteorology until the late 20th century, were planted in the work of Edmund Halley's 1686 mapping of the trade winds and his assertion of a relationship between solar heating and atmospheric change. Benjamin Franklin (1706–90), sometimes credited as the first American meteorologist, observed that North American weather systems move west to east, discovered lightning was electricity (1752), charted the Gulf Stream, linked volcanic eruptions to weather changes, and associated deforestation with climate change. The German H.W. Brandes drew the first weather map in 1819.

Controversies based on the interpretation of the data began to increase as the number of government and academic-related weather observation and recording programs burgeoned in the United States in the first quarter of the 19th century. The most notable of these was the storm controversy (1834–59) involving William Redfield, James Espy, and Robert Hare, concerning the nature, cause, and methodology for studying storms.

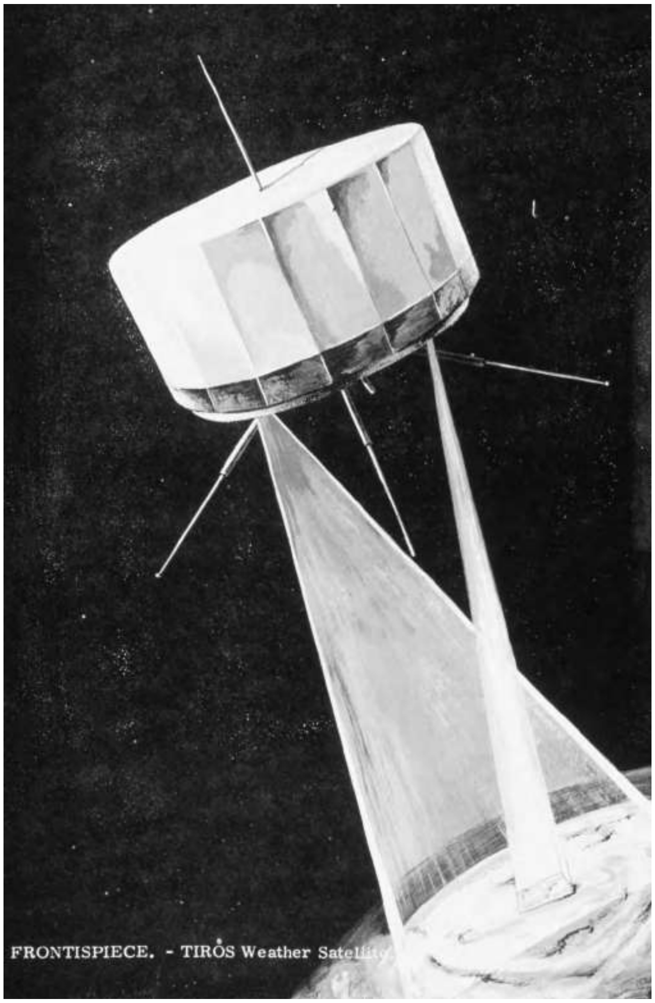
Though never resolved, the controversy gave impetus to increasing observational networks and the theoretical understanding and application of meteorology by the U.S. military, the Franklin Institute, the Smithsonian Institute, and the American Philosophical Society. Samuel F.B. Morse's telegraph and Morse code made the more rapid dissemination and analysis of this increasingly abundant information possible. The Army Signal Corps began using the telegraph in 1849, to disseminate daily weather observations through the U.S. Department of War, and in the same year, the Smithsonian began producing daily weather maps from telegraphic information.

In 1855, France created the first officially-sanctioned national weather service in response to the loss of French vessels at sea during a storm in 1854. The first daily forecast was created by Robert Fitzroy, and first appeared in the London *Times* in 1860, and in 1861 the first system for port storm warnings was instituted.

The modern weather map was introduced by the Paris Observatory in 1863, and was later enhanced by the use of innovative graphic devices, such as symbols and isobars, lines showing constant pressure. The U.S. Weather Bureau, created by the Army Signal Corps in 1870, was ceded to the Department of Agriculture in 1891, and Britain's Meteorological Office was formed in 1872.

William Ferrel's 1856 postulation that mid-latitude circulation cells created the prevailing westerly winds by serving as a deflecting force interacting with pressure gradients was confirmed in the late 19th century and named the Coriolis Effect (Force) in the early 20th century. Vilhelm Bjerknes's work on mid-altitude cyclones led him to create, by 1920, a model of atmospheric change based on hydrodynamics and thermodynamics. The concepts of air masses and weather fronts were forwarded in the 1920s.

Though Bjerknes work, along with Lewis Fry Richardson's 1920s equation-based weather predictions led to a rudimentary three dimensional atmospheric model. The complexity of the equations and magnitude of the calculations caused this area of meteorology to languish until the availability of high-speed computers in the 1950s. Edward N. Lorenz applied chaos theory to the atmosphere in the 1960s, and his theories were integrated into the increasingly complex atmospheric modeling relegated to computers. The advent of the 21st century brought an increased emphasis on computer modeling through such joint projects as the Global Atmospheric Research Programme (GARP), designed to model atmospheric phenomena on a global level.



Rendering drawn prior to launch of the TIROS I satellite system showing its range of vision on Earth's surface.

Though Teisserence deBort began using kites and balloons to gather temperature data in 1899, it was not until the 1940s that radiosones (balloons) began daily measurements of temperature, humidity, and pressure of the upper-air. World War II fighter pilots discovered the jet stream, and later, surplus military radars began to measure precipitation. Doppler radar began replacing conventional radar in the 1990s. The first weather satellite, TIROS I (Television Infrared Observation Satellite), was launched in 1960.

METEOROLOGY AND CLIMATE CHANGE

A hole in the ozone layer of the atmosphere was discovered in 1985, and the earlier detection of the warming of the Earth (1980) gave impetus to the idea that one of the causes was human (androgenic) induced climate change from man-made ozone depleting gases. The United Nations and the World Meteorological Organization (WMO) responded by creating (in 1988) the Intergovernmental Panel on Climate Change (IPCC) and tasking it with studying the hypothesized phenomenon. The IPCC determined that the Earth had warmed over the last 150-year period, and that that warming was due, in part, to human activity. In executive summary of the report, the panel concluded that most of the observed global warming experienced in the last 50 years was due to the increase in greenhouse gas concentrations. The IPCC and former U.S. Vice President Al Gore were jointly awarded the Nobel Peace on October 12, 2007, for their work on global warming.

The ever-increasing calculation power of computers made possible increasingly complex computer modeling of the atmosphere and many of the complex variables that impact weather and the climate. This made possible a greater understanding the causes and effects of such weather phenomenon as global warming and El Niño.

By 1997, a global treaty known as the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) established legally-binding greenhouse gas emission restrictions on signatory countries by 2012, but did not include developing countries such as China and India. President George W. Bush of the United States did not sign the protocol. The enormous growth in the meteorology knowledge base in the 20th century led to its division into subdisciplines such as climatology, geophysical fluid dynamics, and atmospheric chemistry, as well as regional meteorologies.

SEE ALSO: Climate; Climate Cycles; Computer Models; Coriolis Force; Global Atmospheric Research Program (GARP); Hydrological Cycle.

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Holocene Era

THE HOLOCENE, DERIVED from the Greek words *holos* and *kainos* meaning "entirely recent," covers the most recent unit of geologic time. Marked by a major shift in climatic conditions, it spans the last 11,550 calendar years before present to the present time. The prior epoch, the Pleistocene, was characterized by large swings in climate between cold (glacial) conditions and warm (interglacial) conditions. In contrast to the instability of the Pleistocene climate, the Holocene climate is far more stable and warm. This mild climate coincides with the Mesolithic period and the development of human technology, and is thought to play a key, supporting role in the advancement of human civilization.

Despite the generally mild climate, paleoclimate proxies (indicators of past climate) show that climate fluctuations lasting for hundreds to thousands of years did occur during the Holocene, albeit smaller amplitude changes than during the Pleistocene. Scientists use paleoclimate proxies such as ice cores, marine ocean sediment cores, ancient shorelines, fossil pollen, and tree rings, among others, to understand and estimate these changes in climate. These proxies have provided evidence for some of the significant Holocene climate fluctuations including the Younger Dryas, the Neoglacial, the Medieval Warm Period, and the Little Ice Age. Only a general timeline for these events is provided as the exact dates vary from one geographic region to the next.

The first significant climate change of the Holocene, the Younger Dryas, began during the transition from the Pleistocene to the Holocene when a final pulse of cold, glacial conditions interrupted the post-glacial warming. Major cooling in the North Atlantic region is evidenced by pollen records, which show that cold-tolerant plants reinvaded the landscape. The episode is named after *Dryas octopetala*, an arctic plant that spread to lower altitudes during this cold period. Greenland ice cores have also provided evidence of these colder temperatures.

By 6,000 to 7,000 years ago, climate had warmed to what is often referred to as the mid-Holocene thermal maximum. Vegetation zones moved to higher latitudes, and glaciers retreated in many regions of the world. This was followed by a second cooling episode, the Neoglacial, which lasted from approximately 2,500 years ago until 4,500 years ago. The generally cooler and drier Neoglacial climate led to widespread birth and re-growth of mountain glaciers. These glacial advances are physically evidenced by the remnants of debris originally transported down-valley by advancing glaciers and then deposited as the glaciers melted away.

The Medieval Warm period (also known as the Medieval Climatic Optimum) was a time of unusual warmth around 700 to 1,200 years ago. This warmer climate resulted in more harvesting and prosperity for human civilizations. In Greenland, the unusually warm climate attracted Nordic tribes in the high altitudes of the North Atlantic to migrate and settle the area, growing wheat in areas previously covered in deep snow. Pollen records show warm-tolerant plants flourished in these areas.

The Little Ice Age followed the prosperity of the Medieval Warm period. True to its title, the Little Ice Age was a cooling episode that lasted from approximately 200 to 600 years ago and was marked by moderate glaciation, crop failures, and famines. Substantial historical evidence, such as literature, maps, and art, is available to scientists as a record of this advance in alpine glaciers in many mountainous regions of the world.

The Holocene record shows a climate history with which scientists can compare recent changes in global climate. Evidence throughout the Holocene shows clearly that changes in climate have a direct influence on human civilization, and will continue its influence into the future. There is also substantial paleoclimatic evidence that the present greenhouse gas concentrations and rates of global warming are greater than those seen any time previously during the Holocene. This evidence suggests that these changes in climate are unique in the Earth's recent history

Scientists disagree about the exact nature of the Holocene climate changes and the mechanisms giving rise to them are not yet well understood. Researchers have proposed several mechanisms, of which three have been studied extensively. Solar variability (or changes in solar output) was theorized to be a mechanism; however, it is no longer widely accepted due to the large uncertainties in the solar-climate link. Another mechanism, changes in volcanism, has been shown to have a clear link to short-term climate changes, typically less than a few years. Less certain is if long periods of increased volcanism have a clear link with longer periods of climate change, or if short periods of climate change associated with volcanic events then give rise to longer periods. Another mechanism, ocean circulation, has been shown to give rise to lower frequency climate variability. Research in this area focuses on finding evidence concerning changes in ocean circulation that could have been the primary driver of climate change during the Holocene, or if it only served as an amplifier of the smaller changes in climate.

An additional area of active debate is whether these climate changes of the Holocene were global, hemispheric, or regional in nature. It is clear, however, that there were measurable fluctuations in Holocene climate over large regions, and that these changes in climate likely had a significant impact on the human civilizations in those regions.

SEE ALSO: Little Ice Age, Oceanic Changes, Paleoclimates, Pleistocene Era, Volcanism, Younger Dryas.

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Honduras

THE REPUBLIC OF Honduras lies in Central America, and has coastlines with the Caribbean Sea and the Pacific Ocean. Honduras has a land area of 43,278 sq. mi. (112,492 sq. km.), with a population of 7,326,496 (2006 est.), and a population density of 166 people per sq. mi. (64 people per sq. km.). About 15 percent of the land in the country is arable, with another 14 percent meadows and pasture used for the extensive raising of cattle, which contributes to the production of methane gas. In 1990, the carbon dioxide emission per capita for the country was 0.5 metric tons per person, rising to 0.94 metric tons per person by 2003. Some 88 percent of the carbon dioxide emissions come from liquid fuels, with 12 percent from the manufacture of cement. Honduras gets 63.1 percent of its electricity production from hydropower, with 36.9 percent from fossil fuels.

Internal flights in the country are relatively cheap, contributing to further greenhouse gas emissions, but one of the largest potential threats follows the confirmation, in September 1999, of large oil deposits along La Moskitia, one of the most important native environments in the country. This might also affect the Bay Islands, leading to a large oil industry, and further greenhouse gas pollution in Honduras and abroad.

Over 54 percent of Honduras is covered with forest, including much virgin cloud forest, and one of the most extensive tropical forests in the region. The rising water levels and water temperatures will have

U.S. aid workers rush food, shelter, water and medical aid to Hondurans made homeless by Hurricane Mitch in 1998.

the most obvious effects on the Bay Islands off the north coast of Honduras, with some coral bleaching noticed on the reefs there, especially after the El Niño event of 1997–98 and Hurricane Mitch on October 25, 1998. The coral reefs affected by bleaching include the most famous in Honduras, the Black Coral Wall and Pretty Bush, off the north coast of Utila, as well as those around the islands of Roatán and Guanaja. Furthermore, flooding of the Aguan River caused the Cayos Cochinos and Roatán to be inundated with soil and debris washed down during soil erosion. Flooding can also result in a greater prevalence of malaria and dengue fever.

The Honduran neo-liberal government of Rafael Leonardo Callejas ratified the Vienna Convention in 1993, and took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992. The government of Carlos Roberto Flores Facussé signed the Kyoto Protocol to the UN Framework Convention on Climate Change on February 25, 1999, it was ratified on July 19, 2000, and took effect on February 16, 2005.

SEE ALSO: Deforestation; Forests; Oil, Production of.

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Hot Air

INCREASING AIR TEMPERATURES, due to global warming, lead to an increased amount of hot air in the atmosphere. Hot air leads to unstable weather; this correlation could potentially link global warming to an increase in the strength, duration, and frequency of storms and other violent weather.

Hot air cools as it rises, as a result of its expansion due to the lower pressure found at higher altitudes. Importantly, the heat is not transferred to the surrounding air–the loss of heat is due to a decreased amount of energy in the air and the increased volume of the given parcel of air. If the rising air is at a different temperature than the air it rises into, "unstable" weather conditions will result, such as storms. The greater the discrepancy in temperature, the more violent the resulting weather will be.

If global warming continues, surface air will become warmer and warmer. As this warm air rises into the cooler atmosphere, the weather patterns could become less and less stable over the years.

Surface air temperatures have, in fact, been recorded to rise over time, across the globe. The rise has been calculated to be just less than 1 degree Fahrenheit (0.555 degrees C) per decade; this value seems small but it is not insignificant. The British Antarctic Survey (BAS), led by John Turner, reported in the year 2006 that the surface air temperature at the Antarctic Peninsula has risen at a rate three times greater than the rest of the Earth, in the past 30 years, which could be leading to the rising ocean levels.

Nevertheless, some experts warn that weather trends at the poles, such as Antarctica, should not be regarded in the same way as those trends closer to the equator. The temperatures at these extremes of the Earth have not been recorded as long as in regions closer to the equator. Additionally, the atmospheric and surface temperature inertia is largest at the equator due to the largest amount of surface area of the Earth, also affecting the rate of temperature changes.

SEE ALSO: Global Warming; Troposphere; Weather.

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Hungary

Hungary is located in central Europe and is a landlocked nation. Hungary has fertile soil and was an agricultural nation until 1948, when Communists came to power and began to industrialize the country. By the last years of Communist rule, nearly 40 percent of its citizens resided in places where air pollution was above accepted international standards. Coal-burning power plants and cars were responsible for most of the emissions. Inadequate sewage systems and industrial waste polluted the nation's rivers, including the Danube, and ground water. Alarmed by these problems, the Hungarian government passed new environmental regulations and received loans from the World Bank to implement controls. Another major shift in Hungarian history came in 1990 when a non-Communist government was elected and Hungary began the transformation to a free-market economy.

In the early years of changing from a centralized economy to a market economy, Hungary's pollutants decreased. Greenhouse gas emissions fell by 33.5 percent 1990–2000. The trend reversed itself 2000–04 as emissions rose by 2.5 percent. Hungary, a signatory to the Kyoto Protocol, joined the European Union (EU) in 2004. The country remained confident that it could meet the 6 percent reduction in emissions that the protocol required, although the economic advantages of EU membership made exceeding the goal likely.

However, real concerns about the effects of global warming on the nation's resources pointed to the need for more effective national strategies. The first four summers of the 21st century were hotter than normal and rainfall was lower than usual. The combination drained millions of gallons of water from Lake Balaton, central Europe's largest freshwater lake. The changes to the lake posed a direct threat to tourism, which was central to the region's economy. The Danube was also at its lowest levels in over a century, and Hungary's wheat crop was at two-thirds of its expected yield. Hungary signed the United Nations Convention to Combat Desertification agreement in 1999. By the time the agreement was formally announced in 2003, the problem had intensified, particularly in the Homokhatsag district in southern Hungary where ground water levels had fallen nearly 10 feet since the 1970s.

A 2006 Yale University study ranked Hungary in the second quintile according to its overall environmental health, but dependence on fossil fuels, high transport emissions, and a poor development of renewable energy sources were weak areas. The third item became especially significant when the European Union announced in 2007 that its member nations by 2020 should obtain 20 percent of their total energy from renewable energy sources, with 10 percent coming from biofuels. Hungary's Ministry of Economics and Transportation and the Ministry of Environmental Protection announced a 10-point action plan to slow global warming. The plan calls for the establishment of a National Energy Council, environmentally friendly tax changes, and a commitment to renewable energy and meeting the EU standard.

SEE ALSO: Deforestation; Desertification; European Union; Kyoto Protocol.

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Hurricanes and Typhoons

HURRICANES AND TYPHOONS are tropical cyclones with maximum sustained winds of at least 74 mi. per hour (64 knots). Tropical cyclones that originate over the tropical Atlantic basin or the eastern/central North Pacific basin are called hurricanes, while those that originate in the tropical western North Pacific are called typhoons. Before the tropical cyclone reaches hurricane or typhoon status, there are stages of development the system will go through from birth to decay. Initially, when a poorly-organized mass of thunderstorms produces a weak circulation, the system is known as a tropical disturbance or tropical wave. When the winds increase to between 20 and 34 knots, the system is upgraded to a tropical depression, and when the winds increase to between 35 and

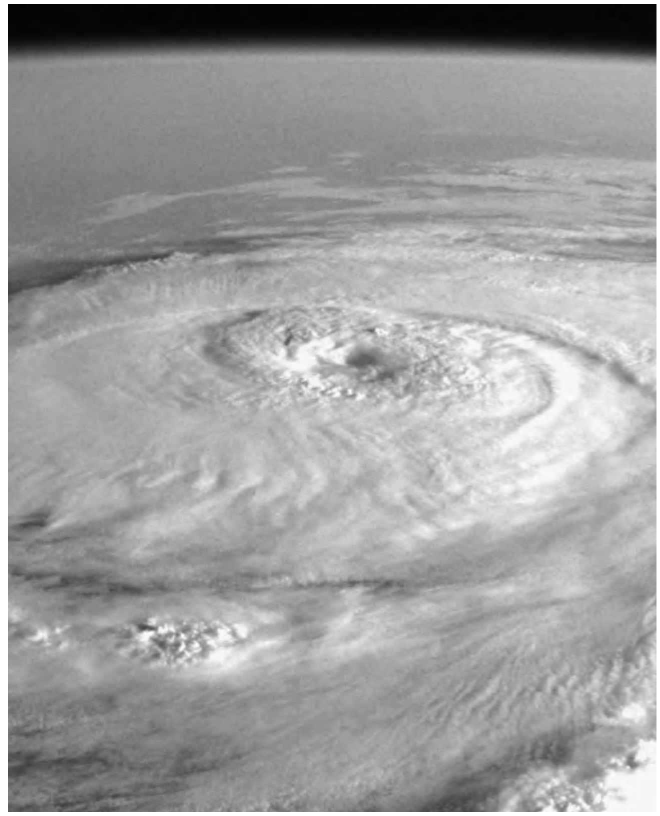
64 knots, the system is then called a tropical storm. At this point, the tropical cyclone is given a name.

For each tropical cyclone basin (Atlantic, eastern North Pacific, central North Pacific, western North Pacific, Australian region, Fiji Region, Papua New Guinea Region, Philippine Region, Northern Indian, Southwest Indian), there is a list of names. In the Atlantic, there is a six-year list of names. The list of names originated in 1953, and was first compiled and maintained by the National Hurricane Center. Currently, the lists are compiled and maintained by the World Meteorological Organization. Until 1979 (1978 in the eastern North Pacific), the list of names featured only female names. With the introduction of male names in 1979, male and female names are now alternated with each letter of the alphabet. The Atlantic basin has names for each letter of the alphabet from A to W, with the exceptions of Q and U.

In the event that each letter is used for a given year (as was the case in 2005), the Greek alphabet is then used (alpha, beta, gamma, and so on) for subsequent storms. If a particular storm is deadly or costly, the name is retired and replaced by a name beginning with the same letter. For example, there were five named storms in 2005 that were retired and replaced by the World Meteorological Organization (Dennis, Katrina, Rita, Stan, and Wilma were replaced with Don, Katia, Rina, Sean, and Whitney). The eastern Pacific basin has a similar six-year list of names, except that the list includes names for X, Y and Z (Q and U are still excluded). The western Pacific has five lists of names that are compiled and used sequentially by 14 contributing nations.

The Atlantic hurricane season begins on June 1st. and runs through November 30, with the peak frequency occurring during the months of August, September, and October. These months correspond to the time period where ocean temperatures are the highest. The eastern Pacific hurricane season is slightly longer, running from May 15. through November 30, with the peak frequency occurring during July, August, and September. Typhoons in the western Pacific can occur year round due to the vast supply of warm water, but typically occur from May to November.

Hurricanes and typhoons need certain conditions in order to intensify and grow. First and foremost, they need warm water to form. The threshold temperature that is generally considered necessary for tropi-



The impact of global warming on hurricane and typhoon formation are not fully understood.

cal cyclone formation is 79 degrees F (26 degrees C). The warm water from the ocean provides the energy that is transferred from the surface to the lowest layers of the troposphere. This causes the atmosphere to be unstable and allows for rising air. As the air rises, it cools, condenses, and releases latent heat, which causes the upper levels of the atmosphere to warm. Thus, an upper level high pressure is produced, which helps evacuate air to enhance the development of the surface low. The deeper the surface low becomes, the stronger the pressure gradient becomes, which creates stronger winds.

In addition to warm water, hurricanes and typhoons must form at non-equatorial locations, because they need Coriolis force (apparent force that causes an apparent deflection to the right of an object in the Northern Hemisphere because of the rotation of the Earth) to help the rotation, and in areas that help trigger surface convergence. One such area is the Intertropical Convergence Zone (ITCZ), which is an area where low pressure develops, however, few Atlantic systems develop there because of the proximity to the equator. The majority of Atlantic systems develop on the eastern side of tropical waves, which is an area that promotes convergence and rain showers. Another condition that must be satisfied for tropical cyclone development is the absence of vertical wind shear. Vertical wind shear is the change in wind speed or direction with height. When a hurricane or typhoon encounters areas with high vertical wind shear, the storm has a tendency to tilt, which inhibits the efficiency of the heat distribution in the atmosphere. Therefore, the upper level cannot form over the surface low that would cause the low to deepen. As a result, vertical wind shear causes the surface low to weaken.

The Saffir-Simpson scale is used to measure the intensity of hurricanes in the Atlantic and eastern Pacific. It uses estimated and measured maximum sustained winds in the eye wall to classify the intensity on a scale from one (weakest) to five (strongest). Only three category five hurricanes have struck the United States: Florida Keys (1935), Camille (1969), and Andrew (1992).

The impacts of global warming upon hurricane and typhoon formation are not fully understood. On one hand, an increase in global temperatures would increase ocean temperatures, which provide more energy for the tropical cyclone. On the other hand, it is not exactly known how warming would change vertical wind shear and the frequency of teleconnection patterns such as El Niño, which impact vertical wind shear. El Niño generally strengthens trade winds, particularly over the Atlantic basin, which inhibits Atlantic hurricane formation (as was the case in 2006). However, during El Niño years, there tends to be a slightly more active eastern Pacific season.

SEE ALSO: Cyclones; El Niño and La Niña; Intertropical Convergance Zone; Weather.

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Hydrofluorocarbons

HYDROFLUOROCARBONS (HFCS) ARE a group of organic compounds that contain carbon, fluorine, and hydrogen. They are by-products of industrial manufacturing and were introduced as a replacements for chlorofluorocarbons and other ozone-depleting substances. However, though HFCs have zero ozone depletion potential (ODP), they have intrinsic and significant global warming potential (GWP), typically in the range of 1,000 to 3,000 times that of CO_2. Thus, they are among the six key greenhouse gases listed in the Kyoto Protocol for emission reduction. Other greenhouse gases listed by the protocol are CO_2, CH_4, N_2O, PFCs, SF6, and HFCs. Industry and government are collaborating on research and development, communication, and other activities to find new technologies, designs, and processes to manage these emissions.

The emissions management is occurring through non-regulatory means, voluntary measures, and industry-government collaborations. The air-conditioning and commercial refrigeration industry has particularly contributed to the success of the management process.

HFCs are generally colorless and odorless gases at environmental temperatures and are mostly chemically unreactive. They are non-flammable, having very low toxicity; they are recyclable, and highly energy efficient. There has been a significant growth in the market for HFCs because they have been identified as important alternative fluids for many end users. They find applications in refrigeration and air-conditioning, foam-blowing, general aerosols, solvent cleaning, firefighting, and metered-dose inhaling. They are preferred due to certain physical and chemical characteristics, especially their low toxicity and low flammability. The main sources of atmospheric HFCs are traceable to their sources of application. Two other major emitters are chemical plants making HCFC 22 (where HFC-23 is emitted as a by-product) and HFCs. There are several points in the lifecycle of HFC-using products at which emissions can occur. A computer model uses four emission factors to characterize the HFC emissions, namely fluid manufacturing, product manufacturing, product life, and disposal loss factors.

Examples of HFCs include trifluoromethane (HFC-23), difluoromethane (HFC-32), fluoromethane (HFC-

41), 2-chloro-1,1,1,2-tetrafluoroethane (HFC-124), 1,1,2,2,2-pentafluoroethane (HFC-125), 1,1,2,2-tetrafluoroethane (HFC-134), 1,1,1,2-tetrafluoroethane (HFC-134a,), 1,1-difluoroethane (HFC-152a), 1,1,1,2,3,3,3-heptafluoropropane (HFC-227ea). HFC-23 is created as a byproduct in the production of HCFC-22. Small amounts are also used in semiconductor manufacture and as fire-extinguishing agents. 1,2,2,2-tetrafluoroethane (HFC-134a) is now used in place of CFC-12, gaining importance as a replacement for CFCs in automotive air conditioners.

HFC-134a is also used as a refrigerant in most new refrigerators and in commercial chillers. Leakage from these sources, which occurs primarily during servicing of the units, rather than during normal operation, is much less than from automotive air-conditioners. Short-term uses of HFC-134a, on the other hand, are becoming an important source of emissions. 1,1-difluoroethane (HFC-152a) is used as a blowing agent, an ingredient in refrigerant blends, and in fluoropolymer manufacturing applications. Other HFCs with considerable radiative forcing potential include HFC-125, HFC-143a, HFC-227e, and HFC-236fa. In addition to replacing HCFC-22 in stationary air conditioning and refrigeration applications, HFCs are expected to gain new markets as foam-blowing agents.

The opportunities to reduce global warming emissions from HFC end-use markets could be considered from four perspectives, namely the minimization of emissions throughout the lifecycle of a product, usage of a zero/low GWP alternative fluid, usage of an alternative technology, and the minimization of indirect emissions of CO_2 from energy used by HFC users. These approaches should be considered from the viewpoints of practical feasibility, environmental effectiveness, and economic impact before the most cost-effective emissions-reduction strategy can be developed.

In some end-use markets, such as refrigeration, there may be significant opportunities for adoption of emissions-reduction techniques. In others, such as aerosols, emission reduction may not be a viable option. HFC emissions should not be considered in isolation, but in relation to emissions of other global warming gases. In some cases, the use of HFCs can reduce CO_2 emissions; therefore, an appraisal of total global warming impact must be made to properly understand the best fluids or technologies to apply.

SEE ALSO: Aerosols; Greenhouse Gases; Pollution, Air.

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Hydrological Cycle

THE HYDROLOGIC CYCLE (water cycle) is a global, Sun-driven process. On Earth, water travels in a cyclic process, transported from water bodies to the atmosphere, then to land, and subsequently, to water bodies in the hydrologic cycle. Water is evaporated by the Sun, incorporated into clouds as water vapor, falls to the land and water bodies as rain, and from land it goes back to the water bodies through several hydrologic processes, such as runoff and infiltration. The hydrologic cycle is a closed system for Earth, as the amount of water remains fixed throughout, but it may vary with its distribution geographically, temporally, and seasonally. Six major components of the hydrologic cycle are precipitation, infiltration, evaporation, transpiration, surface runoff, and groundwater flow. Evaporation and transpiration together are known as evapotranspiration. The volumes of different components of hydrologic cycle are: 110,000 $km.^3$ of precipitation onto land and 458,000 $km.^3$ of precipitation on the ocean surfaces, with 502,800 $km.^{3.}$ of evaporation from oceans and 65,200 $km.^3$ of evaporation from land, of which 42,600 $km.^3$ is of river runoff, and 2,200 $km.^3$ is of underground runoff.

Increasing atmospheric concentrations of greenhouse gases warmed the Earth's surface by nearly 1 degree F (0.6 degrees C) during the 20th century. It may continue in this century, leading to a higher sea-surface temperature. One instinctive consequence of a warmer ocean surface is a larger vapor pressure difference between the sea surface and the adjacent atmosphere. Therefore, there would be an increased evaporation rate and subsequent increase in the other components of the hydrologic cycle. Computer simulation models found that a global warming by 7.2 degrees F (4 degrees C) is expected to increase global precipitation by about 10 percent, and that rainfall intensity will greater than at present. Scientists, through models, found that the upper tropospheric water vapor amount will increase by 15 percent with each degree of atmospheric temperature rise. The global water vapor amount will increase by 7 percent with each degree of atmospheric temperature rise.

Conversely, to make matters worse, water vapor acts as a prominent greenhouse gas. Increased water vapor alters the climate feedback loop. With a rise in surface temperature the water vapor amount in the atmosphere increases. The additional water vapor absorbs additional radiated energy which would normally escape from Earth's surface to outer space, and it makes the Earth's surface even warmer. This somber picture is further complicated by important interactions between water vapor, clouds, atmospheric motion, and radiation from both the Sun and the Earth's surface.

HYDROLOGICAL CYCLE INTENSIFICATION

Several studies have demonstrated that the hydrologic cycle has already intensified, with a distinct (measurable) amount due to an increases in earth surface temperature. The followings is some of the evidence:

Daily minimum nighttime temperatures have increased at twice the rate of daytime temperatures since 1950. Consequently, increased cloudiness and humidity at night as well as increased evaporative cooling during the daytime are encountered. That suggests that atmospheric water vapor amount has increased.

Radiosonde measurements from 1973–93, coupled with satellite data, suggest that there is a substantial increase in the level of water vapor in the atmosphere and the amount of precipitation in all regions of the Americas, except northern and eastern Canada.

There is a near-term collapse of the ocean's thermohaline circulation. More precipitation is falling in northern Europe, some parts of Canada, and northern Russia, but less to swathes of sub-Saharan Africa, southern India, and southeast Asia. A Canadian research team found with 75 years (1925–99) of rainfall data analysis through 14 powerful computer models that the Northern Hemisphere's mid-latitude (a region of 40–70 degrees N) received increased precipitation over the years. The models also showed that, in contrast, the Northern Hemisphere's tropics and subtropics (a region between the equator and 30 degrees N) became drier, while the Southern Hemisphere's similar regions became wetter.

More hurricanes, typhoons, ocean depressions, and floods are being experienced globally. The Americas, China, Japan, Bangladesh, and India are experiencing more than average of these. Flood frequencies and intensities in India and many other countries have increased.

South America and Central America are experiencing more frequent and more severe landslides. This is because the precipitation amount from a single event has increased drastically. Due to increase in monthly mean (average) temperature, precipitation amounts in the United States and Australia have increased. This is consistent with climate model predictions.

Glacial retreat is another example of a changing water cycle and has been extensive since 1850. It is clearly visible in the North Pole, Greenland, and Antarctica. It is happening as the loss of water from melting and sublimation is greater than the supply of water to glaciers from precipitation.

Other human activities are also altering the hydrologic cycle. They include: agriculture, alteration of the chemical composition of the atmosphere, construction of dams, deforestation and afforestation, removal of groundwater from wells, water abstraction from rivers, and urbanization. These are also the cause of global warming. The increase in the amount of precipitation and reduction of the number of freezing days as a consequence of global warming are to some extent helping agriculture. However, the changes in the hydrologic cycle may have adverse consequences, including the ones described.

WATER SHORTAGES

Due to the reduction in snowpack, many perennial rivers in the world are experiencing shortages of flowing water in summer months, and groundwater recharging has weakened. Consequently, agriculture suffers. Increased quick melting of snowpacks (due to the rise in surface temperature) in the northwestern United States and India causes summer floods. Increases in rainfall intensity may cause more soil erosion and less soil infiltration. This would create detrimental effects on agriculture. Many hydrologic structures may suffer damage, and may not withstand the higher precipitation intensity, because they were not designed for atypical storm events or rainfall intensities. Increased numbers of hurricanes, storms, and other activities as a consequence of changes in the hydrologic cycle associated with global warming are causing severe hardship to numerous people living on shorelines. Agriculture in the northern United States and southern Canada depends upon soil moisture conserved by snowpack on agricultural land. With less snowfall because of increased surface temperature, there may be less snow deposited on agricultural land, and agriculture will suffer. In summary, global warming causes and would cause the following visible changes in the hydrologic cycle: changes in total precipitation, changes in precipitation frequency and intensity, changes in flood and drought frequencies, and changes in tropical storm frequencies. It would also further amplify global warming, due to increased water vapor in the Earth's atmosphere.

SEE ALSO: Evaporation and Transpiration; Evaporation Feedbacks; Floods; Precipitation; Sea Level, Rising.

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Ice Ages

ENORMOUS ICE SHEETS hav, at times, spread across the globe, bringing with them a cold climate. One definition holds that the advance of glaciers to middle latitudes marks an ice age. Another, and perhaps complementary, definition holds that the spread of glaciers to encompass roughly one-third of the planet is the signature of an ice age. Glaciers have advanced and retreated from Earth's surface and from the ocean several times. The most exuberant estimate tallies 17 ice ages. A more conservative estimate is that Earth has endured the tumult of six ice ages. Scholars have debated not only the number of ice ages, but also their causes. The causes fall into three categories: astronomical, atmospheric, and terrestrial. The recognition of ice ages is recent. Only in the 1830s did Swiss zoologist Louis Agassiz, building on the work of predecessors, propose that parts of Europe, the Americas, and Asia had been covered by ice. As ice advanced and retreated, Agassiz asserted, it ground up rocks in its path and sometimes carried boulders a great distance. Agassiz thought in terms of a single ice age, but climatologists have increased this number in the 20th century.

The first ice age occurred, not thousands of years ago, but rather 2.6 billion years ago. The sun, comparatively young, was not burning at full strength, though this fact does not explain why the ice age had not begun earlier. A more satisfactory explanation focuses on carbon dioxide. The amount of carbon dioxide in the atmosphere diminished, lowering the capacity of the atmosphere to trap heat and, thereby, warm the Earth. As the amount of carbon dioxide diminished, temperatures fell low enough for ice to spread over parts of the primeval continents. The first ice age, lasting 300 million years, ended 2.3 billion years ago.

THE END OF THE FIRST ICE AGE

The end of the first ice age ushered in a warm climate that endured 1.3 billion years. This period was the longest interglacial, a warm interlude between two ice ages, in Earth's history. When it ended, ice returned in a trio of advances and retreats: one billion years ago, 750 million years ago, and 600 million years ago. Of these three, the ice age 750 million years ago may have been the largest, with ice near the Equator. Glaciers may then have covered half the Earth. Climatologists group these three as the Upper Proterozoic Ice Age. One cause of it may have been an increase in the number of photosynthetic algae in the ocean. During photosynthesis, algae, as well as plants, absorb carbon dioxide and emit oxygen. Carbon dioxide is a greenhouse gas, but oxygen is not. In absorbing carbon dioxide, the algae reduced the capacity of the atmosphere to trap heat.

A second cause of the Upper Proterozoic Ice Age may have been rapid continental drift, bringing the continents into high latitudes, where they acquired glaciers and subsequently drifted into the tropics where the glaciers disappeared. This explanation accounts for the fact that the Upper Proterozoic Ice Age was not a single event, but rather the aggregate of three glaciations. Still another cause may have been an exaggerated tilt to Earth's axis. The current tilt is 23.5 degrees, but the tilt during the Upper Proterozoic Ice Age may have been as large as 54 degrees, an orientation that would have given the Southern Hemisphere less sunlight than the Northern Hemisphere year round, prompting the growth of glaciers in the Southern Hemisphere.

THE ORDOVICIAN ICE AGE

The third glaciation of the Upper Proterozoic Ice Age lasted until 580 million years ago. A warm interlude held back the ice for 130 million years, but the recrudesce of glaciers 450 million years ago ushered in the Ordovician Ice Age. The concentration of carbon dioxide was 25 percent lower than it is today, reducing the capacity of the atmosphere to trap heat. This reduction, if it caused the Ordovician Ice Age, underscores that greenhouse gases play a large role in determining the climate. South America, South Africa, India, and Australia were then part of the super-continent Gondwanaland, much of which was above 60 degrees South. At this latitude, evaporation from the ocean formed clouds, which, in turn, released their moisture in the form of snow. Over time, the snow compacted into ice, giving Gondwanaland large expanses of ice. Parts of the continent drifted over the South Pole, ensuring that ice and snow did not melt at the highest latitudes. Ice covered the remainder of Africa, which was not then part of Gondwanaland. By 440 million years ago, North Africa had replaced Gondwanaland at the South Pole. Glaciers spread as far as what is now the Sahara Desert.

Glaciers retreated 425 million years ago. The periodicity of a 130 million year interglacial nearly repeated itself with an interglacial of 125 million years. The Permo-Caroniferous Ice Age, beginning 300 million years ago, was a time of mountain-building on the continents. As is true today, high elevations were home to ice and snow. Glaciers formed first in the mountains of Tasmania and Australia, lands then part of Gondwanaland. Parts of Angaraland, a super-continent of China and Siberia, were above 75 degrees North and so were cold enough for the formation of glaciers. Only Laurasia, a super-continent of North America, Greenland, and Europe west of the Ural Mountains, being between 15 degrees South and 40 degrees North, was near enough to the equator to be unsuited to the formation of glaciers. By 280 million years ago, the glaciers had reached their greatest extent. Forests, spreading in the tropics around this time, may have cooled Earth by absorbing carbon dioxide. Locking up water in ice, the glaciers reduced sea levels between 492–820 ft. (150–250 m.). Glaciers crept from the South Pole to 30 degrees South. By then, the continents had joined to form the super-continent Pangea. The formation of Pangea caused volcanoes to erupt, spewing debris and ash into the atmosphere. These airborne particles blocked out sunlight, cooling the climate and hastening the formation of glaciers. Lands once covered by warm seas dried out and became cold.

THE PERMIAN AND CENOZOIC ICE AGES

By 270 million years ago the glaciers were in retreat and by 250 million years ago only a few mountain glaciers remained. The ocean, swelled by water from melting glaciers, returned to its pre-glacial level. Dramatic as this transition from ice age to warm climate was, it was shorter than the two previous interglacials. Around 230 million years ago, the return of glaciers heralded the Permian Ice Age. This glaciation coincided with a mass extinction of both terrestrial and marine organisms. Around 180 million years ago, Pangea began to break up into South America, South Africa, India, Australia, and Antarctica, all of which retained glaciers.

The glaciers were again in retreat by 130 million years ago. The interglacial that chased away the glaciers lasted until one million years ago, when the Cenozoic Ice Age inaugurated a new cycle of advance and retreat. This most recent ice age has had several glaciations. Glaciations of 100,000 years have alternated with warm periods of 10,000 years. The most recent glaciation occurred 100,000 years ago. Glaciers spread to their greatest extent 18,000 years ago before retreating. Ice 10,000 ft. (3,048 m.) thick covered Canada,

Glaciers have advanced and retreated from Earth's surface and from the ocean several times; estimates of Ice Age occurrences range from six to 17. Their causes—astronomical, atmospheric, or terrestrial—have been debated by scholars.

Greenland, and northern Europe. The glaciers locked up 5 percent of Earth's water as ice. Sea level diminished, revealing the continental shelves as land. With its continental shelves exposed, Florida was twice as wide as it is today. Temperatures fell to 10 degrees F (5.5 degrees C) below current temperatures.

Colder temperatures reduced the rate of evaporation from the oceans. Rainfall decreased accordingly. The Cenozoic Ice Age was both cold and dry. Land not covered by snow and ice became desert. The glaciers held so much water as ice that the North Sea, the Baltic Sea, and the Bering Strait, bereft of water, did not exist. With ice 2 mi. (3.2 km.) thick in parts of North America and Eurasia, its melting released millions of gallons of water into the oceans. In North America, water flowed south through the Mississippi River as the glaciers retreated north. Once the glaciers reached the Great Lakes, water flowed not south, but rather east through the Lawrence River and into the Atlantic Ocean. The cold water stopped the warm water of the Gulf Stream from heating the Atlantic coast. Bereft of the Gulf Stream, North America retained its glaciers until 10,000 years ago, when they shrank to their current size.

The Cenozoic Ice Age coincided with the origin of modern humans roughly 100,000 years ago. Modern humans arose in Africa, which was warm in contrast to the lands of the ice age. With minimal hair and abundant sweat glands, humans were adapted to warm climes. Nevertheless, they wandered into Europe about 40,000 year ago. There they encountered Neanderthals, a type of human that had lived in Europe for some 200,000 years. In contrast to modern humans, Neanderthals were adapted to the ice age. Their stout frame and short arms and legs minimized the body's surface area exposed to the cold and so conserved heat. In one of the great paradoxes in history, modern humans, adapted to a warm climate, thrived in Ice Age Europe, whereas Neanderthals adapted to the ice age went extinct.

The Cenozoic Ice Age also aided the migration of humans to new lands. The glaciers lowered sea level some 394 ft. (120 m.), revealing a land bridge between

Southeast Asia and Indonesia. To the north, a land bridge between Asia and North America allowed humans to colonize the New World. The end of the Cenozoic Ice Age coincided with the extinction of the saber-toothed cat, the wooly mammoth, the mastodon, the hippopotamus, and the horse in the Americas. Whether humans hunted them to extinction or whether they could not adapt to a warm climate remains open to question.

THE LITTLE ICE AGE

Around 1300 C.E., temperatures fell 2 degrees F (1 degree C), ushering in the Little Ice Age. The number of sunspots decreased during the Little Ice Age, evidence that the sun emitted less heat than it does in warm periods. The number of sunspots reached its nadir 1645–1715, the coldest years of the Little Ice Age. From the outset, Europeans suffered under harsh conditions. Beset by cold, wet weather, their crops rotted in the fields. Famine, acute in 1315 and 1317, consigned some to starve and others to chronic hunger. Malnourished, the people of Eurasia were vulnerable to disease. One of the worst pandemics, the Black Death, struck Europe during the Little Ice Age, killing between one-third and half the population. The Norse of Greenland fared no better during the Little Ice Age. Able to farm the land in warm weather, the Norse struggled to eke out an existence in the cold of the Little Ice Age, and finally failed. In the New World, George Washington's Continental Army nearly disintegrated in the frigid winter at Valley Forge.

By 1850, the Little Ice Age had ended. Shedding its heat at the current rate, the Sun warmed Earth. Well-suited to this new warm period, humanity began its rapid ascent to the current population of more than 6 billion. Some climatologists predict that the current warmth, like warm climates of the past, will not last. The current interglacial has nearly run its course. Soon, ice will again cover vast areas of the world. Others, however, predict that the climate will become warmer, not colder, because of the increase in the concentration of carbon dioxide in the atmosphere. The ice caps and the ice on Greenland will melt. Mountains will lose their snow and ice. Coastal cities may flood. At the moment, no consensus exists whether Earth will or will not descend into another ice age.

SEE ALSO: Climate; Glaciers, Retreating; Glaciology; Global Warming; Ice Albedo Feedback; Ice Component of Models; Weather.

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Ice Albedo Feedback

ALBEDO IS AN estimate of the reflectivity of a surface. The sun produces solar radiation in wavelengths that can be reflected off of many of the Earth's surfaces, some more so than others. The albedo of Earth is estimated as the ratio of the outgoing solar radiation (250–2500 nm.), and the incoming solar radiation. A surface that is perfectly reflective (all incoming light is reflected back again) would have an albedo of 100 percent reflection, or, as a ratio, 1.00. A surface that has no reflectivity would have an albedo of zero percent reflection, and a ratio of zero. On Earth, open water, such as the oceans, has an albedo of 0.05, whereas newly fallen snow has an albedo of 0.90. Ice and snow have an average albedo of 0.80. In the polar regions, this means that approximately 80 percent of the sun's rays are reflected back into the atmosphere and only 20 percent of the ray's transfer energy into melting the snow and ice. As the Earth warms, the amount of snow and ice cover decreases.

As snow and ice are very reflective, this works to keep the polar and high-altitude regions cooler. If, as in the polar regions, particularly the Arctic, approximately 80 percent of the solar radiation is reflected back to the atmosphere, the ice and snow do not melt completely and the permafrost that is located directly beneath the ice and snow is never warmed. If the permafrost remains frozen, the ice and snow on the ground are maintained and the air remains cool. This maintenance of the ice and snow keeps the albedo of the region fairly constant, reflecting most of the solar rays back to the atmosphere, and the ice and snow remain even longer. Scientists believe that this feedback loop that maintains the ice and snow has contributed to ice ages in the Earth's past.

The opposite scenario can also be imagined. If the air temperature at the Earth's surface increases, the ice and snow will melt more quickly. If there is less ice and snow cover at the poles and in the high altitude regions, the albedo will decrease (soil and vegetation are less reflective than ice and snow). If the albedo in a region decreases, more solar radiation will be absorbed by the Earth, which will further increase the surface temperature, melt more of the ice and snow, and perpetually warm the Earth. Scientists believe that global warming drives this ice-albedo feedback loop.

As global warming continues to increase the air temperature at the Earth's surface, continual decreases in the amount of ice and snow covering large areas and the polar regions and high altitudes are expected. If this occurs, the ice and snow may permanently disappear from areas that were previously under snow for the much, if not all of the year. If these areas are exposed, and, specifically, the permafrost is allowed to warm, melting of the permafrost layer will occur. If the permafrost layer were to melt, water drainage into the soil layers would increase. If this occurs, the peat layer beneath the permafrost that never decomposed due to a lack of water, will have vast amounts of water and warmer temperatures, suggesting fast rates of decomposition of the peat. Peat stores carbon, and when it is decomposed, the carbon is released as carbon dioxide (CO_2) to the atmosphere. Scientists believe that CO_2 release is contributing significantly to global warming. If the peat decomposed and released more CO_2 to the atmosphere, even higher temperatures at the Earth's surface would, in turn, melt more ice and snow, and concomitantly release even more CO_2 through further decomposition of the peat. The cycle would continue until no region would be permanently covered in ice or snow.

Without the high albedo to reflect the sun's rays, expansive melting of ice and snow may occur. The contribution of melting ice to seawater would have a multitude of effects on global climate. For instance, if only the western Antarctic ice sheet alone melted, there would be a 16–20 ft. (5–6 m.) increase in mean sea level. However, if the entire Antarctic ice sheet were to melt, over the next thousands of years there would be a 184-ft. (56-m.) increase in sea level, causing catastrophic scenarios. Beyond sea-level rise, experts are concerned that the influx of freshwater to the oceans with the melting of the Antarctic Ice Sheet will significantly alter the salinity and temperature of the oceans, causing unpredictable effects on the ecosystems in this region. With decreased salinity, the evaporation rate of the oceans will change and the living organisms that are dependent on a stable aquatic environment may not survive. Changes in the ice-albedo feedback loop will likely have these and countless unpredicted effects on the Earth.

SEE ALSO: Climatic Data, Ice Observations; Glaciers, Retreating; Glaciology; Greenland Ice Sheet; Little Ice Age; Radiation, Ultraviolet; Sea Level, Rising.

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Ice Component of Models

CLIMATE MODELS HAVE developed from mathematical formulas used in the 19th century to try to predict the weather. The lack of accurate and comprehensive data and the need to rely on manual calculation techniques made these approaches very difficult, and ultimately, they were abandoned as it became clear that the results of the equations did not match real-world conditions. During World War II, military expediencies demanded that more data be collected about the atmosphere, and this capacity remained in force after the war. The quantity of data available enabled researchers to check their calculations against real-world conditions. The advent of computers reduced the time needed to complete calculations.

The result is that climate models were refined and developed to a far more sophisticated degree than had previously been imagined possible. One implication of this is that modelers have been able to include a number of new variables in their models, or else to increase the complexity with which existing variables are treated. As a result, the atmosphere is divided into an increasingly large number of layers, and land cover is divided into different elevations, types, and albedos, for example. The insertion of ice into climate models is a further example of the refinement. Models that include ice components may be referred to as oceanic models, and they are a necessary part of comprehensive Coupled Atmosphere-Oceanic General Climate Models.

Ice may be considered both as land cover and as part of the sea. The composition of the ice, as well as its size and structure, will have an impact on its albedo, which represents the degree to which light is reflected from its surface. Ice is involved in the exchange of salt from water to ice, and also has an impact on the surrounding land cover. Ice will increase or decrease according to fairly predictable patterns. However, the calving process by which icebergs divide is less easy to predict. The momentum of ice is now more accurately calculated by using scaling arguments, while incremental remapping is now used to consider horizontal advection.

In addition to modeling the presence of ice, researchers must also consider the ways in which the different components of the models interact with each other. Atmosphere, ocean, land, and sea-ice components exist in a dynamic state of change, depending on their interactions with each other and with external sources of energy. The impact of rapid ice-loss now experienced, for example, is being studied with great urgency, as it has unforeseen impacts upon the rest of the climate system, as well as the possibility of earthquakes and other tectonic activity. The release of more water into the seas will have an impact upon the amount of land above sea level and will, therefore, have an affect on patterns of human settlement.

As global warming and climate change continue to intensify, the amount of ice on the Earth's surface will continue to decrease. Estimates suggest that, if current trends continue, Himalayan ice will have disappeared within three decades, while polar ice is breaking up and melting at an ever-increasing rate. This will probably obviate the need to integrate the presence of ice into climate models in the future.

SEE ALSO: Albedo; Climate Models; Computer Models; Ice Ages; Ice Albedo Feedback.

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Iceland

OFFICIALLY PART OF Europe, Iceland has been a republic since 1944. The capital city is Reykjavik and the population (2007 est.) is 311,400. The total area of the island is 39,768.5 sq. mi. (103,000 sq. km.). Glaciers cover approximately 11 percent of the landmass. Iceland is located in a geological hotspot and has several active volcanoes. During the last glaciation, Iceland was completely covered with ice. Colonists, primarily from Norway, first settled Iceland in the late 9th century. According to DNA studies, approximately one quarter of the original population was composed of women from the northern British Isles. Woodland cover, now around 1.3 percent of the total landmass, was then approximately 30 percent. The settlers brought a farming economy based on sheep and cattle. With a climate generally unsuitable for grain growing, the main agricultural crop has been the grass on which the livestock have depended for winter fodder. The failure of grass in past centuries frequently led to famines, which caused considerable loss of life. From the late 19th century onwards, fisheries dominated the economy.

The climate of Iceland is largely determined by its position in the middle of the North Atlantic, at a point where contrasting cold and mild ocean and air currents meet. This makes the climate highly variable on all time scales, from days to centuries. The island is favorably influenced climatically by its proximity to the Irminger Current, a branch of the Gulf Stream. However, the Arctic Sea ice, also called drift ice, which is brought to Iceland by the East Greenland Current, has a mainly negative effect. The ice, which may have given the country its name, acts as a heat sink and lowers temperatures on land and, in the past, could block harbors and thus prevent fishing and the access of trading ships. Information on the past incidence of the ice reaching the coasts is a useful climate proxy indicator.

It has been suggested that Iceland experienced a relatively mild climate during the early centuries of settlement, but evidence is largely circumstantial. Barley, for example, which needs relative warmth during the growing season, seems to have been cultivated. Serious erosion, caused by livestock grazing and woodland clearing, was undoubtedly as large a contributing factor to later economic difficulties as climate change may have been.

Iceland's climate has varied considerably during the approximately 1,100 years since human settlement began. From around 1200 C.E., historical evidence begins to shed light on climate change, although 1430–1560 there are very few contemporary sources. From 1600, there is sufficient evidence to be able to reconstruct climate and sea-ice indices. The general view has been that 1600–1900 was unfavorable climatically, but a scrutiny of the data shows much variability. In particular, there was a relatively mild period 1640–70. The 1780s are likely to have been the coldest decade of the 18th century, but this was compounded by volcanic activity from the Lakagígar eruption in 1783. The 1801s and 1830s were also comparatively cold. The last great famine occurred in Iceland in the 1880s, when cold years and much sea ice occurred.

The first meteorological observations on Iceland were made 1749–51, but a continuous series does not begin until 1820. From that time on, there is detailed information on climate change provided by a number of systematic observations and historical records. The modern era of observations began with the establishment of the Icelandic Meteorological Office (Veðurstofa Íslands) in 1920. By the 1920s, a marked warming trend was well under way. Sea ice was an infrequent visitor until the cold period 1965–71. Since the 1980s, there has been a warming trend in the temperature records for Iceland, with very little sea ice reaching the coasts.

SEE ALSO: Drift Ice; Glaciers, Retreating; Glaciology; Greenland Ice Sheet; Volcanism.

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Idaho

LOCATED IN THE Pacific Northwest, Idaho, the 13th largest state in the United States, is also one of the fastest-growing states. Famous for its potato crop, it is an important agricultural state, producing one-third of the potatoes grown in the United States. Manufacturing, particularly electronics manufacturing, and tourism are also major contributors to Idaho's economy, which, according to some sources, is the fastest growing economy in the nation. Perhaps because the state's energy consumption is relatively low (40th among the 50 states) and because it once produced more than 80 percent of its power through hydroelectric facilities, Idaho has been slow to confront climate change and its effects. In 2007, however, the state took a number of significant steps to become more environmentally responsible.

Such reluctance to act seems incongruous for a state that dates its environmental activism to 1897 when President Grover Cleveland established the Bitterroot Forest Preserve, encompassing much of the northern region. More than three decades later, the U.S. Forest Service declared more than three million acres of Idaho's forestland primitive areas. In the 1960s, Idaho Senator Frank Church sponsored the bill that created the National Wilderness System, which now contains most of the primitive areas set aside in the 1930s. Federal legislation was introduced in 2007 that could erode the protection of the wilderness areas and decrease carbon sequestration.

Some experts argue that climate change has already increased the number and extent of forest fires and reduced hydroelectric generation in Idaho. One regional climate model shows that Idaho may experience a 4–5 degree F increase in temperatures, bringing warmer, wetter winters and slightly hotter summers and may face a snow pack reduction of approximately 30 percent. For a state that depends on an abundant water supply for its hydropower plants, irrigation, and fisheries as well as regular use, such a scenario is ominous. Agricultural production in the state accounts for $2.8 billion each year. Well over half of this comes from crops, and nearly 70 percent of farms are irrigated. The predicted climate change could increase production of some crops, but potato production could fall by 18 percent. Water shortages could intensify damages.

Idaho's legislature approved the formation of a Carbon Sequestration Advisory Committee in 2002 to explore a new means of revenue for the state's farmers through sequestration sales to carbon dioxide producers as an effort to address greenhouse gas emissions. Idaho ranks 47th among the 50 states in its carbon dioxide emissions, but this low ranking fails to account for the 42 percent of the state's power that comes from power produced by coal-burning plants in nearby states. Once emissions from the transportation sector are added, almost 80 percent of energy consumed in Idaho is produced by fossil fuels. Despite these data, Idaho has been tardy in working within the state and in allying itself with regional and national groups to address greenhouse gas emissions. The state is not a member of the Western Regional Climate Action Initiative, a collaboration among six western states and two Canadian provinces to reduce emissions. It was only in summer 2007 that Idaho joined the Climate Registry, a multi-state effort to provide accurate data on greenhouse gas emissions to support reduction policies. Idaho has yet to develop a climate action plan, and a legislative attempt to require energy efficiency standards in construction of public buildings failed to move out of committee.

In 2006, the state legislature created the Legislative Council Interim Committee on Energy, Environment and Technology and charged the committee with developing an integrated state energy plan. A year later, the legislature renewed this committee. In 2007, further legislation cleared the way for wind farms on state endowment lands. The 2007 legislature also passed an act adopting the integrated Idaho Energy Plan developed by the Legislative Council's interim Committee on Energy, Environment, and Technology. This plan, the first state energy plan since 1980, encouraged greater reliance on renewable energy sources in place of dependence on fossil fuels and hydroelectric power.

Also, in 2007, Idaho Governor C.L. "Butch" Otter signed two executive orders that suggest a new commitment to action. The first established the Idaho 25 x 25 Renewable Energy Council, a group given the responsibility of developing coordinated programs to buttress the 25 x 25 Initiative for the state's agricultural and forestry sectors. The goal is for renewable sources to provide 25 percent of the state energy's requirements by 2025. The second executive order made the director of the Department of Environmental Quality the central point of contact for all greenhouse gas reduction programs and gave the director the authority to develop a greenhouse gas emission inventory and to recommend methods for reducing the state's emissions. The Department of Environmental Quality is the state's regulatory agency, responsible for enforcing state environmental regulations and administering federal environmental protection laws including the Clean Air Act, the Clean Water Act, and the Resource Conservation and Recovery Act.

Idaho is also home to the Idaho National Laboratory IINL), an 890 sq. mi. (2,305 sq. km.) U.S. government reservation, established in 1949 as the Nuclear Reactor Testing Center. In the more than five decades since its creation, the INL has extended its focus to encompass research and development in biotechnology, energy, and materials research, and conservation and renewable energy. In 2005, a separate unit, the Idaho Cleanup Project, was established to clean up previously contaminated sites and protect the Snake River Aquifer that provides drinking water for more than 300,000 Idahoans. The most recent extension of INL is the Center for Advanced Energy Studies, a $14-million facility that Idaho will be engaged not only in energy research, but also in a climate change technologies program.

SEE ALSO: Agriculture; Carbon Sequestration; Forests; Idaho State Climate Services.

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Idaho State Climate Services

THE NATIONAL CLIMATIC Data Center, the National Weather Service, and the University of Idaho founded the Idaho State Climate Services in May 1978 to provide climate services that had formerly been supplied by a National Weather Service program. Professor Myron Molnau was instrumental in establishing the center. The State Climate Services program is housed in the Biological and Agricultural Engineering Department and is headed by the state climatologist for Idaho. The Idaho Agricultural Experiment Station, Idaho Cooperative Extension System of the University of Idaho, and Idaho Water Resources Research Institute support the center. The tasks of the State Climatologist and State Climate Services are to: act as liaison between Idaho weather information users and the National Climatic Data Center, keep a databank of climatological and hydrological data and information, and compile a regular bibliography of publications pertinent to Idaho and Pacific Northwest climate. The center receives additional cooperation from the National Climatic Data Center, the Western Regional Climate Center, and the National Weather Center.

In 2002, the Idaho State Climate Services received national certification from the American Association of State Climatologists. Following review by the American Association of State Climatologists, the Idaho State Climate Services qualified as an Association Recognized State Climate Office (ARSCO). The center has various databases, including Inside Idaho, a historical record of daily data from more than 250 weather stations in Idaho, some dating as far back as 1890. It includes data on precipitation, temperature, pan evaporation, wind run, snowfall, and snow on the ground. This database, like others managed by the Idaho State Climate Services, can be accessed online and downloaded. In addition to the actual data, the databases include all original forms and maps used by the State Climate Services. The long time span of the data provided by the service allows researchers to accurately assess the variability of weather conditions. Russell Qualls, a faculty member in the department of biological and agricultural engineering, is the Idaho state climatologist and serves as the director of the center. In recent years, the center has specialized in research on the effects of El Niño and La Nina on the Idaho economy.

SEE ALSO: Climatic Data, Historical Records; El Niño and La Niña; Idaho.

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Illinois

ILLINOIS HAS AN area of 57,914 sq. mi. (149,997 sq. km.), with inland water making up 756 sq. mi. (1,958 sq. km.) and Great Lakes coast water of 1,575 sq. mi. (4,079 sq. km.). Illinois's average elevation is 600 ft. (183 sq. m.) above sea level and made up of four geographic regions: the Central Lowland (with extensive flatlands covering most of the state), the Interior Low Plateaus, the Ozark Plateaus, and the Gulf Coastal Plain (in the southern part of state). Illinois has warm to hot summers and cool to cold winters. In the winter, polar air masses move south or southeast across the state from Canada, bringing cold and crisp weather. In the summer, warm air masses move up from the Gulf of Mexico, and the weather is often hot and muggy. Lake Michigan tempers the summer heat somewhat for Chicago and other cities along its shores, and also delays the date of the first fall frosts nearby.

With no natural barriers like mountains, Illinois experiences the full sweep of winds. Easterly and southeasterly winds are mild and wet, southerly winds are warm and showery, westerly winds are dry with moderate temperatures, and northwesterly and northerly winds are cool and dry. The winds are controlled by storm systems. Precipitation (rainfall and snowfall) generally increases from north to south, with a state average of 37 in. (94 cm.) per year. Annual snow average is 30 in. (76 cm.) in the north and 10 in. (25 cm.) in the south. Lake Michigan has minimal influence on prevailing winds, and storm systems move in the same direction.

Rich soil accounts for high crop production (corn and soybeans); the northern two-thirds of the state lie in the Corn Belt. Fruit crops, especially peaches, apples, and strawberries, are raised in the southern hill lands. Industrial and urban centers exist along the Mississippi River. Coal-burning and nuclear power plants generate electricity in Illinois. Based on energy consumption data from the Energy Information Administration's State Energy Consumption, Price, and Expenditure Estimates (SEDS) released June 1, 2007, Illinois's total carbon dioxide emissions from fossil fuel combustion in million metric tons carbon dioxide for 2004 were 235.97, made up of contributions from: commercial, 12.15; industrial, 38.53; residential, 24.71; transportation, 68.58; and electric power, 92.

In the past 15 years, the state experienced a severe drought in 1988, flooding in 1993 and 2002 (partly because of the flatness of the land), heat waves in 1995 and 1996, and a destructive windstorm in Bloomington in 1999. The drought emergency declared throughout much of Illinois in 2005 illustrates the potential problems associated with global warming. Farmers, communities, and wildlife all depend on healthy stream flows throughout the state. Six counties on the shore of Lake Michigan (in the largest lake system, containing one-fifth of Earth's open fresh water) and the city of Chicago rely on Lake Michigan as a source of drinking water. Global warming projections indicate higher rain and snow levels in winter and spring in Illinois, and estimated summer temperatures increasing 9–17 degrees F (5–9 degrees C) by the end of the century.

While climate models vary on the amount of temperature increase possible, potential risks include decreased water supplies, population displacement (both human and animal), and changes in food production, with agricultural production improving in cooler climates and decreasing in warmer climates. Changes in rain patterns to downpours, with the potential for flash flooding, raise the health risks of certain infectious diseases from water contamination or disease-carrying vectors such as mosquitoes, ticks, and rodents. Warmer temperatures can also cause heat-related illnesses and lead to higher concentrations of ground-level ozone pollution, causing respiratory illnesses, especially in cities. Increased temperatures would in turn increase evaporation rates and cause drier soil conditions. Torrential rain would contribute to major flooding. Inconsistent precipitation levels are projected to put more pressure on already scarce water resources, causing the potential for decreased corn and soybean yields.

STEPS TO REDUCE GREENHOUSE GAS EMISSIONS

In July 2005, the Illinois Commerce commission passed a plan urging state power companies to obtain at least 2 percent of electricity from renewable energy sources by 2006, increasing the amount by 1 percent every year to 8 percent in 2012. Illinois's greenhouse gas reduction target is to meet 1990 levels of six greenhouse gases by 2020, with emissions falling below 1990 levels by 2050. Illinois established the Climate Change Advisory Group in October of 2006. Illinois joined the Climate Registry, a voluntary national initiative to track, verify and report greenhouse gas emissions, with acceptance of data from state agencies, corporations, and educational institutions in January 2008.

In 2005, the governor signed a law, effective July 2006, requiring local governments, school districts, universities, community colleges, and mass transit agencies to fuel their diesel vehicles with 2 percent biodiesel, a renewable fuel made from soybeans or agricultural waste. They will join the state facilities already using the two percent biodiesel per an executive order passed in 2002. As early as 1996, Illinois legislators were developing a strategy in response to global greenhouse gas emissions. Illinois wanted to be ahead of potential federal mandates. A taskforce developed greenhouse gas inventories and identified greenhouse gas emissions reduction programs. Some actions were deemed necessary regardless of global warming predictions, including strengthening water laws for quantity and quality, remapping floodplains, and continued research on the structural integrity of construction in vulnerable areas in Chicago, the Illinois River Basin, and the Great Lakes Basin.

SEE ALSO: Carbon Dioxide; Climate Models; Greenhouse Gases.

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Impacts of Global Warming

IMPACTS FROM THE phenomenon known as global warming include environmental, social, and economic effects. Environmental impacts include sea-level rise, melting of the polar ice caps, and an average increase in temperature. These impacts are documented in the reports of the Intergovernmental Panel for Climate Change (IPCC), which commissions reports by scientists worldwide on the issue of climate change. The IPCC Report of 2007 is the first one that reflects scientific consensus that global warming is underway, and that it is primarily human induced. For example, human activities, such as fossil fuel burning, land-use changes, agricultural activity, and the production and use of halocarbons are among the factors causing climate change. The economic report by Nicholas Stern in 2007 highlights that climate change has potentially disastrous consequences for humanity.

TEMPERATURE VARIABILITY

Perhaps best known, is that temperature variability, specifically temperature increase, will be one of the effects of climate change. While the range of projections relating to temperature rise varies, the IPCC scenarios, using a range of climate models, predict overall a rise in globally-averaged surface temperature of 2.5–10 degrees F (1.4 to 5.8 degrees C) 1990–2100. While at local and regional levels this figure will vary, at a global level it is roughly 2–10 times larger than the observed warming of the 20th century, and is unprecedented during at least the last 10,000 years, based on paleoclimatic data.

Changes in temperature and precipitation (rainfall) patterns have increased all around the world. In the United States, average temperatures have increased by roughly 1 degree F (0.6 degrees C) during the past century, and precipitation has increased by five to 10 percent. Alaska has sustained an average temperature increase of 4–7 degrees F (2–4 degrees C) in just the past 50 years. Temperature increase has also had a number of related effects, such as the increased melting of the summer Arctic sea ice. Since 1979, more than 20 percent of the polar ice cap has melted in response to increased surface and ocean temperatures. The oceans are warming. Global ocean temperature has risen by 0.18 degrees F (0.10 degrees C) from the surface to a depth of (2,297 ft.) 700 m. 1961–2003.

WARMING OF WATER MASSES

Key oceanic water masses are changing. Southern Ocean mode waters and Upper Circumpolar Deep Waters have warmed from the 1960s to about 2000. A similar, but weaker pattern of warming in the Gulf Stream and Kuroshio mode waters in the North Atlantic and North Pacific has been observed. Long-term cooling is observed in the North Atlantic subpolar gyre and in the central North Pacific.

SEA-LEVEL RISE

Another predicted effect of climate change is an increase in sea level. Sea-level rise is caused by thermal expansion of the oceans, melting of glaciers and ice caps, melting of the Greenland and Antarctic ice sheets, and changes in terrestrial storage. Changes in sea level will be felt through increases in intensity and frequency of storm surges and coastal flooding; increased salinity of rivers, bays, and coastal aquifers resulting from saline intrusion; increased coastal erosion; loss of important mangroves and other wetlands (the exact response will depend on the balance between sedimentation and sea-level change); and impact on marine ecosystems such as coral reefs.

Sea-level rise is accelerating worldwide. Globally, 100 million people live within about 3.3 ft. (1 m.) of present day sea level. Eight to 10 million people live within 3.3 ft. (1 m.) of high tide in each of the unprotected river deltas of Bangladesh, Egypt, and Vietnam. IPCC reports estimate that the global average sea level rose at an average rate of .07 in. (1.8 mm.) per year 1961–2003, and within that period, the rate of rise was faster 1993–2003, about 0.12 in. (3.1 mm.) per year. Overall, the IPCC concludes there is high confidence that the rate of observed sea level rise has risen from the 19th to the 20th century. The total 20th century rise is estimated to be 0.55 ft. (0.17 m.) In 2001, IPCC projections were for a sea-level rise of between 3.5–34.6 in. (9–88 cm.) 1990–2100 and a global average surface temperature rise of between 2.5–10.4 degrees F (1.4 and 5.8 degrees C.). In 2007, IPCC projections based on different scenarios predict seal level rise from 0.01 to up to 0.02 in. (.18–.59 mm.) by 2099.

Toward the end of the 21st century, projected sea-level rise will affect low-lying coastal areas with large populations. The cost of adaptation could amount to at least five to 10 percent of Gross Domestic Product. Mangroves and coral reefs are projected to degrade further, with additional consequences for fisheries and tourism. Snowmelt runoff as a result of seal level rise will have major consequences. For example, one change will be a change from spring peak flows to late winter peaks in snowmelt-dominated regions. Many species, both aquatic and riparian (riverine) have evolved to take opportunity of the spring flows as a result of snowmelt. For example, some fish time their reproduction strategies specifically to avoid the stress of springtime flows. Changes in springtime flow regimes, or high winter flows associated with rain or snow events, can scour streambeds and destroy eggs. Trees that provide riparian habitat along rivers may find it harder to reproduce as they depend on high spring flows. Many species, such as salmon, already under pressure from other environmental impacts, will be further impacted by climate change. For example, higher temperatures and a reduced stream flow in the Columbia River Basin may be increasing the mortality of juvenile coho salmon; in some cases increased temperatures may be creating thermal barriers for the migration of adult salmon.

Temperature increase has had a number of related effects, such as the increased melting of the summer Arctic sea ice.

There are a number of associated events that are a result of climate change and will also have impacts on sea-level rise. For example, the Kangerdlugssuaq Glacier in Greenland is moving much faster, melting at a rate of 8.7 mi. (14 km.) a year in comparison to just 3.2 mi. (5 km.) a year in 1988. This loss will also have serious implications for sea-level rise, with some scientists predicting that within the next 100 years, ice cover in this region will completely disappear over summer and that species living within it, such as polar bears, will be threatened. The complete melting of the Greenland Ice Sheet and the West Antarctic Ice Sheet would lead to a contribution to sea-level rise of up to 23 ft. (7 m.) and about 16 ft. (5 m.), respectively.

INCIDENCE AND SEVERITY OF STORMS

Increased incidence and frequency of storms is another predicted effect of climate change. For example, since 1996, the number of named tropical storms in the North Atlantic per year has increased by 40 percent, a figure considered extreme in the 1950s. Some research indicates that there is a link between higher sea-surface temperatures and storm frequency. Researchers have found that 1970–2004, warmer sea-surface temperature has been the major factor in the increase in category 4 and 5 hurricanes globally. Scientists have also shown that there is a strong correlation between sea temperature and annual hurricane power in three different hurricane basins in the North Atlantic, and two in the Pacific. Hurricane Katrina and the tsunami in Southeast Asia are both examples of the increased frequency and intensity of natural events that result from climate change.

ATMOSPHERIC COMPOSITION

Another effect of climate change is changes in atmospheric composition. It is possible to measure these changes, as the composition of air, prior to industrialization, is known from testing air bubbles frozen in ice cores from Antarctica. Since pre-industrial times, the concentration of CO_2 within the atmosphere has risen from about 270–280 parts per million by volume (ppm) to over 360 ppm today. Moreover, CH_4 has risen from about 700 parts per billion by volume (ppb) to over 1700 ppb, and N_2O has increased from about 270 ppb to over 310 ppb. Halocarbons, substances that are not naturally present in the atmosphere, are now present in large amounts.

This is important because changes within the atmosphere have disrupted the total energy budget of the planet. The balance between incoming, solar shortwave radiation, and the outgoing long-wave radiations has upset the normal radiative balance. This change is called radiative forcing. The Earth's response to this phenomenon is to try to restore the balance by warming the lower atmosphere. In so doing, the surface temperature of the planet increases.

ECOLOGICAL SYSTEMS

Ecological systems are changing, upset, and modified as a result of climate change. About 20–30 percent of plant and animal species assessed so far are likely to be at increased risk of extinction if increases in global average temperature exceed 2.7–4.5 degrees F (1.5–2.5 degrees C). Significant loss of biodiversity is projected to occur by 2020 in some ecologically rich sites, including the Great Barrier Reef and Queensland Wet Tropics. Other sites at risk include the Kakadu wetlands, southwest Australia, sub-Antarctic islands, and the alpine areas of both countries. In Latin America, by mid-century, increases in temperature and associated decreases in ground water are projected to lead to gradual replacement of tropical forest by savanna in eastern Amazonia. Semi-arid vegetation will tend to be replaced by arid-land vegetation. There is a risk of significant biodiversity loss through species extinction in many areas of tropical Latin America.

A typical example of the effect of climate change is the coral reef ecosystem. Coral bleaching, resulting from the breakdown of the symbiotic relationship between corals and unicellular algae (*zooxanthellae*), is often caused by the warming of sea temperatures. Reef coral are very sensitive to temperatures outside of their acceptable range; a rise of just 1 degree above long-term averages is enough to cause coral stress and bleaching. If these temperatures exceed average levels for a long period of time, the reef system will collapse. The mass bleaching events reported on the Great Barrier Reef and elsewhere around the world over the last five to 10 years have been triggered primarily by anomalously high water temperatures. Increased levels of CO_2 in the sea also affect the acidity of the ocean's surface water, and, hence, reduce the amount of dissolved carbon carbonate for reef-building corals.

The extent of ecological consequences will partly dependent on the extent of temperature change and water availability from precipitation and runoff in any given location, but ultimately, ecological changes will occur across the planet. For example, in North America and Australia, parts of these continents will become wetter and others drier, with variability in precipitation events causing unpredictability in runoff patterns and changes to ecological systems. Many species are dependent on, or live within, specific temperature ranges; thus, a change in temperature, for example, their extremity, duration, and seasonality will have a correlative affect on rates of growth and reproduction. For animals, such as turtles, cassowaries, or salmon, all of which reproduce at certain temperatures (and produce certain sexes within certain temperature ranges), variation in thermal regimes will have significant effects. Some species may be able to adapt and shift the geographic ranges of their distribution, but for many, the effects of temperature change will be catastrophic as the areas they live in become unsuitable and uninhabitable.

Increased air temperatures will also effect wetland, estuarine, and marine species. For example, a warming of water temperatures by 7 degrees F (4 degrees C) in present-day ecosystems would represent a northward latitudinal shift in thermal regimes of about 422 mi. (680 km.), which will have major ramifications for aquatic ecosystems. Moreover, enrichment of soils as by CO_2 will alter species composition in some wetlands.

Climate change will also alter the hydrological regimes of rivers and lakes through changes in water flows. Reductions in the frequency or intensity of high flows that normally inundate flood plains may dry out wetlands, and cause ecological changes from wetland to terrestrial-adapted species. Water tables will rise in areas that become wetter and vice versa, changing species composition in many areas. For example, a reduction in the frequency or magnitude of high flows that inundate the floodplain would tend to dry out floodplain wetlands, isolate them from the adjacent stream or river, and replace wetland plant species with more terrestrially adapted species.

SOCIETAL IMPACTS

Climate change will have major effects on humanity. For example, global climate change and sea-level rise can influence coastal fisheries in a number of ways. Approximately 70 percent of the U.S. fisheries' catch is derived from estuarine-dependent species, and their young are dependent on suitable habitat. Rising sea levels that lead to destruction of coastal wetlands can have direct negative consequences for coastal fisheries. More indirect effects could result from wetland loss that leads to shoreline erosion, which, by adding fine sediments to the water column, would reduce water clarity and, thus, interfere with feeding ability. Many shellfish species also use coastal wetlands as an important habitat and are vulnerable to wetland loss caused by sea-level rise.

There will be a diverse range of socioeconomic costs arising from weather damage and vulnerability to climate change. The *Stern Report* concludes that the economic cost of global warming without action, using conservative scientific estimates for change, will be the equivalent of losing at least 5 percent of global gross domestic product (GDP) per year. Nicholas Stern notes that if little action is taken and a wider range of predictions is considered, then the costs to the global economy will be up to 20 percent of the world's GDP or more.

Socioeconomic systems will be affected by the increase in floods, and droughts. Projections confirm that many countries will experience decreased yields to their crop productivity, especially in areas projected to receive lower rainfall. Climate change will significantly affect those living in the Pacific. In the 1990s, for example, the Pacific Island region sustained costs of up to $1 billion from climate-related incidents.

For many African regions, warmer and drier conditions have led to a reduced length of growing season, with detrimental effects on crops. At lower latitudes, especially in seasonally dry and tropical regions, crop productivity is projected to decrease for even small local temperature increases 1.8–3.6 degrees F (1–2 degrees C), which would increase risk of hunger. In some countries, yields from rain-fed agriculture could be reduced by up to 50 percent by 2020.

Water shortages will put increased pressure on forestry and agriculture. By mid-century, annual average river runoff and water availability are projected to increase by 10–40 percent at high latitudes and in some wet tropical areas, and decrease by 10–30 percent in some dry regions at mid-latitudes and in the dry tropics, some of which are already water-stressed areas. For example, in Africa By 2020, 75–250 million people are projected to experience an increase in water stress from climate change. If coupled with increased demand, this will adversely affect livelihoods and exacerbate water-related problems. In the course of the century, water supplies stored in glaciers and snow cover are projected to decline, reducing water availability in regions supplied by melt water from major mountain ranges, where more than one-sixth of the world population currently lives. Freshwater availability in central, south, east, and southeast Asia, particularly in large river basins, is projected to decrease because of climate changes that, along with population growth and increasing demand arising from higher standards of living, could adversely affect more than a billion people by the 2050s.

Much livestock will find it hard to adapt to the physiological effects associated with climate change, and there are projected increases in pest infestations associated with climate extremes. Projections also show that a warming of the world's temperature by a few degrees will result in a global increase in food prices.

Climate change will also have impacts on human health. For example, people will experience higher heat stress, and loss of life in floods and storms. Heat-related mortality will increase. There will also be a range of direct impacts on disease through increased range of vectors such as mosquitoes. Projected climate change-related exposures are likely to affect the health status of millions of people, particularly those with low adaptive capacity. These indluce increases in malnutrition and consequent disorders, with implications for child growth and development; increased deaths, disease, and injury due to heat waves, floods, storms, fires and droughts; the increased burden of diarrheal disease; the increased frequency of cardio-respiratory diseases due to higher concentrations of ground level ozone related to climate change; and the altered spatial distribution of some infectious disease vectors.

The impacts of climate change will fall disproportionately on developing countries that do not have the economic or social resilience to adapt quickly enough to the effects they will experience. For example, the effects of sea-level rise will affect many Pacific Island nations who will be displaced by coastal flooding and erosion. In Bangladesh, up to 90 percent of the country consists of low-lying land. The effects of climate change on Bangladesh and other countries will be major, displacing millions, and potentially causing a worldwide environmental refugee crisis. Researchers estimate that up to 50 million people worldwide will become environmental refugees by 2010, due to rising sea-level rise, intense and more frequent storms, inundation, and other climate change-induced effects. Ongoing coastal development and population growth in areas such as Cairns and Southeast Queensland (Australia) and Northland to Bay of Plenty (New Zealand) are projected to exacerbate risks from sea-level rise and increases in the severity and frequency of storms and coastal flooding by 2050.

The Working Group 1 Fourth Assessment Report, 2007 has concluded that, of the more than 29,000 observational data series seven, from 75 studies that show significant change in many physical and biological systems, more than 89 percent are consistent with the direction of change expected as a response to warming. Importantly, both past and future anthropogenic CO_2 emissions will continue to contribute to warming and sea-level rise for more than a millennium, due to the timescales required for removal of this gas from the atmosphere.

SEE ALSO: Diseases; Ecosystems; Floods; Global Warming; Hurricanes and Typhoons; Oceanic Changes; Sea Level, Rising.

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India

INDIA WILL BE greatly affected by global warming. The effect will be experienced in the reduction of snow cap size in the Himalayas, retreat of glaciers that feed the rivers, an increased flooding of the snow-fed rivers initially, followed by partial drying up of the rivers, and formation of new lakes and flooded lakes at upper altitudes.

Outside the polar region, the Himalayas contain the largest volume of ice. The size of this ice depends on South Asian monsoons, as well as the winter precipitation that the area receives resulting from the flow of moisture-laden winds that originate in the North Atlantic Ocean and pass through the Mediterranean Sea. About six centuries of historical records and analyses of ice dust and chloride concentrations in the Tibetan ice field have shown that there were modest monsoon failures in India in 1230, 1280, 1330, 1530, 1590, and 1640. The most catastrophic failure, with severe drought, occurred 1790–76. Researchers have ascertained that there is a positive correlation between snowfall and temperature. In recent years, the Himalayas and the Tibetan plateau have experienced warming periods, such as 1960–90, causing diminution of snowfall.

Glacial retreat has been observed in the Himalayas. The United Nations climate report predicts that by 2035, some Himalayan glaciers will disappear with the rising temperatures. Gangotri glacier, the source of the Ganges River, is retreating at a rate of 755 ft. (230 m.) per year. The glacial retreat and lower ice cap after 2035 will lower the volume of the snow-fed rivers of north India, such as the Indus, Ganges, and Brahmaputra rivers, and some of the tributaries originating from the Himalayan ice field. Flooding will endanger riverside cities, such as Varanasi, Kanpur, and Patna.

These million-plus cities already experience flooding during the high monsoon season and will be further endangered. Flooding will also wreak havoc on the farming areas of northern India and cause dislocation in the road and rail transports. Some of the multipurpose River Valley Project dams, such as those across the Kosi and Sutlej rivers, will overflow, causing extreme devastation of rice paddies, cornfields, and settlements.

When a tipping point is reached by 2035, the ice melting will either stop, or be minimized because of continued warming; therefore, the rivers will experience weakened streams during monsoon months and in summer. The perennial nature of these rivers then will be challenged, as they will look like those of south India, where the size of the rain-fed rivers is much diminished during the non-monsoon dry months. Variation in water flows will disrupt river irrigation, on which a large number of the farmers depend, particularly in the Bihar, Uttar Pradesh, Haryana, Punjab, and northwestern Rajasthan states.

As global temperature continues to rise from about 57 degrees F (14 degrees C) (base) in 2000 to an estimated 66 degrees F (19 degrees C) (maximum) in 2100, various effects will be felt on weather, water bodies, farming, desertification, precipitation, and diseases. Sea levels will rise to an estimated 3.9 in. (0.1 m.) (minimum) to 35 in. (0.9 m.) (maximum) by 2100. Parts of coastal cities of India, such as Mumbai, Chennai, and Kolkata, and coastal area farmlands will be inundated, especially during high tides. Parts, or entire coastal islands will also be submerged. Lohachara is the first island in the world to be submerged due to global warming. This Sunderbans Island is situated in the southern edge of the Ganges delta in the Bay of Bengal. Its 10,000 residents turned into the first global warming-generated refugees. The Lakhadweep group of 27 islands, scattered in the Arabian Sea off the coast of the south Indian state of Kerala, is home to about 61,000 people. These low-lying coral islands are in danger of submergence as well. If this happens, the Indian Union will lose one of its seven territories.

India is the world's fourth largest greenhouse gas emitter. Such man-made environmental pollution aggravates the process of global warming. With increased temperatures, there will be a constant rise in precipitation. Higher intensity of cyclones reaching levels 4 and 5 that originate mainly in the Bay of Bengal will plague the coastal states of West Bengal, Orissa, Andhra Pradesh, and Tamilnadu; the territory of Andaman and the Nicobar islands will also be affected.

Rising evaporation resulting from warmer conditions in the Indian Ocean and Arabian Sea will accentuate the desertification process around the West Indian Rajasthan Desert. Rising temperature will also enable farmers and plantation (tea and coffee in particular) operators to increase their domain upwards to higher altitudes. Therefore, there will be an increase in primary sector activity in certain mountainous parts of north-northeast and southwest India. Anopheles mosquitoes spreading malaria will also invade the same higher altitudes. Higher altitude areas and the resort towns like Darjeeling, Nainital; Massouri in the Himalayas; and Ooty (Udhagamandalam) and Kodaikanal in the Western Ghats Mountain Range will be invaded by anopheles mosquitoes spreading malaria, which will only breed in warm weather.

SEE ALSO: Diseases; Drought; Floods; Glaciers, Retreating; Hurricanes and Typhoons; Monsoons.

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Indiana

INDIANA IS A Great Lake State, with a 41-mi. waterfront on Lake Erie. Parts of Indiana are agricultural, and the state is a leading producer of corn. Most of

Indiana is urban, but the iron, steel, and oil companies that swell the economy of the state tend to be located in smaller cities. Indiana ranks 15th in the United States in population. The combination of a large urban population and heavy industry means that much of the state faces major challenges to protecting the environment from global warming and climate change. Educating the public is the major environmental focus. Government actions include emission reduction programs designed to reduce smog, soot, dust, sulfur dioxide, nitrogen dioxide, carbon monoxide, and lead. Air quality monitors have been placed throughout Indiana. Improving waste management is also a priority, and Indiana is concentrating on cleaning up contaminated sites, leaking underground storage tanks, spills, landfills, and open dumps. Environmental activists are pressuring the government to initiate policies promoting sustainable energy and to withdraw support for new coal-fired power plants in the state.

The Indiana Department of Environmental Management (IDEM) and the Indiana Department of Natural Resources share the chief responsibility for dealing with issues arising from global warming and climate change. The Office of Air Quality, the Office of Land Quality, the Office of Water Quality, and the Office of Pollution Prevention and Technical Assistance are housed within IDEM. The Land Bureau, which is part of the Department of Natural Resources, is responsible for environmental issues concerning fish and wildlife, forestry, and state parks and preserves.

Indiana has instituted the Environmental Stewardship Program to encourage business leaders to become more environmentally aware. Benefits of the program include expedited and flexible business permits, reduced reporting and inspections, and, in some cases, reduced monitoring. The government also sponsors the Indiana Comprehensive Local Environment Action Network (CLEAN) to encourage local governments to become involved in protecting the environment. Benefits of the program include matching funds for recycling and pollution prevention.

Environmental priorities often clash with economic goals in Indiana. In 2007, the governor announced that construction would begin on a 40 billion cu. ft., $1.5 billion coal-gasification plant. Indiana Gasification, LLC owns the facility, which was the first in the United States to use eastern coal to generate natural gas of pipeline-quality. Environmentalists were opposed to the construction because of potential sulfur emissions, but it won popular support because of the potential for significantly reduced fuel prices.

Industries consume about half of the energy used in Indiana, and most of that energy comes from coal. Consequently, Indiana has one of the highest levels of coal consumption in the United States. Between 1990 and 2001, Indiana's population increased by 10 percent; at the same time, carbon dioxide (CO_2) levels rose 12 percent, to a total of 230.2 million metric tons. Indiana is fifth in the United States in CO_2 emissions. A lawsuit filed by eight states and the City of New York has accused major energy companies of perpetrating global warming and climate change as a result of toxic emissions.

Two of those companies operate in Indiana. The American/Electric Power Company, Inc./American Electric Power Service Corporation, which generates an estimated 226 million tons of CO_2 each year, tops the list. Cinergy Corporation, which produces an estimated 70 million tons of CO_2 emissions per year, is ranked fifth on the list.

CLIMATE CHANGE GOALS

Efforts to combat global warming and climate change resulted in Indiana becoming 23 percent more carbon dioxide efficient 1990–2001. However, in the summer of 2007, Environmental Integrity Projects released a list of the 50 American energy companies emitting the highest levels of CO_2 during the previous year. With 17 plants on the list, and four in the top 50, Indiana was ranked second only to Texas in having the most environmentally damaging energy plants. The group also identifed a number of power plants that release contaminants such as sulfur dioxide, nitrogen oxide, and mercury. Duke Energy Company received federal tax incentives to build a new clean-coal plant in Indiana, but CO_2 emmissions continue to pose problems after other contaminants are removed at such facilities. PSI Energy, Indianapolis Power and Light, and Northern Indiana Public Service Company (NIPSCO), which were ranked in the top 50, decreased CO_2 emissions 2005–07 by millions of metric tons. At the American Electric Power Plant in Rockport, however, CO_2 emissions rose by 17.4 million tons during that timeframe.

SEE ALSO: American Electric Power; Coal; Energy; Indiana University.

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Indiana University

INDIANA UNIVERSITY (IU) is public university internationally known for the quality of its academic programs, which attracts students from all over the world. IU plays a key role in the economic and social well-being of Indiana residents, offering educational, cultural, and financial benefits to the state. The University consists of eight campuses: the original campus in Bloomington, which is a residential campus; an urban campus in Indianapolis, which also includes the IU Medical Center; and six regional campuses in Gary, South Bend, Fort Wayne, Kokomo, Richmond, and New Albany. IU offers a total of 963-degree programs for undergraduate and graduate students at its statewide campuses.

The School of Public and Environmental Affairs (SPEA) offers Bachelors, Masters and Ph.D. degrees in Environmental Science. Fields of expertise include global warming, global climate change, carbon sequestration, and conservation of forests, coral reefs, wildlife, and watersheds. The SPEA also houses several centers of excellence in research. Distinguished Professor, Ronald A. Hites is the director of the Environmental Science Research Center. The goals of the center are to promote excellence in environmental science research and to foster increased interdisciplinary collaboration among environmental science faculty on the Indiana University-Bloomington (IUB) campus. The center does not offer degree programs. Its activities include seminars, discussion groups, and proposal preparation workshops.

Dr. Hans Peter Schmid Professor and Director of Graduate Studies is also Director of the Institute for Research in Environmental Science (IRES). His research interests include biosphere-atmosphere interactions, exchange of CO_2, water vapor and energy between forests and the atmosphere, boundary layer meteorology, boundary layer development over complex surfaces, surface-atmosphere exchange over inhomogeneous surfaces (observation and modeling), spatial aggregation modeling of turbulent fluxes, modeling of subgridscale variability in terms of surface texture, source area/footprint modeling for turbulent flux, and experimental design and measurement of turbulent surface-atmosphere exchange processes.

IRES MISSION

The mission of the IRES is to promote and coordinate research collaboration among environmental scientists at Indiana University Bloomington (IUB). IRES' activities enhance and facilitate communication between scientists affiliated among other departments and schools at IUB. This collaboration also supports integrative graduate research projects with cross-disciplinary mentorship, provides administrative support for externally-funded research programs in environmental science, and enhances the visibility and competitiveness of environmental science at IUB for research funding agencies, professional organizations, and the recruitment of prospective graduate students and faculty.

Schmid, along with Dr. Sue Grimmond, oversee the Morgan Monroe State Forest Project. This project, assisted by funding from the Department of Energy, manages the AmeriFLUX/FLUXNET tower located in Morgan-Monroe State Forest north of Bloomington, Indiana. The tower is designed to measure CO_2, H_2O and heat fluxes over a deciduous forest along with collecting other meteorological data. Courses offered at Indiana University that focus on Global Warming and Climate Change include: Environmental Change, Weather and Climate, Environmental Change—Nature and Impact, Environmental Remote Sensing, Hydroclimatology, and Climate Change.

SEE ALSO: Environmental Science Research Center; Climate Change; Climate Solutions.

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Indian Ocean

THE INDIAN OCEAN has seen some dramatic changes owing to the effects of global warming and climate change. The major effects of global warming have been the rise of waters temperature, and also the rise in the water level. Researchers have shown not only a general warming of the surface of the Indian Ocean, but also warming of about 3.6 degrees F (2 degrees C) over the last 40 years, in the region of 40 degrees S and 50 degrees S, down to a depth of 262 ft. (800 m.). A study by the National Aeronautics and Space Administration (NASA) showed that tradewinds that cover the southern part of the Indian Ocean have also weakened 1992–2000 so much that there has been up to a 70 percent reduction in up-welling and cool currents. Scientists are also worried about the survival of many of the marine turtles in the Indian Ocean, for which global warming and climate change represent yet another threat.

Most of the focus of world attention on global warming in the Indian Ocean remains focused on the potential loss of land through rising sea levels. This is because there is much low-lying land around the Indian Ocean. The Republic of the Maldives, an archipelago of 1,190 islands (202 of which are inhabited), is at risk of submersion if there is a significant rise in the level of the Indian Ocean. With the Maldives having an elevation of less than 8 ft. (2.5 m.), the government of the Maldives has been actively campaigning for countries around the world to reduce greenhouse gas emissions.

Although the Maldives is at greatest risk of being entirely submerged, many other islands in the Indian Ocean are also under threat. These include the Laccadive Islands, and some of the islands in the Andaman and the Nicobar groups (all parts of India), as well as islands of the British Indian Ocean Territory, especially in the Chagos Archipelago. Some of these islands, too, have the very real risk of total submersion with rising water levels. There is also a concern about islands in the Seychelles, Mauritius, and the French island of Réunion. Parts of mainland Asia are also at risk, especially Bangladesh, which is suffering increasingly from floods, and the land around the mouth of the Irrawaddy in Myanmar (Burma).

The problems in Bangladesh, one of the most densely-populated countries in the world, have been serious for many decades, and further floods threaten to cause even longer-term economic problems. Many geographers believe that global warming has led to more frequent floods and cyclones, regularly displacing many farmers who lived on the Ganges-Brahmaputra Delta. The Sunda Islands, off the west coast of Sumatra, have also seen a rise in flooding that has led to increased breeding of mosquitoes and the rise in the prevalence of insect-borne diseases such as malaria and dengue fever, problems also exacerbated by more flooding in Myanmar, which has become more regular since the 1980s. Prolonged flooding would seriously undermine the agricultural base of both Bangladesh and

The most dramatic effects of global warming on the Indian Ocean due to have been a rises in temperature and sea levels.

Myanmar, resulting in worsening coastal problems. As the coastline is battered by the Indian Ocean, it is expected that some of the farmers will move inland, threatening, in the case of Bangladesh, the Sundarbans, which is currently the largest mangrove forest in the world, home of the Royal Bengal tiger, and other fauna and flora.

The most dramatic instance of flooding in the Indian Ocean was caused by a tsunami that caused devastation to parts of northern Sumatra and also along the coasts of Sri Lanka and Thailand on December 26, 2004. It resulted in the deaths of some 230,000 people, of whom the majority (168,000 by some estimates) were from Indonesia. The worst affected areas were the Indonesian province of Aceh, and the town of Galle in Sri Lanka, with deaths in many other countries, including an estimated 289 people in Somalia. There was devastation to the coastline, and loss of marine life, including shrimp off the west coast of Sumatra and Thailand. Although trade had long linked the countries of the Indian Ocean, the 2004 tsunami emphasized to the people in the region, the environmental problems in the area, and the links between global warming and a greater prevalence of flooding. The tsunami caused casualties in 15 countries.

Researchers have turned to studying the ocean currents. Although the water of the Indian Ocean has received warm saline water from the Red Sea past the Gulf of Aden, the rising water temperature has caused a decline in the diversity of fish in that part of the Indian Ocean. Global warming has also been suggested as a possible cause of changes in the temperature of the Agulhas Current, affecting the population of sardine and tuna off the coasts of southern Africa.

SEE ALSO: Agulhas Current; Hurricanes and Typhoons; Indonesia; Oceanic Changes; Sea Level, Rising.

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Indonesia

THE REPUBLIC OF Indonesia covers an archipelago of 13,667 islands, and has a land area of 735,355 sq. mi. (1,904,569 sq. km.), with a population of 231,627,000 (2006 est.), and a population density of 347 people per sq. mi. (134 people per sq. km.), although this reflects a massively overpopulated Java, and many underpopulated islands. Jakarta, the capital and the largest city, has a population density of 33,049 per sq. mi. (12,738 per sq. km.).

Agriculture is the most important sector of the economy, with 10 percent of the land arable, 7 percent used for meadows and pasture, and 62 percent of the country covered by forests. Indonesia is a significant oil producer, and 81 percent of its electricity production comes from fossil fuels, mainly petroleum, with liquid fuels making up 55 percent of Indonesia's carbon dioxide emissions, and gaseous fuels making up 21 percent. The increased demand for electricity for air conditioning and personal use is reflected in a greater demand for electricity in the country than during the 1990s. However, although Indonesia contributes about one percent of the world's carbon dioxide emissions, because of its large population, the rate of per capita carbon dioxide emissions is low, at 0.8 metric tons per person in 1990, rising gradually to 1.4 metric tons by 1996, and fluctuating between those levels since then.

One of the reasons for these fluctuations is the extensive forest fires on the islands of Sumatra and

Borneo (Kalimantan), where large portions of the jungles were burned to help clear them, and caused pollution in the region. In 1998, up to 2 million acres (809,371 hectares) of land, one-eighth of which was primary forest, was damaged in fires, severely reducing the local habitat of the orangutan. Although Indonesia is relatively well served by public transportation, much of it is offered by older buses and pickup trucks, which. The increased private automobile ownership, brought about by increased affluence in the Indonesian middle class, has led to transportation producing 18 percent of carbon dioxide emissions. Another 18 percent comes from manufacturing construction, 17 percent from residential uses, and 21 percent from electricity and heat production.

Global warming is expected to increase flooding, as dramatically seen in the Boxing Day Tsunami, on December 26, 2004, which devastated the northwest coast of Sumatra, especially the town of Banda Aceh, resulting in the deaths of about 131,000 people, with an additional 37,000 listed as missing. Subsequently, there has been damage sustained to the west coast of Sumatra around Bengkulu, which was struck by a number of earthquakes in September 2007, resulting in the deaths of 13 people. Flooding has the risk of increasing the prevalence of insect-borne diseases, and in 1997 malaria was detected at 6,900 ft. (2103 m.) in the highlands of West Papua (Irian Jaya), the highest place that it has been found. Some rainforests have been cleared to make way for golf courses, an issue that became important in local politics in parts of Indonesia in the early 1990s.

To try to combat some of the problems presented by global warming, Indonesia has tried to increase its use of hydropower, but it still accounts for only 14 percent of electricity production. The Suharto government of Indonesia ratified the Vienna Convention in 1992, and took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, which was ratified two years later. On July 13, 1998, the Indonesian government signed the Kyoto Protocol to the UN Framework Convention on Climate Change, ratified it on December 3, 2004, and it took effect on March 3, 2005.

SEE ALSO: Agriculture; Floods; Forests; Hurricanes and Typhoons.

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Industrialization

INDUSTRIALIZATION, SOMETIMES CALLED development, has been a far-reaching, evolutionary process for more than 200 years. Industrialization is not only a process of extracting resources from the Earth and turning them into goods for consumption. It has significant implications for ways of thinking, social relationships, and the view of the Earth and its resources. Because of its dependence on fossil fuels to spur production and growth, industrialization has radically changed the global environment.

HISTORICAL ROOTS

The Industrial Revolution began around the turn of the 19th century. It marked a significant turn in human history, sparking a protracted effort to lower risk to human survival by increasing economic surplus, and mastering the environment. The Industrial Revolution's shorter-term impacts included a general increase in the living standard, improved overall nutrition and health, increased life spans, intensification of global trading, and increased gaps between the rich and poor within and across nations. The level of industrialization is a measure for a country's stage of development. Increased industrialization implies a higher quality of life and progress for a country's residents.

Industrialization initially emerged in Britain in the context of emerging capitalist social relations and rapidly spread to North America and Western Europe. Later, in the 20th century, communist and socialist economies adopted industrial processes and technology. Industrial development continues today in widely varying cultural circumstances, in nations such as China, India, and Indonesia, which are now major contributors of airborne pollutants.

Industrialization, historically seen as a linear process, is particularly suited to enriching mass societies because it allows for the efficient exploitation of vast amounts of natural resources and the use of fossil fuels to produce goods seen as necessary for improved overall social well-being. In essence, industrialization allows for the creation of an economic surplus that, in the relatively short term, lessens risk and increases the comfort for large segments of the population around the globe. Where industrialization is limited, living standards tend to be lower, with attendant poverty, poor health, and shortened lifespan.

WIDESPREAD BENEFITS

Typical analyses of industrialization study changes in local, regional, national, and global economies; social class relationships; government policy; industrial locations; and work processes and industrial organizations. While industrialization's impacts have been debated, the predominant view has been positive, equating industrialization with human progress. Until relatively recently, industrialization's environmental impacts have been ignored or relegated to the background. The mainly positive view of industrialization has prevailed, despite a long history of profit-maximizing firms that failed to account fully for the environmental costs of natural-resource extraction and production.

The positive view of industrialization is pervasive and understandable. For example, the overall wealth of developed countries is a powerful example for countries seeking to industrialize. The compelling myth that a seemingly unlimited supply of material goods is essential to individual freedom and happiness, a corollary to Adam Smith's insatiable wants and needs, bolsters this view. As industrialization spreads to more areas of an increasingly global sociocultural system, the growing demand for fuel and goods increases stress on the planet's ecosystems.

CHALLENGES TO INDUSTRIALIZATION

The traditional linear economics of industrialization posed a particularly thorny problem for the environment. Until relatively recently, industrial efficiency tended to revolve around ways to transform various materials into finished goods in the quickest, cheapest way, with limited regard for byproducts that may have had value if processed or reprocessed. Waste minimization was not a high priority because the costs of limiting pollution appeared to exceed the cost of releasing toxins into the air, soil, and water. In fact, for generations, economists tended to write off pollution costs as an externality, a price paid by someone else, not the industrial operation creating the pollution. Only in the past generation or so have plant operators, responding to laws and economic realities, focused on building loops to capture and reuse what once was considered waste.

The sheer abundance of natural resources in North America masked wider environmental effects of industrialization. Locally, it was easy for people to see denuded forests or fouled water or feel the sting of polluted air in their eyes or lungs. Yet, local leaders equated spewing smokestacks and polluted water with growth, jobs, and overall community economic well-being. Those who questioned industrial pollution, even if they had support from scientific data, faced criticism because they were said to oppose growth and development. In addition, scientific tools to assess impacts of industrial pollution were limited. Improved scientific techniques have increased knowledge about pollution and implications of industrialization on the global climate. This new knowledge has added power to traditional social critiques of industrialization.

Industrialization has not been accepted universally; critical analyses tend to focus on negative impacts of wealth concentration into fewer hands, worker exploitation, and, to some extent, local impacts of pollution. Analyses of industrial pollution have become more common since the environmental movement of the 1960s and 1970s. In addition, clearly recognizable historic, literary, and scientific threads link industrialization to environmental degradation. In the United States, for instance, Transcendentalists such as Ralph Waldo Emerson and Henry David Thoreau rebuked encroaching industrialization during the early 1800s. By the 1860s, nascent conservationists were beginning to develop scientific techniques to measure hydrological impacts of widespread deforestation driven by insatiable timber demands, of coalmines, railroads, and construction that underpinned the growing industrial economy. At the same time, these researchers speculated about the possibility of climate change related to the loss of forest cover across North American. Meanwhile, other researchers, especially in Europe, were beginning to research the impacts of what are now called greenhouse gases on the climate.

ROLE OF ENERGY

Energy consumption is key to understanding industrialization's impacts on climate. Pre-industrial economies were based on human and animal labor. In the mid-1800s, the industrial transition to larger operations, fired first by coal and later by oil and natural gas, unlocked carbon and other chemicals that had been sequestered under the Earth for eons. By the late 1700s, much of Europe had already been deforested, so the emergence of coal as a widely-used fuel was essential for continued survival of Western civilization, much less industrialization. Yet, coal opened opportunities for industrialization, making possible the production of steam-driven machines to replace human and animal labor. It also opened the way for stronger iron and steel for machinery and construction. In North America, the emergence of coal power occurred alongside forest clear-cutting, so the country was in the wood and steel age at the same time.

Industrial processes of the 19th and much of the 20th century wasted energy and polluted the atmosphere. Palls of smoke laden with carbon dioxide, nitrogen compounds, sulfur dioxide, and other pollutants hung over industrial cities and towns, blocking sunshine and creating dangerous smog. Acid rain damaged stone edifices, vegetation, and surface water supplies. Massive amounts of useful gas were flamed off into the atmosphere as coal was turned into coke to fuel the burgeoning metallurgical industry. Later, oil refineries burned off volatiles regarded as useless byproducts. Meanwhile, forests across the country were cut indiscriminately, eliminating ecosystems that could have cleaned the air. Farmers

Mining coal: At the turn of the 19th century, the Industrial Revolution began a significant turn in human history, sparking a protracted effort to lower risk to human survival by increasing economic surplus and mastering the environment.

burned forests to clear land for agriculture; wood left over from deforestation was burned on purpose or by forest fires. Gradually, however, people became more aware of the immediate health risks posed by industrial pollutants. Yet, discussions of climate change resulting from industrial fossil fuel emissions still have to vie for attention; it is difficult for people to discern the long-run impacts of climate change, and industrial progress is still valued in many circles.

Whatever its negatives, industrialization offers short-term, tangible benefits. Since the dawning of industrialization over two centuries ago, immediate benefits generally have been more important than environmental considerations that affect future generations. Continued industrialization has virtually guaranteed an economic surplus to decrease risks, increase general living standards, and stimulate long-term growth in demand. Supply and demand feed each other, not only in already-industrialized nations, but in the hopes and dreams of industrializing nations seeking to increase their material wealth. Pressure on the Earth's resources grows as atmospheric pollutants continue to increase.

SEE ALSO: Capitalism; Conservation; Coal; Deforestation; Energy; Forests; Globalization; Health; Oil, Consumption of.

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Institute of Energy Economics (Argentina)

THE INSTITUTO DE Economía Energética asociado a la Fundación Bariloche (IDEE/FB), or the Institute of Energy Economics associated with the Fundación Bariloche (Bariloche Foundation) is an institute in Argentina that works to promote environmental awareness and education of environmental economics. It is independent, although strongly allied with the Bariloche Foundation.

The Bariloche Foundation is a nonprofit, private institution, allied with the United Nations Educational, Scientific and Cultural Organization (UNESCO) and other international organizations. Scientists and businesspersons at a conference in the city of San Carlos De Bariloche, Argentina founded it on March 28, 1963. The goal of the Bariloche Foundation is to facilitate and foster research, innovation, training, technical assistance, and the dissemination of information and knowledge. Its purpose is "to promote teaching and research in all branches of science, based on a solid, humanist culture and in accordance with the democratic principles contained in the Argentine Constitution." The Bariloche Foundation headquarters are located in San Carlos de Bariloche, with a business office in Buenos Aires, Argentina. The IDEE/FB is based in San Carlos de Bariloche.

The Bariloche Foundation has four major programs: Energy, Environment, Philosophy, and Quality of Life. The Energy program evolved in 1978 from the Bariloche Foundation's previous Department of Natural Resources and Energy, founded in 1967. This program employs agronomists, computer specialists, economists, diverse engineers, mathematicians, and statisticians, and is chiefly in charge of the IDEE/FB. The Environment program studies climate change, energy and the environment, natural resources accounting and other environmental issues, and rational energy use.

The Philosophy program fosters international collaboration and conflict analysis and resolution. Researchers study gender research, history of philosophical ideas, metaphilosophy, philosophy and history of science, philosophy of social sciences, practical and theoretical aspects of conflict analysis and resolution, and rationality. The Quality of Life program began as a project in 1989, and matured into a complete program five years later in 1994. This program monitors social equity and environmental sustainability in the San Carlos de Bariloche region as well as greater Argentina; and also the qualities of life experienced by residents of these regions as globalization continues.

The Bariloche Foundation's Energy program focuses on Argentina and Latin America, as well as in the global economic marketplace and international energy. Research, consulting, economic assistance, and other IDEE/FB services are focused on energy production and use, and how they relate to the economy, the environment, economical and environmental policy-making, and economic and environmental planning.

A major educational initiative of the IDEE/FB is the Latin American Postgraduate Course on Energy and Environment Economics and Policies. This course is a four-month long immersion course that has been conducted annually since 1969, and has trained more than 600 Latin American professionals. People who enroll in the course represent all sectors: energy companies publicly or privately funded, universities, and governmental or nongovernmental organizations from around Latin America, for example.

Additionally, the IDEE/FB offers the MEPEA, a Master's Program in Energy and Environment Economics and Policies. This program lasts for two years and meets every Friday and Saturday. It is assisted by the University of Comahue's Faculty of Economics and Administration, and is held in Argentina's city of Neuquen. The MEPEA has been in operation since 1999.

The major research foci of the IDEE/FB are: Energy Policies in the sense of institutional and managerial strategies, prices and tariffs, rational use of energy, regional integration, regulation, the sector's institutional structure, and technological progress; Energy and Environment in terms of emissions mitigation, and impact caused by each level of the energy chain, including sustainable development; Development of Methodology and Models for studies of energy in the fields of supply, demand, financing, and sources; Integrated Energy Studies for Different Geographical Areas; Economic, Technical, and Environmental Studies for various natural resources; and Sectorial Energy Studies for various energy-demanding sectors.

SEE ALSO: Argentina; Economics, Cost of Affecting Climate Change; Economics, Impact From Climate Change.

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Intergovernmental Panel on Climate Change (IPCC)

THE FIRST WORLD Climate Conference organized by the World Meteorological Organization (WMO) expressed concern about significant extended regional and even global changes of climate due to human's activities on Earth. The conference appealed to nations of the world to foresee and prevent potential human-made changes in climate that might have adverse effects on human race. A joint UNEP/WMO/ICSU conference convened in Villach, Austria on the "Assessment of the Role of Carbon Dioxide and of Other Greenhouse Gases in Climate Variations and Associated Impacts." The conference concluded that a rise of global mean temperature could occur due to the increasing greenhouse gases and warming of the globe could result in sea level rises. This warming and probable rate and degree of warming are closely linked with other major environmental issues which will/could be profoundly affected by policies on emissions of greenhouse gases, just like the emissions of chlorofluoro- compounds under the Montreal Protocol and their effect on ozone depletion.

Recognizing the problem of potential global climate change, the WMO and the United Nations Environment Programme (UNEP) established the Intergovernmental Panel on Climate Change (IPCC) in November 1988 and was open to all members of the United Nations and WMO, with the aim of assessing in a comprehensive, objective, open, and transparent manner the scientific, technical, and socioeconomic information relevant to understanding the scientific basis of risk of human-induced climate change, its potential impacts, and options for adaptation and mitigation. Although the WMO and UNEP were the two main organizations involved in the creation of the IPCC, there were other intergovernmental organizations as well as nongovernmental organizations that were involved in establishing the IPCC. Also, the UN General Assembly, recognizing the need for international cooperation on climate change, joined the call through its resolution on "Protection of the Global Climate for Present and Future Generations of Mankind" during their 43rd session, held in 1988. The IPCC does not carry out any research on its own, nor does it monitor climate-related data or other relevant parameters. On the contrary, IPCC bases its assessment mainly on peer reviewed and published scientific/technical literature.

A small bureau of 15 was created to oversee the work of the panel and three working groups were also formed: Working Group I addresses topics including greenhouse gases and aerosols, processes and modeling, observed climate variations, and change. The experts of Working Group I have concluded that emissions from human activities are substantially increasing the atmospheric concentration of greenhouse gases and this will result in warming of the Earth's surface. Working Group II assesses the climate change impact on agriculture and forestry, natural terrestrial ecosystems, hydrology and water resources, human settlements, oceans and coastal zones, and seasonal snow cover, ice, and permafrost. Working Group III has further established subgroups to define mitigative and adaptive response options in energy, industry, agriculture, forestry, and other human activities, including coastal zone management. Each working group has two co-chairs, one from a developed country and another from a developing country, and a technical support unit. IPCC activities, including travel costs for experts from developing countries and countries with economies in transition, are financed through voluntary contributions from governments.

The IPCC has an official definition for climate change: climate change refers to a statistically significant variation in either the mean state of the climate, or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or external forces, or due to persistent anthropogenic changes leading to change in the composition of the atmosphere or in land use.

The IPCC, in its two decades of existence, has produced many reports; four assessment reports have been produced at the behest of the UN General Assembly. On receipt of the *First IPCC Assessment Report 1990*, the UN General Assembly decided to establish an Intergovernmental Negotiating Committee (INC) in 1990 to initiate negotiations of an effective framework convention on climate change, to be completed prior to the UN Conference on Environment and Development (UNCED) in June 1992. Eventually, at the completion of negotiations, the United Nations Framework Convention on Climate Change was created in 1994.

The *Second IPCC Assessment Report 1995* prepared a comprehensive report on climate change and was recognized as the most authoritative assessment of climate change, its impacts, and response options. It indicated that the continued rise of greenhouse gases in the environment would have serious socioeconomic and environmental impacts, especially for developing countries. This second IPCC report, provided input to the negotiations for the Convention's Kyoto Protocol.

The *Third IPCC Assessment Report 2001*, also known as TAR, set out to meet new requirements. Some of the facts according to IPCC, Executive summary, January 2001 are: warming during the past 50 years can be attributed to humans, global surface temperature is expected to increase by degrees 2.5–10.4 F (1.4–5.8 degrees C) by 2100, and warming on this scale has not occurred during the previous 10,000 years.

The *Fourth IPCC Assessment Report 2007* was prepared with an aim to emphasize new findings, therefore, the structure and mandates of the Working Groups were kept unchanged. The report was presented to the United Nations General Assembly in 2007. Some of the observed impacts are detailed in the report: 11 of the previous 12 years ranked among the 12 hottest on record since 1850, Global sea-level rise had accelerated, mountain glaciers and snow cover have declined, and more intense and longer droughts have been observed over wider areas since the 1970s. The report also established direct links to human health and other issues and has raised international concern over climate change and need to act quickly to prevent the catastrophic impacts of climate change. The IPCC shared the 2007 Noble Peace Prize with Al

Gore for its efforts in bringing climate change to the forefront.

SEE ALSO: Nongovernmental Organizations (NGOs); United Nations; United Nations Environment Programme (UNEP); World Meteorological Organization (WMO).

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Internal Climate Variability

INTERNAL OR NATURAL climate variability refers to variations over time in one or more measures of climate, resulting from natural causes. The distinction between climate variability and weather variability is not a matter of different timescales; rather, it is based on the fundamental distinction between climate and weather: weather refers to meteorological conditions at a specific time and location, whereas climate refers to any statistical characterizations (such as a long-term mean) of weather conditions. Thus, for example, a single measurement of diurnal temperature range measures a weather variation, whereas an estimate of a multi-year mean diurnal temperature range is a climate variation. An alternative definition is that natural climate variability is any variation in climate not resulting from human influences, such as increasing atmospheric greenhouse gases.

Natural climate variations occur on all timescales up to the age of Earth (for billions of years), and can be classified as either forced or unforced. Forced variations are caused by factors external to the climate system, including: Earth's rotation (resulting in the daily cycle); Earth's orbit (resulting in the seasonal cycle); large volcanic eruptions, which can result in more small particles in the stratosphere, lowering temperatures for a few years; variations in the Sun's inherent energy output, which may have caused, for example, the Little Ice Age during medieval times; variations in Earth's orbital parameters, which result in redistributions of incoming solar radiation, and trigger glacial/interglacial cycles; slow motions of continents (plate tectonics); and slow changes in atmospheric composition, particularly greenhouse gas concentrations, resulting from changes in the balance between natural sources and sinks of these gases.

Unforced variations are internally generated redistributions of energy within the system that occur without changes in external factors. Important modes of unforced climate variability include: the Madden-Julian oscillation, or variations in winds, cloudiness, and other phenomena in the tropics, with a timescale of 40–50 days; the El Niño/Southern Oscillation, a dominant mode of year-to-year tropical climate variability, characterized by changes in sea-surface temperatures in the tropical Pacific; the North Atlantic Oscillation, also known as the Arctic Oscillation and the Northern Annular Mode, variations in sea-level pressure in the Arctic, occurring simultaneously with variations of opposite sign at mid-latitudes in the Atlantic, reflecting North-South motions of atmospheric mass; and the Pacific Decadal Oscillation, changes in north Pacific climate, with a timescale of 20–30 years.

FEEDBACKS

Both forced and unforced modes of natural climate variability are affected by feedbacks: responses of the climate system that either amplify or dampen the underlying variability. Glacial/interglacial cycles, for example, are exaggerated by ice-albedo feedback, in which land ice sheets (which result from cooling temperatures) reflect sunlight into space and thereby amplify cooling. Natural climate variability can be measured via traditional meteorological measurements, or different types of geological (proxy) measurements. Both approaches have limitations: the instrumental record (weather station measurements) is too short to characterize variability on many timescales of interest, while proxy measurements are typically too sparse to yield reliable estimates of variability over large regions (such as continents).

In principle, computer models of climate can be used to help understand natural variability, and simulations of intra-seasonal and intra-annual variability have improved in recent years. However, computational limitations prevent adequate simulation of millennial- and longer-timescale variability, and evaluation of simulations on these timescales is difficult. The character of natural climate variability has itself varied over time. In particular, records derived from ice cores show that the past approximately 10,000 years (the Holocene) have been unusually stable compared to the rest of the most recent 400,000 years; this is thought to have been a significant factor in the development of agricultural societies.

Natural climate variability on timescales of decades to a century complicates "detection of anthropogenic climate change," the search for signals of human influences in the observed climate record since the late 19th century. Because there is no a priori way to attribute an observed climate trend to either natural variability or human influences, a common approach has been to determine if an observed trend is too rapid to result from natural variability alone. While simple in principle, this approach is complicated by the difficulty of characterizing natural variability on the timescale of about a century.

SEE ALSO: Climate Feedbacks; Climate Forcing; Climatic Data, Atmospheric Observations; Climatic Data, Historical Records; Climatic Data, Instrumental Records; Climatic Data, Proxy Records.

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International Council of Scientific Unions (ICSU)

THE INTERNATIONAL COUNCIL of Scientific Unions (ICSU), today known as the International Council for Science, was founded in 1931 as a nongovernmental organization, which would foster international scientific collaboration among all scientists, to work toward the greater good for humanity. The ICSU motto is "strengthening international science for the benefit of society."

The parent foundations of ICSU are the International Association of Academies (IAA), which lasted from 1899 until 1914; and the International Research Council (IRC), which lasted from 1919 until 1931. In the year 1998, the Council officially changed its name to the International Council for Science, keeping the acronym ICSU as a tie to its history.

The ICSU addresses global issues through international initiatives aimed to support scientists in undertaking a task that he or she could not do alone. Successful examples of these initiatives include International Geophysical Year (1957–58) and the International Biological Program, which took place between the years 1964–74.

In 1992, the United Nations Conference on Environment and Development (UNCED) took place in Rio de Janeiro, Brazil. The ICSU was invited to this Conference to act as the chief scientific adviser. Ten years later, the World Summit on Sustainable Development (WWSD) also invited the ICSU as chief scientific adviser, this time to Johannesburg, South Africa. In 2006, the ICSU celebrated its 75th anniversary, noting achievements in the fields of International Research Collaboration, Science and Policy, and the Universality of Science.

Internationally, the ICSU carries out its initiatives either by creating interdisciplinary bodies or supporting joint initiatives. Initiatives led by either of these groups can be organized into one of five categories: Assessment Bodies, Data and Information, Global Environmental Change Programs, Monitoring/Observations, or Thematic Organizations.

Globally, ICSU aims to "mobilize the knowledge and resources of the international science community". Along with this aim, the Council works to determine major issues of interest to this international science community, as well as of concern to science and the society at large. Another chief mission of the ICSU is to engender scientific collaboration among all scientists, regardless of race, gender, nationality, politics, or another potential division to communications.

A current issue that the ICSU is assisting in resolving is the difficulty and sometimes impossibility that international scientists from 'high-risk' countries have in obtaining visas to conduct research in the United States. This issue has been predominant since 2002; in 2006, Professor Goverdhan Mehta, then President of the ICSU, was initially denied such a visa. Professor Mehta is from India.

The ICSU is headquartered in Paris, France. The Council has additional regional offices in the areas of Africa, the Arab Region, Asia and the Pacific, and Latin America and the Caribbean. The African office was established with the vision of strengthening science through fostering sustainable socioeconomic growth in Africa. The other offices support international collaboration in their respective regions, as well as the sharing of knowledge and ideas.

The ICSU is governed by a General Assembly. Additionally, the Executive Board is composed of elected representatives who carry out resolutions of the General Assembly. The 14-member Executive Board is made up of six officers and eight ordinary members. The six Officers are the president, two vice presidents for Scientific Planning and Review and External Relations, the secretary-general, the treasurer, and the past president or the president-elect. These officers are distinct from the ordinary members because they manage the ICSU between Executive Board meetings. Additionally, the ICSU has numerous committees, acting on policies or ad hoc initiatives such as the Policy Committee on Developing Countries and the Planning Group on Natural and Human-Induced Environmental Hazards and Disasters, respectively.

SEE ALSO: Brazil; International Geophysical Year (IGY); Nongovernmental Organizations (NGOs); South Africa; United Nations.

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International Energy Agency (IEA)

THE COUNCIL OF the Convention on the Organisation for Economic Co-operation and Development founded the International Energy Agency (IEA) on November 15, 1974. Initial member countries were: Austria, Belgium, Canada, Denmark, Germany, Ireland, Italy, Japan, Luxembourg, the Netherlands, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States. The initial documents allowed for further nations to join the IEA; as of 2007, 26 countries are members, from Europe, Asia, North America, and the South Pacific (Australia and New Zealand). Its French name is *Agence Internationale de l'Energie.*

There was an oil crisis 1973–74 in which the Organization of Arab Petroleum Exporting Countries (OAPEC) refused to ship oil to nations that had supported Israel during the Yom Kippur war. Affected countries included the United States, Japan, and Western European nations. In response to the dependency of these affected countries on Organization of the Petroleum Exporting Countries (OPEC) oil (OAPEC is made up of the Arab nations in OPEC along with Egypt and Syria, the two major countries fighting Israel during the Yom Kippur War), the International Energy Agency (IEA) was formed.

CURRENT GOALS

Today, the IEA has expanded its initial goal of reducing dependence on Arab oil to include what it calls the Three E's: economic development, energy security, and environmental protection. Its motto is "Energy Security, Growth and Sustainability through

Co-operation and Outreach." The IEA, headquartered in Paris, France, has five major offices: the Executive Office, Energy Technology and Research and Development, Long-term Cooperation and Policy Analysis, Office of Global Energy Dialogue, and Oil Markets and Emergency Preparedness. A staff of 150 comes from member countries, and is made up of scientists, statisticians, and management personnel.

In September 2007, the IEA Energy Efficiency and Environment Division was awarded the International Star of Energy Efficiency by the Alliance to Save Energy. The award recognized the IEA's efforts to research and foster energy efficiency, particularly its campaign to quickly phase-out incandescent light bulbs. 2007 was the 30th anniversary of the International Star of Energy Efficiency Award.

The IEA has several Standing Committees: the Committee on Energy Research and Technology (CERT), the Standing Group on Emergency Questions (SEQ), the Standing Group on Global Energy Dialogue (SGD), the Standing Group on Long-Term Cooperation (SLT), and the Standing Group on the Oil Market (SOM). The CERT focuses on technology for energy efficiency, from the research of such technology to its implementation. To carry out this purpose, the CERT has four major groups: the Fusion Power Coordinating Committee, the Working Party Energy End-Use Technologies, the Working Party on Fossil Fuels, and the Working Party on Renewable Energy Technologies.

The SEQ keeps member countries prepared for oil-shortage emergencies, and continuously reviews these countries', as well as the greater IEA's, emergency plans. As several major countries are not part of the IEA, the SGD works to continue communication with these countries, including China, India, and Russia. Meanwhile, the SLT maintains communication among IEA nations; in doing so, it refers to its Working Party on Energy Efficiency.

The SOM analyzes the international oil market and integrates short- and medium-term developments to keep the IEA member nations informed and prepared in the event of another oil emergency. Frequently, the IEA hosts workshops and other events to promote education and awareness in energy efficiency. Additionally, the agency often offers press releases to keep the public informed of its activities and concerns.

Experts at the IEA provide consulting to the leaders of the G8 countries (Canada, France, Germany, Italy, Japan, Russia, the United Kingdom, and the United States) at the G8 summits. For example, at the 2005 Summit in Gleneagles, the G8 developed a Gleneagles Plan of Action. This plan stressed the need for a dialogue between major energy and oil producing countries, as well as energy-consuming nations. The G8 requested the assistance of the IEA in fostering this dialogue. The six major areas covered by the Gleneagles Plan of Action are: alternative energy scenarios and strategies; carbon capture and storage; cleaner fossil fuels; energy efficiency in buildings, appliances, transport, and industry; enhanced international cooperation; and renewable energy.

SEE ALSO: Oil, Consumption of; Oil, Production of; Organisation for Economic Co-operation and Development (OECD).

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International Geophysical Year (IGY)

THE INTERNATIONAL GEOPHYSICAL Year (IGY), in French, *Année Géophysique Internationale*, took place between July 1, 1957 and December 31, 1958. The International Council for Science (ICSU) began designing it in 1952. The ICSU addresses global issues through international initiatives aimed to support scientists. A successful example of these initiatives, besides the International Geophysical Year, is the International Biological Program, which took place 1964–74. The International Geophysical Year was inspired by National Academy of Sciences (NAS) member Lloyd Berkner and colleagues in 1950. It was modeled after previous International Polar Years, 1882–83 and 1932–33.

The IGY was to invite and allow all scientists to collaborate internationally in organized geophysical examinations. It would take place during peak solar activity, 1957–58. Initially, 46 nations pledged to send representatives; however, the IGY was such a success that within the year, 67 nations actually participated. Participating scientists in the IGY represented 11 chief fields of Earth sciences: aurora and airglow, cosmic rays, geomagneticsm, gravity, ionospheric physics, longitude and latitude determinations, meteorology, oceanography, rocketry, seismology, and solar activity.

The NAS assembled a U.S. National Committee (USNC) to blueprint the extent of American involvement in the IGY. The USNC was established in March 1953 and chaired by Joseph Kaplan, then a Professor of Physics at the University of California at Los Angeles. The vice chairman of the UNSC was Alan H. Shapley, a physicist at the National Bureau of Standards. The NAS appointed another National Bureau of Standards member, Hugh Odishaw, as executive secretary. He would later become the executive director. Initially, the American contingent was to be 16 core UNSC members overseeing five working groups and 16 technical panels; however, the team quickly reached more than 200 member scientists.

As part of the IGY, both the United States and the Soviet Union launched artificial satellites into outer space. The Soviet Union launched the first artificial satellite in October of 1957; it was called Sputnik I. The U.S. artificial satellite Explorer I launched in January 1958. In 1956, the British established the Halley Research Station on the Brunt Ice Shelf in Antarctica, for the IGY; the bay housing it was named Halley Bay, in honor of the English astronomer Edmond Halley (1656–1742). The work carried out in the Antarctic, while not initially as esteemed as Arctic or equatorial work, proved to be pivotal for modern estimates of total ice content on Earth. These estimates were determined from measurements of ice depths in the Antarctic.

SEE ALSO: International Council of Scientific Unions (ICSU); International Union of Geodesy and Geophysics (IUGG); Nongovernmental Organizations (NGOs).

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International Geosphere-Biosphere Program (IGBP)

WITH THE DRIVING force of global climate change, a need emerged for a mechanism of international cooperation. In response to this need, the International Council of Scientific Unions (ICSU) appointed a committee for planning and implementation. In 1987, the International Geosphere-Biosphere Program (IGBP) was formed, and, in 1989, found headquarters at the Royal Swedish Academy of Sciences in Stockholm, Sweden. The scope of IGBP's mission is to study the dynamics of Earth's biological, chemical, and physical processes, and climate changes, along with the impact of human actions on Earth systems, and Earth systems on human society. By bringing together the wide range of academic and social disciplines on an international level, IGBP ensures a better understanding of the forces shaping the future. By integrating the knowledge base on all these processes and sharing the information, IGBP envisions a sustainable living Earth.

The initial planning took three years (1987–90) and required cooperation from many scientists (IGPB estimates approximately 500) before implementation of initial projects, 1989–92. The first projects addressed interactions of the water cycle with soil, vegetation, and atmosphere; predicting changes in terrestrial ecosystems from changing climate; determining effects of chemical transformations on the atmosphere and air quality; evaluating ocean circulation effects on atmosphere, sea floor, and continents; and collecting and studying climate change data throughout history. During the 1990s, projects were added to address the role of the coastal zone on Earth systems; evaluate how human and biophysical systems change land surfaces; use Global Analysis, Integration, and Modeling for predicting climate changes and directing research to clarify systems dynamics; create a network for the collation and dissemination of research and coordination of projects internationally; and establish access for exchanging data.

Institutions in Europe, North America, and Australia hosted much of the research. The first phase laying the groundwork and completing initial research ended in 1999. The IGBP evaluated past successes and determined a new set of questions to be answered. IGPB launched the second phase of research, 2004–13. Some projects were considered complete, such as the water cycle, terrestrial ecosystems, ocean circulation, land surfaces, Global Analysis, Integration and Modeling, and established access for exchanging data. The remaining projects were incorporated with new focuses and joined new projects in restructured research programs to include the major Earth System components (atmosphere, ocean and land), the points of interaction between the components, and the dynamics over time and space.

The study of Earth system science parallels the process of Earth systems, as a whole, for common goals. The commitment of IGBP to integrating the activities with the greater international community has fostered cooperation for developing scientific plans and created dialogue between participants to agree on a science question agenda. By involving hundreds of scientists from around the world, IGBP ensures the development of truly international research frameworks, and fosters the building of international and interdisciplinary networks, within national and regional research efforts.

Supporting the work of IGPB are the secretariat and the International Project Offices (IPOs), which maintain the network and manage the various aspects of communication, data exchange, and bringing together the various members of the scientific community. The secretariat manages records, meeting minutes, and membership, as well as public relations, and provides the scientific results of its research to international stakeholders and interested audiences. National Committees are situated around the world (in approximately 73 different countries) to assist with the activities of IGPB on a local or regional level. These committees assist in the coordination of studies in their area and provide a link between their area and the international community, as well as assisting with raising the necessary financial support for the research. The IGBP has received steady funding for project activities through contributions from approximately 35 countries of about $1.5 million per year since 2000.

SEE ALSO: International Council of Scientific Unions; Nongovernmental Organizations (NGOs); Sweden.

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International Institute for Sustainable Development (IISD)

THE INTERNATIONAL INSTITUTE for Sustainable Development (IISD), a Canadian-based nonprofit organization established in 1990, with nonprofit status in the United States, is a pioneer policy research institute focused on the development and implementation of policies on international trade and investment, climate change, and natural resource management that are beneficial to both the economy and environment on a global scale. The IISD believes that sustainability is a win-win approach that protects the natural world, while generating resources and economic growth. The IISD, which is funded by Canadian and foreign governments, agencies of the United Nations, foundations, individual donors, and the private sector, is committed to capacity-building in developing countries. The IISD cooperates with more than 200 organizations throughout the world and has managed programs in Africa, Asia, Canada, Central Europe, China, Eastern Europe, South America, the United States, and Western Europe.

EARLY PRACTICAL APPROACHES

In its early years, the IISD surprised members of the public and the press by supporting approaches that were more practical than those of other environmentalists, in large part through recognition of the interdependence of environmental and fiscal interests. The surprise grew exponentially, however, when the IISD criticized the payment of subsidies to move grain by rail, which encouraged cropping that was ill-advised, and attempted to control supply, stating that it was more advisable to simply subsidize farm income. The IISD has aggressively promoted its vision of sustainability to the global media. The IISD's Media Mail newsletter provides online subscribers immediate access to press statements. Press releases include not only statements issued by the IISD, but those in which the IISD is cited. According to the IISD, its website recorded 52 million visits from more than 100 different countries in 2004, resulting in more than 2 million documents downloaded.

GlobeScan, a Canadian business enterprise that provides global survey research and strategic guidance to corporations, governments, and nongovernmental organizations, voted the IISD as the most effective sustainable development organization in the world. The IISD's work and knowledge fall within a number of areas, including sustainable markets, security, natural resources, international trade, foreign investment for sustainable development, economics and sustainable development, and climate change and energy. For example, the IISD launched the Sustainable Commodity Initiative in 2002, by endorsing global efforts to improve the environmental and economic sustainability of commodities production, beginning with the coffee sector and the creation of the Sustainable Coffee Partnership. The IISD's extensive list of publications includes books, papers, and institutional history resources. Additionally, the IISD's readership base of 45,000 decision-makers and experts benefit from the institute's publications and objective research.

WIDE-REACHING PUBLICATIONS

IISD publications that reach wide audiences include *Environment and Trade: A Handbook*, a collaboration between the IISD and the United Nations Environment Programme, which meets the needs of readers who are generalists and policy-makers seeking a solid resource tool, and the *IISD Sustainable Development Timeline*, which features important milestones in sustainability, including, events, meetings, and publications using the release of Rachel Carson's *Silent Spring* in 1962 as a starting point. Publications include not only research findings, but program proceedings as well. In 2007, the IISD co-hosted a two-day workshop, "Early Lessons From the Implementation of Climate Change Adaptation Projects in Eastern and Southern Africa," with SouthSouthNorth, a coalition-based nonprofit organization committed to reducing structural poverty in Sub-Saharan Africa, Asia, and Latin America and to positioning poverty as a central issue in discussions about climate change. Representatives from nongovernmental organizations, government agencies, and funders attended the workshop.

SEE ALSO: Canada; Nongovernmental Organizations (NGOs); United Nations Environment Programme (UNEP).

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International Research Institute for Climate Prediction

THE INTERNATIONAL RESEARCH Institute for Climate Prediction (IRI) is based at Columbia University in New York City, New York. The IRI partners with numerous local and global organizations, including the World Bank, the United Nations Food and Agriculture Organization (UNFAO), the World Meteorological Organization, the U.S. Department of Energy, the Geophysical Fluid Dynamics Laboratory, and the National Center for Atmospheric Research, to provide accurate seasonal forecasts of climate patterns to communities around the globe. The IRI has five programs: Agriculture, Climate and Environment, Economics and Livelihoods, Health, and Water. These programs address the concerns of the global regions of Africa, Asia and the Pacific, and Latin America.

The Agriculture program focuses on the study of climate and its impact on agriculture. A large part of the Earth's population is what the IRI calls "poor and food-insecure," relying on rainfall for watering of their crops. Thus, understanding weather patterns and accurate predictions of weather, such as rainfall, could be of great benefit to these communities. In response to this potential benefit, the IRI works with countries to develop methods for food security, natural resource sustainability, and poverty reduction.

The Climate and Environment program focuses on providing accurate weather forecasts in enough time to allow a country to prepare for adverse conditions such as drought. According to the IRI, tropical climates have the most predictable weather patterns, and yet the societies inhabiting these climates are often the most susceptible to hardship during difficult weather. The principle behind the Climate and Environment program is that when a community has access to accurate seasonal weather information, it can better plan for, and allocate resources for, adverse conditions, as well as for optimal weather conditions.

The IRI's Economics and Livelihoods program focuses on the economic impact of the climate. Because residents of rural areas are often reliant on good weather to travel and to obtain necessary goods and services, such as clean water, nutritious food, and healthcare, the Economics and Livelihoods program aims to provide accurate climate predictions so people can best take advantage of, and invest in, a good growing season.

The Health program at the IRI recognizes the impact of climate on the health status of individuals and populations. Beyond stress from heat or cold, other illnesses are correlated with certain climate conditions. The WHO classifies Malaria, for example, as a "climate sensitive communicable disease," along with cholera. Accurate climate prediction could warn healthcare providers prior to a surge in climate sensitive diseases, communicable and noncommunicable alike, and, thus, give them a chance to prepare proper treatments, potential preventative measures, and infrastructure to reduce the potential spread of such a disease.

Finally, the Water program investigates the effect of climate on availability of clean, fresh water to those who need it. Accurate seasonal climate predictions would assist countries and communities in developing plans for storage of water in times of plenty, and distribution of this stored water in times of drought or other adverse conditions. Additionally, the IRI Water program advises communities in proper urban planning to best manage the risk of a water shortage.

The institute maintains several seminar series to share information and knowledge, and to keep its members up to date with late-breaking research and technology. A board of 12 people from different countries manages it. A board chair leads them. An International Scientific and Technical Advisory Committee (ISTAC) provides the board with scientific advice. ISTAC members represent all aspects of science and society. For example, an ISTAC member may be from government, a nongovernmental organization, academia, the private sector, or climate organizations from local to international levels.

SEE ALSO: Columbia University; New York; World Health Organization.

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International Solar Energy Society (ISES)

THE INTERNATIONAL SOLAR Energy Society is an international nonprofit, nongovernmental organization with a focus on the development and diffusion of renewable energy technologies.

The society has 30,000 members globally from industry, research, and government; there are national sections in 54 countries. The following goals are stated in the society's mandate: to encourage the use and acceptance of renewable energy technologies; to realize a global community of industry, individuals, and institutions in support of renewable energy; to create international structures to facilitate cooperation and exchange; to create and distribute publications for various target groups to support the dissemination of renewable energy technologies; to bring together industry, science, and politics in workshops, conferences, and summits on renewable energy, and to advise governments and organizations in policy, implementation, and sustainability of renewable energy activities world-wide. The motto of the ISES is "think globally, act locally."

The ISES is headquartered in Freiburg, Germany. The international office is supplemented with national sections that network and coordinate energy professionals and sponsor activities in the member countries. The national sections spearhead local projects. Members are encouraged to engage at both the national and international level. In addition, regional offices have been opened to coordinate beyond the national level. Regional offices exist for Africa, the Asia Pacific region, Europe, and South America.

The society was founded as a nonprofit organization in 1954, as the Association for Applied Solar Energy. The first meetings of the society were held the next year in Tucson and Phoenix, Arizona. The society journal began in 1957. In 1963, the name of the society was changed to the Solar Energy Society.

In 1970, the society headquarters were moved from the American Southwest to Melbourne, Australia. The current name was adopted in 1971. The society took part as a consulting nongovernmental organization in the United Nations Conference on Environment and Development (UNCED), held in Rio de Janeiro, Brazil in 1991. In 1995, the international headquarters moved to Freiburg, Germany.

PUBLICATIONS FOR DEBATE AND DIALOGUE

The ISES has several publications, most notably its official journal *Solar Energy*, which includes articles on the science and technology of solar energy applications. The journal also publishes articles on indirect applications of solar energy, such as wind energy, and biomass.

The ISES also publishes *Renewable Energy Focus*, formally known as *Refocus*. This bimonthly publication aims to provide a "forum for debate and dialogue" between research, industry, and government on the topic of renewable energy. The society also hosts the biennial Solar World Congress, which fosters communication between industry, government, and the research community. The conference is a major event within the field.

The ISES supports a variety of projects. The Solar Academy training program focuses on the integration of solar technologies into building design, with a focus on renewable energy, conservation, and efficiency. The Solar Cities initiative aims to promote renewable energy use in long-term planning processes. The project highlights "solar communities"; cities or towns that make a commitment to emissions reduction targets, renewable energy sources, and energy efficiency.

The RESuM project, (Rural Energy Supply Models) is a tool-design project intended to help rural areas secure a sustainable energy supply. The solar food processing and conservation initiative is a newer project designed to increase knowledge of solar cooking and drying by creating a global network of interested solar food experts, farmers, producers, and decision-makers. The Solar Schools-Brighter Future program, launched as part of the 2000 Earth Day Celebrations, aims to bring solar applications into the classroom setting, both to save energy and to act as a teaching aide.

The ISES is dedicated to the use of the internet as a networking tool and as a means of knowledge dissemination. *Refocus* is also published as a weekly online newsletter, and the society has also designed a global network and database with online cooperative authoring, known as WIRE, or World-wide Information System for Renewable Energy. ISES is also a member of the International Renewable Energy Alliance.

SEE ALSO: Alternative Energy, Solar; Energy Efficiency; Solar Energy Industries Association (SEIA).

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International Union of Geodesy and Geophysics (IUGG)

THE INTERNATIONAL UNION of Geodesy and Geophysics (IUGG) was established in 1919 as a nongovernmental organization. Original members were Australia, Belgium, Canada, France, Japan, Portugal, the United Kingdom, and the United States. It is based at the University of Colorado in Boulder, Colorado, and is also known by its French name, *Union Géodésique et Géophysique Internationale*.

Geodesy and geophysics refer to the study of the sciences of the Earth and its position in space. Individual fields within these faculties include composition and tectonics of the Earth, dynamics of the Earth and its components, Earth shape, internal structure of the Earth, gravitational and magnetic fields, hydrological cycles of the Earth including ice and snow, magma generation, volcanism and rock formation, solar-terrestrial relations, and anything to do with the atmosphere, ionosphere, magnetosphere, and oceans. Additionally, study can be extended to the moon and the other planets in our solar system. These studies can be carried out using data collected on the Earth or via high-altitude data-collection instruments or artificial satellites.

The IUGG is "dedicated to advancing, promoting, and communicating knowledge of the Earth system, its space environment, and the dynamical processes causing change." When a natural disaster occurs, the IUGG partners with the United Nations Educational, Scientific, and Cultural Organization (UNESCO) to investigate. UNESCO is a United Nations agency that was established in 1945 to foster international communication in the fields of culture, education, and science.

Members to the IUGG are individual countries. When a country wishes to join the IUGG, a current member country must first nominate the country; the nominating country is thereafter called the adhering organization. The country must next nominate a national committee to serve the IUGG, including at least an officer. There are multiple associations within the IUGG; joining countries must nominate a correspondent to each association. Finally, the applying country must choose to be a regular or associate member. As of 2007, there were 65 member nations representing Africa, Asia, Central America, Europe, North America, Oceania, and South America.

The IUGG is currently a scientific union within the International Council for Science (ICSU), along with 24 other unions. The ICSU was founded in 1931, as the International Council of Scientific Unions (hence the acronym); it became the International Council for Science in 1998, keeping the acronym ICSU as a tie to its history.

Within the IUGG, there are eight associations. These associations are the International Association of Cryospheric Sciences (IACS), the International Association of Geodesy (IAG), the International Association of Geomagnetism and Aeronomy (IAGA), the International Association of Hydrological Sciences (IAHS), the International Association of Meteorology and Atmospheric Sciences (IAMAS), the International Association for the Physical Sciences of the Ocean (IAPSO), the International Association of Seismology and Physics of the Earth's Interior (IASPEI), and the International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI).

The IUGG is a self-proclaimed "purely scientific organization," with the objectives of "the promotion and coordination of physical, chemical and mathematical studies of the Earth and its environment in space." It is managed by an IUGG council and holds a general assembly with delegates from each adhering body. The first general assembly was held in Rome, Italy in 1922. Since then, it has been held around the globe approximately every two to four years; it was held in Boulder, Colorado, in 1995, and at Perugia, Italy, in 2007. The first recorded attendance rate is 333 people for the 1930 meeting in Stockholm, Sweden; the 2003 meeting in Sapporo, Japan hosted 4,151 people. All member countries are invited to propose to host the general assembly; applications must be submitted at least six months prior to the scheduled meeting date.

SEE ALSO: Colorado; International Council of Scientific Unions (ICSU); Nongovernmental Organizations (NGOs); United Nations; University of Colorado.

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Intertropical Convergence Zone

THE INTERTROPICAL CONVERGENCE Zone (ITCZ) is a narrow band where the trade winds of the two hemispheres collide. At or near the ITCZ, sea-surface temperature (SST) is at a maximum. As the winds travel over the tropical water, they pick up moisture; where they collide, they are driven upward. The air is also forced upward by convection resulting from heating by the ocean. As the air rises, it cools, the moisture condenses, and heavy rain results. The heat released drives the regional and global atmospheric circulation. It also makes the ITCZ an origin site for cyclones. Another effect of the upward movement of air is relatively calm surface winds. This causes the ITCZ to be an area of downwelling, and, thus, low nutrients and productivity. The ITCZ interacts with other climatological features, affecting weather and climate in the tropics and subtropics.

The ITCZ might be expected to fall directly on the equator, because, on average, this is where the Sun is strongest. In actuality, the ITCZ moves, but tends to fall preferentially in the northern hemisphere, over the eastern Pacific and the Atlantic oceans. The shift can be 10 degrees or more in latitude, or several hundred mi. (km.), and it has significant effects.

The cause appears to be related to the western boundaries of South America and Africa, particularly the northwest to southeast slopes of the boundaries at the equator. This weakens the northeasterly trade winds, thereby warming the water north of the equator and allowing southeasterlies to cross into the north prior to convergence.

The easterly trade winds are the prevalent winds in the tropical Pacific and Atlantic oceans. These winds push the warm surface water west, exposing cooler water, known as the Equatorial Cold Tongue. Stronger trade winds in the south favor upwelling below the equator. Low-level stratus clouds above the cold water and evaporative cooling aided by the winds reinforce the hemispheric temperature difference and move it westward. The Sun is closest to the Earth during northern winter, which may also favor prevalence of a northern ITCZ. The dominance of monsoons over trade winds in the Indian Ocean maintains equatorial symmetry there.

The ITCZ fluctuates over many timescales. Local winds are important seasonally, more distant winds can be significant interannually, and ocean circulation can affect sea-surface temperatures on decadal or greater scales. Normal annual migration is from 10 degrees north latitude in August to 3 degrees north in February. In March and April, a double ITCZ above and below the equator can form. Weak trade winds and subsequent decreased upwelling in El Niño years may move the ITCZ south of the equator in the Pacific.

The asymmetry of the ITCZ aids in establishing an annual, rather than a biannual, weather cycle in the tropical eastern and central Pacific Ocean, even though the sun crosses the equator twice yearly. Seasonal air temperatures there exhibit wide divergence because the seasonal weakening and strengthening of the southeasterlies reduce or enhance upwelling and evaporative cooling. Models indicate that this phenomenon could intensify in response to increased greenhouse gases. Interannual and decadal variation in the ITCZ can result in droughts in some years, and floods in others. Southward displacement is associated with increased the occurrence and intensity of El Niño, while El Niño is suppressed by northward displacement.

The southward shift brings dry conditions to South America and perhaps western Africa, and increased rain in eastern Africa. Warming in one hemisphere or cooling in the other moves the ITCZ in the direction of warming. Past deflection of the ITCZ likely resulted from orbital changes that affected how the sun strikes Earth. Prolonged shifts have been linked to changes in human society, because of their effects on precipitation. The Northern Hemisphere is currently experience greater warming than the Southern Hemisphere because of the greater ocean heat sink in the south. This raises the possibility of change in the El Niño/Southern Oscillation regime. Changes in the Atlantic Meridional Circulation could also reorganize heat distribution, thereby evoking a response in the ITCZ.

SEE ALSO: Doldrums; Meridional Overturning Circulation; Trade Winds; Upwelling, Coastal.

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Iowa

IOWA HAS AN area of 56,272 sq. mi. (145,744 sq. km.), with inland water making up 402 sq. mi. (1,041 sq. km.), including 31 natural lakes most formed by glaciers and reservoirs. Iowa's average elevation is 1,100 ft. (335 m.) above sea level, with a range in elevation from 480 ft. (146 m.) at the Mississippi River, to 1,670 ft. (509 m.) in Osceola County. Iowa has 2 million acres of forested land. The topography is central lowland, part of the interior plains. Iowa's rivers drain into the Mississippi River system. Iowa has many small lakes, and dams on smaller rivers have created several reservoirs. Dams on the Mississippi River have created large reservoirs on the eastern state line formed by the Mississippi River.

Iowa's climate is fairly uniform throughout the state, with hot, muggy summers, and harsh winters. Des Moines's average January temperature is 20 degrees F (minus 6 degrees C) and the average July temperature is 76 degrees F (24 degrees C) (with warmer daytime temperatures in the high 80s to low 90s F, or 27–32 degrees C). The highest temperature recorded in the state was 118 degrees F (48 degrees C) on July 20, 1934, and minus 47 degrees F (minus 44 degrees C) is the lowest temperature recorded in the state on February 3, 1996. The annual precipitation is between 26–36 in. (66–91 cm.) around the state, with more precipitation in the eastern part of the state. With no natural barriers like mountains, Iowa experiences the full sweep of winds.

Iowa's major crop is corn (hybrid corn developed to resist disease and drought). Hot and muggy summers and a long growing season (170 days in the south and 140 days in the north) lead to a good corn harvest. Beef, pork, wheat, soybeans, and apples are also major agricultural contributions to the economy. Major industries include chemicals, machinery, and electrical equipment manufacturing. Iowa has large coal reserves and most of the coal mined is burned to make electricity.

Iowa experienced a sample of possible impact of climate change with the Great Flood of 1993. Heavy rain (Des Moines reported 29.67 in. of rain) and snow runoff raised the Missouri, Mississippi, Des Moines, Cedar, and Iowa rivers and many smaller streams, causing severe flooding in much of the state.

Climate models vary on temperature increase for Iowa, from 2–7 degrees F (1–4 degrees C) in autumn and winter, from 1–4 degrees F (0.5–2 degrees C) in summer, and from 1–5 degrees F (0.5–3 degrees C) in spring by the end of the 21st century. Potential risks include increase in frequency and intensity of summer and autumn rainfall, making flooding a possibility in many areas, made worse by difficult drainage and the increasing chance of topsoil erosion. Flooding and runoff could contaminate water supplies (with eroded soils and agricultural chemicals containing high concentrations of nitrates, pesticides, and soil nutrients). Changes within established ecosystems (wetlands, forest, cropland, and prairies) would affect wildlife, including breeding grounds of waterfowl and migratory birds. Human health risks include, but are not limited to, contracting certain infectious diseases from water contamination or disease-carrying vectors such as mosquitoes, ticks, and rodents. Warmer temperatures would increase the incidence of heat-related illnesses and lead to higher concentrations of ground-level ozone pollution, causing respiratory illnesses (diminished lung function, asthma, and respiratory inflammation).

Agriculture, the major source of the Iowa economy, may not be affected at lower temperature increases. Only if summer temperatures rise to the higher predicted levels and drier conditions become prevalent will livestock be affected by failure to gain weight and limited pasture yield. Iowa has the potential for an additional source of income selling emission credits achieved by carbon sequestration.

Based on energy consumption data from the Energy Information Administration's State Energy Consumption, Price, and Expenditure Estimates (SEDS) released June 1, 2007, Iowa's total carbon dioxide (CO_2) emissions from fossil fuel combustion in million metric tons CO_2 for 2004 were 80.20, made up of contributions from: commercial, 3.54; industrial, 15.58; residential, 4.77; transportation, 20.37; and electric power, 35.93.

Iowa established the Climate Change Advisory Group in April 2007 to assess climate change impact and develop a strategy for reducing greenhouse gas emissions. The Department of Natural Resources Air Quality must include greenhouse gas emissions estimates in construction permitting and emissions inventory programs. Iowa's 2002 Comprehensive Energy Plan Update required state facilities to purchase at least 10 percent of their electricity from renewable energy by 2005 and to reduce their energy consumption to 20 percent below 2000 levels. Iowa joined the Climate Registry, a voluntary national initiative to track, verify, and report greenhouse gas emissions, with acceptance of data from state agencies, corporations, and educational institutions, beginning in January 2008.

FARMER PILOT PROGRAM

Iowa farmers are participating in a pilot program that pays them to store carbon in their soil by not tilling. The Chicago Climate Exchange program then sells carbon credits to utilities and other big carbon polluters to offset emissions. Conservation in Iowa began long before global warming became an issue. In 1972, Iowa established the first soil conservation cost-share program in the United States, and, in 1980, renewed the commitment to soil conservation with a 20-year schedule for soil-erosion prevention measures. In addition, research and education continue to decrease the use of chemicals in farming. The Iowa legislature also passed environmental protection bills to preserve ground water and air quality, with the task performed by the Department of Natural Resources.

SEE ALSO: Carbon Sequestration; Iowa State University.

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IOWA STATE UNIVERSITY of Science and Technology (ISU) is a public land-grant and space-grant university located in Ames, Iowa. Until 1959, it was known as Iowa State College of Agriculture and Mechanic Arts. ISU houses 8 different colleges, 54 different departments, and enrolls 20,440 undergraduate and 4,583 graduate students annually. The College of Liberal Arts combined with the College of Agriculture offers undergraduate and graduate degrees in Environmental, Geological and Atmospheric sciences.

The Department of Geological and Atmospheric Sciences has implemented an internet-based university course addressing issues of global environmental change. The course provides access to recent scientific literature and structured learning activities on a wide range of global environmental issues. An electronic dialog allows online discussion organized by topic. A web-based laboratory allows students to test hypotheses and conceptual models by accessing and running a research-quality model of soil-vegetation-atmosphere interactions. Each student has a personalized password-protected electronic portfolio for managing all interaction with the course and the laboratory. A global learning resource network has been established to facilitate multi-directional flow of information and ideas from many countries on global change issues.

The authors have compiled pertinent information in the form of summary information, images, and suggested readings. The topics are subdivided into three blocks. The first block, Climate and Agents of Global Change, sets the foundation for understanding global change through observations of global mean temperature and trends in carbon dioxide. The second block, Models and Measurements of Global Change, focuses on climate modeling, the limitations of models and what we can learn from them. Block three, The Biosphere and Human Component of Global Change, addresses the impact by humans through population, deforestation, and desertification. The course objectives are to demonstrate the interconnectedness of the earth's environmental system, and to explore the scientific evidence for changes in the global environment; instill in students the value of peer-reviewed literature on global-change issues; engage students, by means of the internet, in dialog among themselves, with outside experts, and with students from other countries on the scientific, economic, social, political, and ethical implications of these global changes.

For each of the assigned units, members of the group read and discuss online the material and references for that particular unit, and monitor the outline dialog. The group constructs a short document for the entire class that summarizes key points from the Summary Information and from the online dialog.

SEE ALSO: Global Warming; Iowa; National Aeronautics and Space Administration (NASA).

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Iran

ONE OF THE largest countries in the Middle East, the Islamic Republic of Iran has a land area of 636,372 sq. mi. (1,648,195 sq. km.), with a population of 71,208,000 (2006 est.), and a population density of 109 people per sq. mi. (42 people per sq. km.). Tehran, the capital and the largest city, has a population density of 26,620 people per sq. mi. (10,260 per sq. km.). Ten percent of the country is arable land; 27 percent is used for meadows and pasture, much of it for low-intensity grazing of sheep and cattle; and 7 percent of the land is forested, although this is declining rapidly with heavy deforestation.

With an economy heavily reliant on oil, and with the price of petroleum low in the country, Iran had a per capita rate of carbon dioxide (CO_2) emissions of 3.9 metric tons in 1990, rising to 5.6 metric tons by 2003. As for electricity production in the country, 94.2 percent comes from fossil fuels, and only 5.8 percent from hydropower. Iran embarked on a nuclear power program in the 1970s.

This nuclear power program was disbanded in 1979, but has been started up again, ostensibly to try to remove Iran's dependence on oil. Of the country's CO_2 emissions, 55 percent come from liquid fuels, 34 percent from gaseous fuels, and 7 percent from gas flaring. The low price of gasoline, along with the size and increasing prosperity of the country, has led to widespread use of private automobiles. As a result, there is considerable air pollution in Iran, with nearly 70 percent of it coming from fumes from vehicle exhausts. Also, few cars have catalytic converters, which allow for the worst pollutants to be removed before the fumes come through the exhaust. In recent years, the price of gasoline has risen, and this has helped reduce the increase in automobile use, but transportation still accounts for 24 percent of CO_2 emissions, the same percentage as electricity. Residential uses account for 17 percent of emissions, and 21 percent of emissions come from manufacturing and construction.

DEVELOPMENT AND DEFORESTATION

There has also been massive urban and industrial development, as well as deforestation, with soil erosion and overgrazing noticeable around the Alborz Mountains. A widespread drought hit Iran in 1999–2001, and, in one study in 2001, it was found that 90 percent of the wetlands had dried up because of the drought, with the winter of 1999–2000 the driest on record, and the years 1999, 2000, and 2001 ranking as the fifth, third, and seventh driest since records began in 1900.

The Iranian government ratified the Vienna Convention in 1990 and took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, which was ratified in 1996. They accepted the Kyoto Protocol to the UN Framework Convention on Climate Change on August 22, 2005, and it took effect on November 20, 2005.

SEE ALSO: Drought; Deforestation; Oil, Consumption.

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Iraq

THE REPUBLIC OF Iraq, located in the Middle East astride the Euphrates and Tigris rivers, has a land area of 169,234 sq. mi. (434,924 sq. km.), a population of 28,993,000 (2006 est.), and a population density of 171 people per sq. mi. (66 people per sq. km.). Baghdad, the capital and the largest city, has a population of 5,831,000.

The Iraqi economy is heavily reliant on oil, and 12 percent of the land is arable, with a further 9 percent used for meadows and pasture. To try to reduce the reliance on imports from overseas, the Iraqi government of Saddam Hussein embarked on a process of turning the land in the delta of the Tigris and the Euphrates into farmland, alienating many of the Marsh Arabs in the area, and leading to major environmental changes in that region. During the Gulf War, 1990–91, many oil wells in Kuwait were set on fire, leading to massive environmental pollution in the region, and having a considerable effect on carbon dioxide (CO_2) emissions.

Because of the low price of gasoline in the country and increasing affluence during the 1990s, in 1998, some 90 percent of the country's CO_2 emissions came from liquid fuels, with a further 7 percent from gaseous fuels. The rate of CO_2 emissions per capita remained low, with 2.6 metric tons per person in 1990, reaching 3.4 metric tons in 1994, and then falling to 2.7 metric tons by 2003, a rate similar to that of its eastern neighbor Syria, which has no significant petroleum facilities. In spite of the reliance on petroleum, there have been studies of the possible use of solar power and wind power in Iraq. The studies have shown that there is clear capacity for solar power to heat domestic water and to supply continuous hot water to all the major population centers in the country.

The Iraqi government did not ratify the Vienna Convention and sent an observer to the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, but did not sign the agreement. Iraq is one of the few major countries whose government has not expressed a position on the Kyoto Protocol to the UN Framework Convention on Climate Change.

SEE ALSO: Alternative Energy, Solar; Oil, Consumption of; Oil, Production of.

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Ireland

AN ECONOMIC BOOM that began in the 1990s and continued through 2001 transformed Ireland from one of the poorest countries in Europe to one of the wealthiest, but the boom came with an environmental cost. No part of Ireland is more than 70 mi. (113 km.) from the Atlantic Ocean, and this proximity to the ocean renders the country particularly vulnerable to coastline erosion. Greenhouse gas emissions from land and air transportation increased 140 percent 1990–2004, making Ireland the second worst offender (next to Luxembourg) in spewing pollutants among European Economic Area nations. Deforestation has added to Ireland's environmental offenses.

A study compiled by climatologists for the Environmental Protection Agency draws a direct correlation between Ireland's shrinking shoreline and greenhouse gas emissions. The researchers reported that Ireland's average temperature has been rising at the rate of 0.75 degrees F (0.42 degrees C) each decade since 1980, the fastest rate of change in more than a century. At the same time, Ireland has experienced its 10 hottest years on record, rainfall has increased in frequency and intensity along the Atlantic coastline, and the study predicts worsening conditions.

Ireland, as a signatory of the Kyoto Protocol, is bound to limit its emissions increase to 13 percent by 2010. The European Union (EU), in 2006, questioned Ireland's ability to meet the target, predicting that the country will likely increase its emissions by 29 percent. The Irish government has defended its policies, insisting that increases in the nation's use of renewable energy for electricity production and more stringent measures for its building industry will make results better than EU predictions. However, as the opposition party is quick to note, road building increases emissions, as does Ireland's low level of forest cover. Despite 20 years of encouraging afforestation, Ireland's rates are 30 percent below target.

Ireland can claim some successes. Emission rates were reduced in energy supply, industry, agriculture, and waste management during the same period when transportation emissions increased dramatically. In April 2007, the Ministry for the Environment, Heritage and Local Government announced the National Climate Change Strategy for 2007–12. The plan included such measures as a goal of 15 percent of electricity to be generated from renewable sources by 2010, and 33 percent by 2020, with biomass to contribute up to 30 percent of energy input at peat stations by 2015; new support for afforestation, changes in tax regulations to discourage the use of fuel-inefficient cars; and grants for renewable energy heating sources for homes. A more detailed Transport Action Plan was promised for late 2007. The government believes these srategies will allow Ireland to meet 80 percent of its Kyoto target, with the remaining 20 percent coming from Ireland's use of the Flexible Mechanisms that allow Kyoto Protocol Parties to support the development of clean technology in the developing world in return for emissions credits.

Sea level in the Dead Sea. Israel may have 40 percent less water by the end of the 21st century than it had in 2000.

SEE ALSO: Afforestation; European Union; Luxembourg.

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Israel

A POLITICALLY TROUBLED country since its inception in 1948, Israel is nevertheless a progressive nation. Israel's early commitment to environmentalism is in line with its progressiveness. The Israel Environmental Protection Service was established in 1973, and the Ministry of the Environment, largely responsible for monitoring compliance with the nation's environmental laws, began operating in 1988. The country is also a signatory to many international environmental agreements, including Climate Change, Climate Change-Kyoto Protocol, Desertification, and Ozone Layer Protection. But air and water pollution remain a problem. Israel's power consumption has increased 7.5 percent per year since 1990, the highest rate in the developed world, and its contributions to global warming doubled during the same period.

Although the Climate Change Convention classified Israel as a developing country, its greenhouse gas emissions are on the levels of developed countries. The largest source of carbon dioxide (CO_2) emissions is the burning of fuels for energy production, a source that has grown steadily since 1996, Israel's self-selected baseline year for the Kyoto Protocol agreement. Electricity production and road transportation account for more than 80 percent of the nation's CO_2 emissions. Ironically, Israel was at the vanguard of solar innovation, using solar water heaters as early as the 1950s. However, little effort has been devoted to using solar energy commercially to generate electricity. A 2006 Yale University study ranks Israel well above the average for its geographical region in both overall environmental health and its Environmental Performance Index, but Israel is still a long way away from meeting targets in CO_2 emissions and in its use of renewable energy sources.

Local experts warn that Israel could have 40 percent less water by the end of the 21st century than it had at its start. High-intensity rainstorms may cause runoff of topsoil and water into the Mediterranean and the Dead Sea.

The latter has already experienced major ecological damage. A new report by the Israel Union for Environmental Defense studied the United Nations Intergovernmental Panel on Climate Change's report and concluded that Israel's annual rainfall could decrease by 20 percent to 30 percent and that rising sea levels caused by the melting of polar icecaps could result in flooding that could devastate the nation's ports, power plants, and residential communities.

A rise in sea levels can also increase salinity, which would endanger Israel's potable water supply. The country opened a new desalinization plant in 2007, which, according to projections, will supply one-third of its water requirements by 2020. But the plant will exact costs as well, since more greenhouse gases will be emitted by the energy required to run the facility.

Israel has approved three new projects that reputedly could reduce CO_2 emissions by as much as 150,000 metric tons per year. Israel's status as a developing nation and the Clean Development Mechanism allow the country to sell "the reduction percentage" to developed countries eager to meet their own targets. These projects could mean good news for Israel, the developed countries, and the entrepreneurs who developed the new technologies.

SEE ALSO: Clean Development Mechanism; Intergovernmental Panel on Climate Change (IPCC); Salinity.

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Italy

21ST CENTURY ITALY is a modern, industrialized nation with the seventh highest Gross Domestic Product in the world. Like other developed countries, Italy must struggle with high consumption of resources and the environmental effects of that consumption. The leading causes of greenhouse gas emissions in Italy are road transport and fossil-fuel burning energy production. Water pollution and desertification are environmental problems. Italy has been slow to confront these problems, but, beginning in 2006, has been able to see some positive outcomes as a result of new technologies and environmental policy changes.

Italy has the third highest rate of private car ownership in the world, and the low percentage of unleaded gasoline sold, a mere 18 percent, intensifies the emissions problem, as do the popular motor scooters. In the 1990s, Italy's industrial carbon dioxide (CO_2) emissions gave the country the world's tenth highest level of industrial CO_2 emissions. Between 1990, Italy's base year for greenhouse gas emission according to the Kyoto Protocol, and 2005, Italy's emissions rose annually. Methane emission is also a problem. Experts suggest that methane emissions have the potential to reach levels comparable to emissions from Italy's fossil fuel industry.

Italy's greenhouse gas emissions have risen 12 percent since 1990. Italy did achieve a 1.5 percent reduction in 2006, but emissions from electricity production rose 4 percent, and automobile emissions were stable. To reduce CO_2 emissions, Italy has considered expanded rail systems, car-free Sundays, and a move from trucking to water transport, among other experiments, but local politics and contradictory opinions about what is best for the environment and the country's citizens make changes difficult.

The connection between the emissions problem and desertification is strong. The country's National Environmental Strategy for Sustainable Development (NESSD) included the reduction of greenhouse gases as the first item in its plans to protect and sustain natural resources. Some reports warn that climate change and its effects, such as declines in precipitation levels, could result in the desertification of as much as 32 percent of Italy's land area. In southern Italy, land that has been cultivated for millennia is being abandoned. Even flourishing businesses, such as the wine and olive industries, are suffering. In 2007, when Italy had its hottest summer in 250 years, the nation recorded its earliest harvest of wine grapes in 30 years, and production was down by over 10 percent. Olive production has been forced northward by the changes. Water levels in the Po River, which feeds irrigation channels in four Italian regions, have fallen 20–25 percent in the last 30 years. Researchers caution that average temperatures could increase by up to 9 degrees F (5 degrees C) by the end of the century.

FOUR DECADES OF INITIATIVES

Italy's initiatives to protect the environment now have a history of more than four decades. The Clean Air Law, the first legislation to deal specifically with air pollution, was passed in 1966. Ten years later, the Water Pollution Control Law was enacted. The Ministry of the Environment was established in 1896, and the Environmental Protection Agency was added in 1994. In addition to the Kyoto Protocol and the Convention to Combat Desertification (CCD), Italy is a signatory to more than 20 international environmental agreements, including Air Pollution, Air Pollution-Nitrogen Oxides, Air Pollution-Persistent Organic Pollutants, Air Pollution-Sulfur 85, Air Pollution-Sulfur 94, Air Pollution-Volatile Organic Compounds, Climate Change, Ozone Layer Protection, and Ship Pollution. However, enforcement of existing laws and commitments to international agreements has been inconsistent. A 2006 Yale University study ranked Italy 21st among 133 nations on its Environment Performance Index, but Italy's score of 79.8 placed it below average among both its income and geographical groups.

The country's wind power generation capacity has been growing. Wind power supplied 1 percent of the nation's total power demand in 2006 and should exceed the target capacity by 2012. Italy also developed Europe's first train with solar-power assistance providing energy for air-conditioning, lighting, and safety systems, thus making the train more fuel-efficient. Italy's higher energy prices provide a strong stimulus for businesses to invest in energy efficiency research and development.

SEE ALSO: Alternative Energy, Wind; Carbon Emissions; Desertification.

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Jamaica

LOCATED IN THE Caribbean, the Republic of Jamaica has a land area of 4,244 sq. mi. (10,990 sq. km.), with a population of 2,714,000 (2006 est.). It has a population density of 626 people per sq. mi. (241 people per sq. km.), making it the 49th most densely populated country in the world, with more than a third of the population living in Kingston, the country's capital. Fourteen percent of the land is arable, with a further 24 percent used for meadows and pasture. Although 27 percent of the country is still forested, the deforestation rate, 5 percent per year, is the highest of any country in the world. This is threatening wildlife diversity and contributing to ecological problems, not just in Jamaica, but also in the region, as there has been a rise in the carbon dioxide (CO_2) emissions per capita in Jamaica. Emissions were 3.4 metric tons per person in 1990, rising to 4.1 metric tons per person by 1997, and falling only slightly since then. Jamaica is 86th in the world in terms of its per capita CO_2 emissions.

Affected regularly by hurricanes in the Caribbean, the rising sea levels are less of a problem for Jamaica than many other Caribbean islands, but the rising temperature levels in the seas have already caused some problems with the bleaching of some coral reefs. There is also a threat to the entire coral reef system and its related marine life along the north coast of Jamaica. To highlight the problem, the Negril Coral Reef Preservation Society operates to encourage responsible diving, which has added to the problems caused by global warming. The threat is also to the green, hawksbill, and loggerhead turtles that nest on beaches in Jamaica, and also the West Indian manatees that can still be found on the south coast. The threat to marine life and land animals means that Jamaica is in the top 10 countries in the world in number of endangered amphibians and plant species.

To try to combat the factors that influence global warming and climate change, the Jamaican government maintains a comprehensive public transport system. Despite being in the tropics, some parts of Jamaica receive little rainfall. The town of Lucea in western Jamaica suffers from periodic droughts. The Jamaica Environment Trust (J.E.T.) has encouraged the replanting of trees, with help from the forestry department. The Jamaican government of Percival Patterson took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, and two years later Jamaica was represented at the Global Conference on the Sustainable Development of Small Island Developing States held in Barbados. On June 28, 1999, the Jamaican government accepted the Kyoto Protocol to the UN Framework Convention on Climate Change; it took effect on February 16, 2005.

SEE ALSO: Afforestation; Drought; Hurricanes and Typhoons; Tourism.

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Japan

AN ISLAND NATION with the world's 10th largest population, Japan is one of the most powerful economic centers of the globe. Only the United States is more technologically advanced than Japan, and among single nations, only the United States can claim a larger economy, based on Gross Domestic Product. Unfortunately, Japan has also joined the ranks of world leaders in its contributions to global warming. In 2004, the country ranked fourth, behind the United States, China, and Russia, in its carbon dioxide (CO_2) emissions. Despite continued efforts to lower emissions through conservation, legislation, and technology, Japan continues to produce nearly 5 percent of the world's CO_2.

Japan began passing laws to control harmful industrial emissions as early as 1968, when the Basic Law for Environmental Pollution Control was passed in response to factory-produced air and water pollution. As awareness of environmental hazards increased, the law was revised with more stringent requirements. The Ministry of the Environment was established in 1971 and is given the responsibility for monitoring compliance with environmental laws and coordinating policies. In 1993, the Basic Environmental Law was passed to manage environmental problems on a global scale. The Ministry of Health, Labor, and Welfare and the Ministry of Agriculture, Forestry, and Fisheries are also involved in enforcing environmental policies.

KYOTO PROTOCOL

Japan is a signatory to the Kyoto Protocol and is obligated by the agreement to reduce its emissions by 6 percent of the 1990 level, but reports indicate that the country is far from the target. Even as CO_2 emissions from small-to-medium-sized industries have decreased, emissions from electricity consumption have increased 45.8 percent over the base year. During recent years, the share of passenger cars as a proportion of total passenger transport has increased, and even though Japan has established vehicle emissions standards for nitrogen oxides, carbon monoxide, and hydrocarbons, greenhouse gas emissions from automobiles for personal use have increased. In the case of CO_2, the increase has been 52.6 percent since 1990. To meet the Kyoto target would require a 14 percent reduction based on 2005 figures, and 2006 emissions were even higher. Complicating the picture is the Kashiwazaki-Kariwa Nuclear Power Plant, site of the world's largest nuclear output, where operations were suspended after an earthquake shook the facility in July 2007. Experts estimate that this suspension alone may raise Japan's CO_2 emissions by as much as 2 percent.

Pressure for more action is increasing as the immediate effects of global warming are felt throughout the nation. The production of rice, Japan's most important crop domestically, is expected to increase in some regions of the country as temperatures warm. Researchers predict that the rise in temperatures will decrease wheat production throughout the country. Concerns about heavier weed growth, harmful insects, and changes in rainfall patterns that create drought in some areas and cause flash floods in others generate fear as well.

A harbor on the island of Kyushu beneath the Sakurajima volcano in Japan. Host to the conference that led to the Kyoto Protocol, Japan has signed and ratified more than a dozen other international environmental agreements.

Japan has actively responded to these challenges. It has become a world leader by developing and implementing pollution control technologies and energy efficiency innovations. The Revised Energy Savings Law, adopted in 1999, encourages both central and local government to implement environmentally friendly technologies such as solar energy, wind power, and multi-fuel vehicles. Japan, host to the conference that led to the Kyoto Protocol, has signed and ratified more than a dozen other international environmental agreements, including Biodiversity, Desertification, Endangered Species, Environmental Modification, Hazardous Wastes, Ozone Layer Protection, Ship Pollution, Tropical Timber 83, and Tropical Timber 94.

Japan's investment in solving environmental problems on a global level has also included substantial contributions to the Global Environment Facility (GEF), a principal international multilateral funding mechanism set up in 1991 to aid developing countries in developing programs and projects that protect the global environment and promote sustainability. Japan contributed $84 million 1991–93, followed by an additional $415 million 1994–98, and $412 million 1998–2002. In 2007, concerned that Asia's energy consumption had grown by 230 percent since 1977, and alarmed by predictions that it would double again by 2030, Japan pledged $100 million in grants to the Asian Development Bank. The money is intended to promote renewable energy resources in a region that now accounts for a quarter of the world's greenhouse gas emissions.

Ignoring prognosticators, Japan insists that the nation will meet its Kyoto target. Not only did Japan focus on the improvement of its national and private forests at home through afforestation and forest conservation, but also its training and technology was made available to developing countries in Asia and South America. Domestic afforestation is expected to account for 3.9 percent of the 6 percent total deduction. With carbon credits earned through promoting projects in developing countries and carbon credits earned through resultant savings accounting for 1.6 percent, only .5 percent from standard emissions reduction will be required to meet the target.

POST-KYOTO

Looking beyond Kyoto, Japan has been bold in its long-term planning. In 2006, the nation identified five environmental objectives: improve energy efficiency by at least 30 percent, reduce oil dependence to 40 percent or lower, reduce oil dependence in the transport sector to 80 percent, target the share of nuclear power in electricity generation to 30–40 percent, and increase the share of crude oil owned by Japanese companies to 40 percent. In May 2007, former Japanese Prime Minister Shinzo Abe proposed a new initiative for cutting the world's greenhouse gas emissions by 50 percent of current levels by 2050. Abe praised the Kyoto Protocol for identifying the initial steps toward global solutions, but he insisted that the time had come for a new strategy that used innovative technologies, responsible use of resources, and the collaborative efforts of developed and developing countries to protect the Earth and the common interests of all nations. He challenged nations that have not ratified the Kyoto Protocol, including the United States, China, and India, to commit themselves to newly defined goals.

Abe also reiterated Japan's commitment to meeting his country's original Kyoto target by the year specified in the agreement. Some critics have speculated that Japan's objectives will require a green tax, a move frequently considered in the past, but delayed by opposition from the steel and electric power industries, whose greenhouse gas emissions are among the largest in the nation. The decline of gas consumption after price spikes and the decrease in consumption of plastic shopping bags after fees were levied on usage of the bags suggest that a green tax could be an effective measure on a larger scale.

SEE ALSO: Afforestation; Global Environment Facility (GEF); Kyoto Protocol; Nuclear Power.

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Jet Streams

THE JET STREAMS are fast-flowing eastward currents of air in the mid-latitudes of both hemispheres, with their cores at altitudes above 30,000 ft. (9,144 m.). Although they flow eastward, they are driven by the temperature contrast between the equator and the poles. Near the equator where surface temperatures are at a maximum, the air rises and, in the upper atmosphere, flows poleward. As the air moves away from the equator, the eastward winds increase in speed relative to the Earth's surface, becoming the jet streams in mid-latitudes. (This is a consequence of the conservation of angular momentum.)

The jet streams are most intense during the winter season when the temperature difference between the equator and pole is at a maximum. When too intense, they become unstable, start to meander, and create weather phenomena. The meanders, which are associated with the southward flow of cold air and the northward flow of warm air, in due course become turbulent, creating a variety of weather phenomena including cyclones, anti-cyclones, warm fronts and cold fronts. This variability is strongest in winter, when the jets are most intense, and is weakest in summer when weather tends to be associated with local, convective phenomena such as thunderstorms.

Regarding global warming, if it warms primarily high northern latitudes, it will weaken the northern Jet Stream so that summer (rather than winter) weather will become more common.

SEE ALSO: Coriolis Force; Doldrums; El Niño and La Niña; Winds, Easterlies.

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Johns Hopkins University

THE JOHNS HOPKINS University, founded in 1876, is a private institution of higher learning located in Baltimore, Maryland. Johns Hopkins offers its undergraduate and graduate programs at the main campus in Baltimore and maintains full-time campuses in greater Maryland; Washington, D.C.; Italy; and China. Johns Hopkins was the first university in the United States to emphasize research applying the German model developed by Alexander von Humboldt and Friedrich Schleiermacher. More than 4400 undergraduate students attend Johns Hopkins annually with majors offered in 10 divisions from Arts and Sciences to Applied Physics.

The Department of Geography and Environmental Engineering, a division of the Whiting school of Engineering, offers graduate and undergraduate programs focusing on topics from pollutants in our air and soil, global warming, the effects of suburban sprawl on water quality and wildlife, and political and legal aspects of environmental policy. The Department of Geography and Environmental Engineering is consistently ranked among the top U.S. universities. The Johns Hopkins University Bloomberg School of Public Health also offers programs in Environmental Health. Several degree programs, bachelors, masters, and Ph.D. programs are offered.

CLIMATE CHANGE POLICY

President William R. Brody recently announced the adoption of a climate change policy that will make Johns Hopkins a driving force in the development of solutions to the ingoing many climate crisis. The university will set an example through the reduction of greenhouse gas emissions derived from university operations, with the vision of carbon neutrality. The university will also offer leadership and assistance on actions to reduce the carbon footprint of the Baltimore-Washington region. The policy will also call on to JHU to focus its strengths in science, technology, public health and public policy to find new solutions to climate change on a global level.

The President's Task Force on Climate Change will be charged with developing a comprehensive climate strategic plan and creating an interdisciplinary working group of experts who will focus on innovative and novel approaches related to climate change. In addition, the task force will begin to partner with state and local governments within the greater Baltimore-Washington region on climate change efforts, such as more-energy-efficient facilities, alternative fuel use, addition of climate-related courses to the curriculum, collaborative efforts with the community and other schools, and other proposals.

The Climate Change and Human Health Integrated Assessment website provides information on research conducted between 1998 and 2000 about the potential impacts of climate change through integrated assessment. This website aims to appropriately characterize and communicate the scientific research to support policy development and analysis. The site is a program of the Johns Hopkins University and the Johns Hopkins Program of the Health Effects of Global Environmental Change. Courses offered at Johns Hopkins University focused on climate change and global warming include:

RESEARCH ISSUES AND METHODS

The Research Issues and Methods course explores the trends and prospects of climate change and other global environmental changes (GEC). It focuses on three categories of "primary" research, using climate change as the foundation: improved empirical understanding of climate-health relationships; issues in detecting and attributing health impacts; and scenario-based modeling of future health risks.

This course explores how global environmental issues such as global warming, urban sprawl, deforestation, mining, environmental refugees, biodiversity loss, and food security may cause increasing human harm. It provides an overview of the science and policy issues related to the changing environment, how environmental problems affect human health, and emphasizes potential solutions and sustainable development methods essential for resolving a myriad of environment-health problems.

The Program on Health Effects of Global Environmental Change is dedicated to the scientific discovery and application of new knowledge pertaining to the human health risks posed by global environmental degradation. Students in the MPH, MHS, and DrPH programs are encouraged to participate in the activities of the program.

SEE ALSO: Global Warming; Climate Change, Effects.

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Joint Institute for the Study of the Atmosphere and Ocean (JISAO)

THE JOINT INSTITUTE for the Study of the Atmosphere and Ocean (JISAO) was founded in 1977, for the purpose of fostering research collaboration between the National Oceanographic and Atmospheric Administration (NOAA) and the University of Washington. The administrative units most directly connected with JISAO are NOAA's Pacific Marine Environmental Laboratory (PMEL) and the University's Department of Atmospheric Science and College of Ocean and Fisheries Science (COFS).

JISAO is governed by 36 Senior Fellows, almost evenly divided between University faculty and NOAA/PMEL staff, who hold affiliate faculty appointments in the University. JISAO provides funding and administrative support for postdoctoral fellows and senior visitors on leave from their academic institutions.

FOUR CORE RESEARCH AREAS

The Institute has four core research areas: climate, global environmental chemistry, marine ecosystems and coastal oceanography. The study of global warming represents a big part of the Institute's activities. Within JISAO is the Center for Science in the Earth System (CSES). CSES carries out integrated research on the impacts of climate on the U.S. Pacific Northwest by taking into account climate dynamics, ecological dynamics, hydrologic dynamics, and institutional and policy analysis. The CSES is divided into three groups: the Climate Impacts Group, the Climate Dynamics Group, and the Office of the Washington State Climatologist.

The Climate Impacts Group (CIG) is an interdisciplinary team researching the impacts of natural climate variability and global climate change phenomena, such as global warming on the Pacific Northwest. The CIG conducts research to understand the consequences of climate fluctuations for the Pacific Northwest, and works with local planners and policy makers to make this information relevant for regional decision-making processes. The research of the group centers on four key sectors of the Pacific Northwest environment: water resources, aquatic ecosystems, forests, and coasts. In addition to scientific research, the group also works to make such research available to policymakers and the general public. Thus, the CIG aims to establish a productive dialogue between decision-makers and the research community, to encourage planning for climate impacts. The CIG also aims to improve the skills of other research teams in the United States and abroad to carry out regional integrated climate impacts assessment and outreach. The group tries to reach these ambitious aims by periodically hosting meetings and workshops to discuss the most recent developments in research and methodologies in climate impacts.

Examples of these workshops include annual climate and water forecast meetings (held near the beginning of the water year) and policy meetings on how to prepare for climate change. CIG researchers also give lectures and presentations at conferences, public meetings, and special events. The group also works closely with the local media to disseminate ideas on climate, climate science, and climate impact. The CIG has also got its own media. It launched a quarterly electronic newsletter and list-serve in January 2005 to supply regular updates on Pacific Northwest (PNW) climate, climate research, meetings, and other information related to planning for climate variability and change in the PNW. As CIG and JISAO are part of the University of Washington, researchers of CIG develop and teach courses at the graduate level at the

University concerning Pacific Northwest climate, climate impacts, and the use of climate information and the role of uncertainty in decision-making. The team holds weekly seminars during the academic year for faculty, staff, students at Washington University which are also open to the public.

The Climate Dynamics Research Group (CDG) studies the physical dynamics of climate variability and climate change over the Pacific, especially as it affects the United States and the Pacific Northwest area. The group focuses, in particular, on the dynamics of the El Niño/Southern Oscillation and the Pacific Decadal Oscillation and their atmospheric effects both in the region and in distant areas. The areas of expertise of CDG members include atmosphere, ocean, and coupled modeling; the diagnostics of the atmosphere and ocean; and the analytic description of the climate system. CDG members are involved in the formulation of national and international climate programs.

The office of the Washington State Climatologist collects and disseminates weather data for the state, thus providing an authoritative source for local policy-makers and agencies working on different aspects of climate change. These data are also available to the public.

SEE ALSO: Atmospheric Absorption of Solar Radiation; Atmospheric Boundary Layer; Clouds, Cumulus; Clouds, Stratus; Convection; National Oceanographic and Atmospheric Administration (NOAA); University of Washington.

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Jordan

LOCATED IN THE Middle East, the Kingdom of Jordan has a land area of 45,495 sq. mi. (89,342 sq. km.), a population of 5,924,000 (2006 est.), and a population density of 166 people per sq. mi. (64 people per sq. km.). Only 4 percent of the land is agricultural, with a further 9 percent used as meadow or pasture, mainly for the grazing of sheep and goats. There is also a small forestry sector in Jordan. For electricity production, 99.4 percent comes from fossil fuels, with only 0.6 percent from hydropower.

The high level of fossil fuel for electricity has contributed to a relatively high level of carbon dioxide emissions, making up 36 percent of total carbon dioxide emissions. These have been relatively stable, at 3.1 metric tons per person in 1990, rising slowly to 3.2 metric tons in 2003.

Other energy industries contribute to another 5 percent of emissions, with manufacturing and construction making up 14 percent, and residential use another 12 percent. Automobiles are heavily used in Jordan, which does not have an effective system of public transport outside of Amman and Irbid (where the suburbs are well-serviced), 23 percent of the country's carbon dioxide emissions come from transportation. Liquid fuels make up 91 percent of emissions by source, and of the remainder, 4 percent come from gaseous fuels, and 5 percent from the manufacture of cement.

The Jordanian government ratified the Vienna Convention in 1989, and took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, which they ratified in 1993. It accepted the Kyoto Protocol to the UN Framework Convention on Climate Change on January 17, 2003, which went into effect on February 16, 2005.

SEE ALSO: Carbon Dioxide; Energy; Israel; Transportation.

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Jurassic Era

THE JURASSIC PERIOD extended from about 199 million years ago to 145 million years ago. This geological time period constitutes the middle of the Mesozoic era, also known as the Age of Dinosaurs. The start of the period is marked by the major Triassic-Jurassic extinction event. This period was named by Alexandre Brogniart for the extensive marine limestone exposures of the Jura Mountains, in the region where Germany, France and Switzerland meet.

During the early Jurassic, the supercontinent Pangaea broke up into the northern supercontinent Laurasia and the southern supercontinent Gondwana. The Gulf of Mexico opened in the new rift between North America and what is now Mexico's Yucatan Peninsula. The Jurassic North Atlantic Ocean was relatively narrow, while the South Atlantic did not open until the following Cretaceous Period, when Gondwana itself rifted apart. The Tethys Sea closed, and the Neotethys basin appeared. Climates were warm, with no evidence of glaciation. As in the Triassic, there was apparently no land near either pole, and no extensive ice caps existed.

The Jurassic geological record in western Europe is clear, where extensive marine sequences indicate a time when much of the continent was submerged under shallow tropical seas. In contrast, the North American Jurassic record is the poorest of the Mesozoic, with few outcrops at the surface. Though the epicontinental Sundance Sea left marine deposits in parts of the northern plains of the United States and Canada during the late Jurassic, most exposed sediments from this period are continental, such as the alluvial deposits of the Morrison Formation. The first of several massive batholiths were emplaced in the northern Cordillera, beginning in the mid-Jurassic, marking the Nevadan orogeny. Important Jurassic exposures are also found in Australasia, India, Japan, Russia, South America, and the United Kingdom. During the Jurassic period the primary vertebrates living in the seas were fish and marine reptiles. The latter include ichthyosaurs, plesiosaurs, and marine crocodiles, of the families Teleosauridae and Metriorhynchidae. In the invertebrate world, several new groups appeared, including rudists and belemnites. The Jurassic period also had diverse encrusting and boring communities, and it saw a significant rise in the bioerosion of carbonate shells and hardgrounds. Especially common is the ichnogenus Gastrochaenolites. On land, large archosaurian reptiles remained dominant.

The Jurassic period was the golden age of the great sauropods, Camarasaurus, Diplodocus, Brachiosaurus, and many others that roamed the land late during this period. They were preyed upon by large theropods (Ceratosaurs, Megalosaurs, and Allosaurs). During the Late Jurassic, the first birds evolved from small coelurosaur dinosaurs. Ornithischian dinosaurs were less predominant than saurischian dinosaurs, although some, such as stegosaurs and small ornithopods, played important roles as small and medium-to-large herbivores.

In the air, pterosaurs were common, filling many ecological roles now taken by birds. The arid, continental conditions characteristic of the Triassic steadily eased during the Jurassic period, especially at higher latitudes; the warm, humid climate allowed lush jungles to cover much of the landscape. Conifers dominated the flora, as during the Triassic; they were the most diverse group and constituted the majority of large trees. Extant conifer families that flourished during the Jurassic included the Araucariaceae,

A marine fossil: the European Jurassic geological record indicates continental submersion in tropical seas.

Cephalotaxaceae, Pinaceae, Podocarpaceae, Taxaceae and Taxodiaceae. The extinct Mesozoic conifer family Cheirolepidiaceae, dominated low-latitude vegetation, as did the shrubby Bennettitales. Cycads were also common, as were Ginkgos and tree ferns in the forest. Smaller ferns were probably the dominant undergrowth. Caytoniaceous seed ferns were another group of important plants during this time and are thought to have been shrub to small-tree sized. Ginkgo-like plants were particularly common in the mid- to high northern latitudes. In the Southern Hemisphere, podocarps were especially successful, while Ginkgos and Czekanowskiales were rare.

There was no polar ice during the Jurassic period, so the sea levels were higher than they are now. The climate was warm. Early in the Jurassic, the continents were jammed together into a supercontinent known as Pangaea, making much of the inland area dry and desert-like. Toward the middle of the Jurassic period, when Pangaea began to break up, there were vast flooded areas, temperate and subtropical forests, and coral reefs. The extensive water moderated the strong seasonality so that by the end of the Jurassic there was less seasonality than we have now. Many giant sauropods lived during the late Jurassic period. Conifers dominated the landscape.

There was a minor mass extinction toward the end of the Jurassic period. During this extinction, most of the stegosaurid and enormous sauropod dinosaurs died out, as did many genera of ammonoids, marine reptiles, and bivalves.

SEE ALSO: Mesozoic Era; Triassic Era.

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Kansas

PREDOMINANTLY AN AGRICULTURAL state, one out of every five residents in Kansas is involved in farming or food production. Kansas leads the nation in the production of wheat and sunflowers. Like many of its midwestern neighbors, Kansas is experiencing a rural exodus, with large numbers of residents leaving farms to move to urban areas. This exodus has increased the pollution that concentrates in industrial regions. With a total population of almost 3 million people, the state has specific concerns about activities that lead to global warming and climate change. One of those concerns is the regional haze that blankets the large cities of Kansas. In response, Kansas has initiated a regional haze program designed to reduce toxic emissions.

Between 1990 and 2001, carbon dioxide (CO_2) emissions in Kansas rose by 4 percent, reaching a total of 71.9 million metric tons. Kansas currently ranks 26th in the United States in CO_2 emissions. Concern over the threat that CO_2 emissions pose to global warming and climate change has resulted in program initiatives that successfully increased CO_2 efficiency by 23 percent. However, the government is engaged in a balancing act, attempting to protect health and the environment while promoting economic growth. In 2007, Kansas joined some 30 other states in establishing the Climate Registry, which is designed to measure, track, and report greenhouse emissions in order to reduce national levels of pollution.

Environmentalists began putting pressure on the Kansas state government in 2006, when it was announced that the Sunflower Electric Power Corporation would build three new coal-fired power plants in western Kansas. The plan proceeded, despite the fact that eight states had filed lawsuits accusing such plants of accelerating global warming and climate change. Opponents of the project were also concerned about possible threats to the Wichita Mountain National Wildlife Refuge, located 260 mi. (673 km.) away in Oklahoma. The Environmental Protection Agency predicted that sulfur emissions released by the coal-fired power plants would surpass federal limitations and threaten health and the environment. Sunflower officials answered concerns about mercury emissions by insisting that they would be well below federal standards. Government officials were faced with the dilemma of balancing threats to health and the environment against the 2,000 jobs created by the construction project.

The Department of Health and Environment is the Kansas agency that exercises major responsibility for programs designed to reduce activities associated with global warming and climate change. The Environment

In 2006, the Kansas Department of Transportation won national recognition through the Kansas Prairie Ecosystem Restoration, Education, and Conservation Initiative, which strives to protect endangered tall, mixed, and short-grass prairies.

Division is specifically involved with oversight and implementation of laws and regulations that deal with air, radiation, public water resources, industrial discharges, solid waste landfills, hazardous waste, asbestos removal, and fuel storage tanks. This agency has the authority to levy fines and impose penalties to enforce compliance. Responsibilities include offering financial aid assistance programs designed to reduce global warming and climate change.

The Environment Division houses the Bureau of Environmental Field Services and the Bureau of Environmental Remediation. Other Kansas agencies involved in protecting the environment are the Department of Agriculture, which implements the Pesticide and Fertilizer Program, the Department of Wildlife and Parks, the Kansas Forest Service, and the State Conservation Commission.

In Kansas, programs that target global warming and climate change include efforts to promote public awareness. Kansas Don't Spoil It and Get Caught Recycling are statewide educational campaigns that encourage recycling of solid waste products. Aging wastewater and deficient public water supply systems pose particular environmental threats, and efforts are underway to rebuild or improve existing facilities. To this end, the state appropriated $94 million to 37 localities in 2006. The Kansas Department of Health and Environment has also been engaged in a massive effort to decontaminate 28 public water supply wells that serve approximately 150,000 residents. Through the Watershed Restoration and Protection Strategy, the state works with local governments and federal agencies to address problems with the state's watersheds. The Stream Probabilistic Monitoring Program generates physiochemical and biological data from randomly selected streams to estimate overall compliance with state environmental regulations.

Recognizing the importance of energy conservation in decreasing global warming and climate change, Kansas provides assistance to low-income residents to make their homes more energy-efficient through the Kansas Warm Homes project. Volunteers from churches and civic and community organizations distribute energy conservation kits that include plastic window coverings, weather stripping, rope caulking, switch plate insulators, a door sweep, and florescent light bulbs. Volunteers also assist those who are unable to install kits on their own. The Kansas Energy Office of the Kansas Corporation Commission and the Kansas Housing Resources Corporation of the Kansas Development Finance Authority provide funding for the project.

In 2006, the Kansas Department of Transportation won national recognition for its efforts to protect the state's environment through the Kansas Prairie Ecosystem Restoration, Education, and Conservation Initiative. The purpose of the program is to protect endangered tall, mixed, and short-grass prairies that play a major role in preserving the habitats of the state's wildlife.

Although Topeka is the state capital, Wichita is the largest city in the state, in both population and area. Pollution in Wichita comes chiefly from motor vehicles, trains, and industries. City officials established the Air Quality Section of Environment Services to monitor the air quality around the city, perform asbestos inspections at demolition sites, and investigate complaints about air quality and hazardous materials. Kansas City partners with the Mid-America Regional Council to deal with air quality, watershed management, solid waste management, and green infrastructures. Initiatives include raising public awareness, protecting natural habitats, and promoting sustainable growth. In summer 2007, the Kansas City region failed to meet federal regulations established by the Environmental Protection Agency. The city immediately proposed plans to establish new emission controls on power plants, industrial boilers, and idling long-haul trucks. A voluntary initiative was also launched to educate the public about environmental threats posed by driving, painting, and using gas-powered lawn and gardening equipment.

SEE ALSO: Agriculture; Missouri; Oklahoma; Transportation.

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Kazakhstan

KAZAKHSTAN IS LOCATED in Central Asia at the center of the Eurasian continent. With 1.05 million sq. mi. (2.72 million sq. km.), the country is the ninth largest nation of the world, and the largest landlocked country of all. The population of Kazakhstan was 16.7 million in 1990, and the population density of 3.9 people per sq. mi. (6.3 people per sq. km.) is one of the sparsest in the world. 280,200 people live in the capital city of Astana. The city with the largest population is Almaty, with 1,185,900 inhabitants.

The climate is continental; precipitation varies from less than 5.9 in. (150 mm.) in the central desert areas to more than 59 in. (1,500 mm.) in mountainous regions. Average temperatures in January range from minus 0.4 degrees F (minus 18 degrees C) in the north to 27 degrees F (minus 3 degrees C) in the south. Spatially averaged seasonal and annual air temperatures increased about 2.3 degrees F (1.3 degrees C) 1984–97, manifested especially in spring. Four major landscapes are the forest-steppe, steppe, semi-desert, and desert. The river network has had only limited development. However, it is important for irrigation and power generation.

Temperature rises caused the recession of glaciers in the mountains and changed mass water balances from positive to negative, threatening water supply and with it the farming economy and peace of the region, since many rivers are transboundary. Even more dangerous, resulting glacial lakes dammed by unstable moraines drain in an uncontrolled way. One of the most powerful recent debris flows to affect the northern valleys of the Tian Shan occurred in July 1973 in the Malaya Almatinka Valley.

Kazakhstan has about 57,000 lakes and more than 4,000 artificial water reservoirs, some of them drying out, like the Balkash lake and the Aral Sea, with disastrous ecological impacts in the south of the country.

Oil and gas condensate production are the keystone of Kazakhstan economy and amounted to 51.2 million tons in 2003. Kazakhstan holds about 4 billion tons of proven recoverable oil reserves, many of them untapped, and 2,000 cu. km. of gas. Expansion is planned, to produce as much as 3 million barrels (477,000 cu. m.) per day by 2015, lifting Kazakhstan into the ranks of the world's top 10 oil-producing nations. This is why the country received high credits from international organizations. Accordingly sound is the economy, which first went under the typical dynamics of a transition country after the breakdown of the Soviet system. While its gross domestic product (GDP) in purchasing power parity (PPP) amounted to $4,089 per capita in 1990, in 1994 it slid 40 percent to $2,442.

Forests cover 3.75 percent of Kazakhstan's total territory and are not commercially used. The available agricultural land consists of 79,151 sq. mi. (205,000 sq. km.) of arable land and 235,908 sq. mi. (611,000 sq. km.) of land devoted to pastures and hay. Agriculture accounted for 13.6 percent of Kazakhstan's GDP in 2003. Kazakhstan is the sixth-largest grain producer in the world. Wheat, barley, cotton, rice, and livestock, especially sheep-breeding are the most important agricultural commodities. Agricultural land occupies more than 326,642 sq. mi. (846,000 sq. km.).

PROJECTIONS

All General Circulation Models (GCMs) predict an increase in climate aridity, suggesting temperature increases from 7–12 degrees F (4–7 degrees C) under doubling carbon dioxide (CO_2) rates 2050–75. Precipitation change is projected to between a 10 percent decrease to a 20 percent increase, and is expected to be redistributed. Decreased wheat yields and negative impacts on sheep-breeding productivity are expected due to grassland yield decrease and the direct impact of increases in duration of stable hot weather on sheep. Doubled CO_2 levels would reduce water resources by about 20–30 percent in Kazakhstan. In the mountain areas the snow line will rise by 0.3–0.4 mi. (500–700 m.); mudflow activity will increase, with a reduction of the sub-humid zone for grain crop cultivation of about 6–23 percent. UKMO predicts the complete disappearance of the sub-humid zone from Kazakhstan territory.

EMISSIONS

Kazakhstan ranks as the 30th largest greenhouse gas emitter in the world, with per capita emissions of 8.14471 CO_2 equivalents per 1,000 people. It has been demonstrated that the energy share in 2005 was 78 percent, in second place was agriculture (8.4 percent), and the third source of emissions was industrial processes (6.7 percent). The wastes share amounts to 6.9 percent. The percentage share of the contribution of three basic gases with direct greenhouse effects in 2005 was the following: CO_2, 77.4 percent; methane, 17.7 percent; and nitrous oxide, 4.9 percent.

Further sequestering of CO_2 is planned to be achieved by increasing forests to 4.6 percent of land area by 2010 and to 5.1 percent by 2020, which would increase sequestration of about 6,000 Gg. Reducing arable areas on less productive land with simultaneous intensification in others, could sequester up to 674 Gg. Kazakhstan has a huge potential for energy saving in the power sector, especially by energy saving, and increasing energy efficiency, and the share of this sector already substantially decreased.

Adaptation strategies are long-term, market-based and oriented to external development. International assistance is required. Kazakhstan signed the United Nations framework Convention on Climate Change in June 1992 and ratified it in May 1995. In 1997, the government of Kazakhstan supported the World Bank Carbon Initiative on establishment of international carbon credits market and adopted a law on Energy Saving. In March 1999, Kazakhstan signed the Kyoto Protocol as a non-Party to Annex 1 of the UNFCCC and a non-Party to the Kyoto Protocol.

SEE ALSO: Glaciers, Retreating; Oil, Consumption of; Oil, Production of; Salinity.

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Keeling, Charles David (1928–2005)

CHARLES DAVID KEELING was a pioneer of climate science and atmospheric monitoring. Through his work at the Scripps Institution of Oceanography, Keeling constructed the most extensive record of atmospheric levels of carbon dioxide (CO_2) ever produced. Keeling's careful charting of rising concentrations of CO_2 in the Earth's atmosphere served to confirm scientific theories about the impacts of industrialization on the global environment and provided the empirical cornerstone for subsequent analyses of climate change.

Born in Scranton, Pennsylvania on April 20, 1928, Charles David Keeling studied chemistry at the University of Illinois (graduating in 1948), before obtaining his Ph.D. (also in chemistry) from Northwestern University in 1954. His move into atmospheric studies was confirmed in 1956, when the Scripps Institution of Oceanography recruited him to work on a new research program exploring the complex links between CO_2, global warming, and ocean systems. Keeling's initial work at Scripps was guided by the oceanographer Roger Revelle, who at the time was the director of the Institution of Oceanography. As an early advocate of the theory of an enhanced greenhouse effect, Revelle's work proved that the heightened levels of CO_2 produced by industrial society would not be absorbed, to any significant extent, by the oceans. This observation brought in to question the conventional wisdom of the early post-war period that anthropogenic CO_2 would be absorbed by ocean systems, plant-life, and other carbon cycle sinks, thus maintaining the global atmospheric balance of CO_2. It was, however, the assiduous work of Charles David Keeling that would confirm this crucial scientific theory.

Following his arrival at Scripps, Keeling worked to establish the necessary monitoring sites and equipment that would facilitate the accurate measurement of global atmospheric ratios of CO_2. With the support of the Environmental Sciences Services Administration of the U.S. government, Keeling was able to collect research data from two remote, pristine air locations: the Mauna Loa Observatory, Hawaii, and a monitoring station established at the South Pole. The use of pristine air-monitoring locations was crucial to Keeling's work. The fact that the Mauna Loa and South Pole monitoring stations were located at great distances from major local anthropogenic and biotic sources of CO_2 meant that they could provide accurate measurements of global changes in atmospheric CO_2 concentrations (although the Hawaii station was subject to occasional spikes in CO_2 created by local volcanic activity and vegetation).

In addition to securing the sites necessary to monitor global fluctuations in atmospheric CO_2, Keeling was also involved in developing the techniques and instruments that were needed to actually measure CO_2 in the atmosphere. The method deployed by Keeling for measuring air-borne CO_2 involves passing air through an aluminum tube using a diaphragm pump, and then forcing the air through a filter, to remove water vapor, after which an infrared analyzer tests the air sample. The assiduous monitoring of atmospheric CO_2 at Mauna Loa and the South Pole by Charles David Keeling and his colleagues 1958–2005 provided fascinating hourly, daily, and seasonal records of CO_2 fluctuations. It was, however, only when the biannual concentrations of atmospheric CO_2 were plotted over a longer time that the dramatic implications of Keeling's work become apparent. The so-called Keeling Curve that emerges from such a time-sequenced data plot reveals the inexorable rise of CO_2 in the atmosphere from 1958 to the present day. In discussing the ominous simplicity of the Keeling Curve, Michael McCarthy recently described it as one of the key images in human history.

Beyond his contribution to assessments of the changing fractions of CO_2 present in the atmosphere, Charles David Keeling took a holistic interest in the operation of the carbon cycle and the broader problems associated with air pollution. In relation to the carbon cycle, Keeling was at the forefront of attempts to accurately model the flow of carbon and show its changing seasonal patterns. His interest in the carbon cycle also led him to conduct detailed studies of the processes that determine the rate of, and levels of CO_2 that can be absorbed in seawater, while also hypothesizing about the role of plants in the removal of excess CO_2 from the atmosphere. In an address to a symposium on atmospheric pollution in 1969, Keeling reflected on the likely implications of global warming for human populations, while also highlighting the ongoing dangers associated with traffic pollution and urban smog. His combined interest in CO_2, atmospheric geochemistry, and the carbon cycle are expressed throughout his numerous publications.

Charles David Keeling's role as a pioneer of science and an advocate of environmental care and protection resulted in him receiving a number of awards and honorary positions. During his career, Professor Keeling was Guggenheim Fellow at the Meteorological Institute, University of Stockholm and scientific director of the World Meteorological Organization's Central CO_2 Calibration Laboratory. In 2002, he received the U.S. National Medal of Science, and in April 2005, he was awarded the Tyler Prize for Environmental Achievement. Charles David Keeling died on June 20, 2005 in Hamilton, Montana.

SEE ALSO: Carbon Dioxide; Climatic Data, Instrumental Records; Revelle, Roger; Scripps Institution of Oceanography; Seasonal Cycle; World Meteorological Organization.

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Kentucky

THE COMMONWEALTH OF Kentucky is known chiefly for producing horses, tobacco, whiskey, and bluegrass music. The state's coalfields, wetlands, waters, and forests are valuable resources, but they present unique environmental concerns that affect global warming and climate change. Forests and agricultural lands are regularly converted for industrial use, destroying habitats that are essential in protecting the state's ecosystems. Fuel-fired power plants pose a major threat to health and the environment. Kentucky borders seven states: Tennessee, Virginia, West Virginia, Missouri, Illinois, Indiana, and Ohio. Because of this, Kentucky's environment has a significant impact on a large area beyond its own borders.

STEPS TO REDUCE GLOBAL WARMING

The key element in Kentucky's environmental initiatives is educating the public and businesses, teaching residents about the ways in which specific behaviors make Kentucky more vulnerable to global warming and climate change. In 1992, Kentucky began tracking and reporting on 100 indicators involved in protecting the environment. The reports have been instrumental in passing environmentally-friendly laws, forcing state agencies to set environmental policy priorities, and holding the government accountable when they fail to protect Kentucky's environment.

The chief responsibility for reducing activities that increase global warming and climate change in Kentucky is assigned to the Department for Environmental Protection (DEP), which houses the Division for Air Quality, the Division of Environmental Services, the Division of Waste Management, and the Division of Water. The Environmental Services Division supports the DEP in ensuring compliance with state and federal guidelines in underground storage tanks, groundwater, superfund sites, toxic emission control, rivers, lakes, and streams. Additional responsibilities for Kentucky's environment are divided among the Department of Agriculture, the Governor's Office of Agricultural Policy, the Office for Consumer and Environmental Protection, the Environmental Education Council, the Environmental and Public Protection Cabinet, the Environmental Quality Commission, the Department for Natural Resources, the Natural Resources and Environmental Protection Cabinet, and the State Nature Preserves Commission.

Kentucky is ranked 26th in the United States in terms of population. The capital of the commonwealth is Frankfurt, but population and industry are centered in the Louisville-Jefferson County and

Lexington-Fayette County areas. The population of Kentucky increased by 10 percent 1990–2001. During that same period, carbon dioxide (CO_2) emissions rose by 30 percent, reaching a total of 152.2 million metric tons. Kentucky is ranked 13th in the United States in CO_2 emissions. Initiatives targeting this problem have resulted in a 6 percent rise in carbon dioxide efficiency.

In 2007, in the largest settlement resulting from violations of the federal Clean Air Act's acid rain program, East Kentucky Power Cooperative was required to pay at least $11.4 million in penalties for emissions violations generated by coal-fired power plants. These emissions included more than 15,000 tons of sulfur dioxide and 4,000 tons of nitrogen oxide emitted 2000–05. East Kentucky was also ordered to reduce toxic emissions by 400 tons annually, and to offset 20,000 tons of emissions that had been generated at two Dale Generating Stations units that were operating without acid rain permits. The company was ordered to install control technology to reduce nitrogen oxide (NOx) emissions at both units.

Eight states and New York City have filed suit against corporations with documented records of contributing significant amounts of pollutants that lead to global warming and climate change. American Electric Power Company, Inc./American Electric Power Service Corporation, which controls Kentucky Power, is number one on that list because it generates an estimated 226 million tons of CO_2 emissions each year. The Tennessee Valley Authority and Cinergy, which own and operate Kentucky fuel-fired power plants that respectively produce an estimated 110 million tons and 70 million tons of CO_2 emissions annually, are third and fifth on the list of companies involved in the lawsuit.

Pollution in the agricultural sector is addressed through the Kentucky Environmental Quality Incentives Program, which offers financial help and technical assistance to farmers who engage in conservation practices. Under the direction of the Natural Resources Conservation Service of the U.S. Department of Agriculture, EQIP provides funding for reducing soil erosion, improving water quality, animal waste management, wildlife management, and targeting watersheds and regions of particular environmental sensitivity.

Conscious of the impact of transportation and industries on global warming and climate change, the Louisville Metro Government, the University of Louisville, and Jefferson County Public Schools have formed the Partnership for a Green City to coordinate environmental efforts. The organization is focused on changing behaviors that threaten the environment, encouraging environmentally friendly transitions, and promoting environmental sustainability within communities.

The Kentucky Environmental Council publishes *Land, Legacy, and Learning: A Master Plan for Environmental Education in Kentucky* to raise public awareness of the effects of global warming and climate change on Kentucky. Since the first edition was released in 1999, Kentucky has required all teacher preparation programs to include environmental education and has provided specialized training for advanced environmental training. Specific recommendations in the publication are aimed at pressuring the state to provide basic environmental information to all residents of Kentucky. Specific activities inspired by the publication include the launching of a five-year project in 2004 designed to promote improved water quality through individual behavior.

The Commonwealth of Kentucky encourages controlling pollutants that accelerate global warming and climate through the KY Excel Program, a voluntary leadership program. The goal of this program is to promote cooperation among individuals, state and local government, and the business community by recognizing significant efforts made toward environmental progress in Kentucky. Members are required to conduct at least one environment-related project each year in the fields of conservation, education, energy efficiency, financial support, mentoring and technical assistance, performance improvement, public health, restoration, and waste reduction. Specific projects have dealt with promoting plans to get motor vehicles off the road through carpooling, walking, and biking; encouraging the use of vehicles that use alternative fuels; taking showers instead of tub baths; cleaning up dump sites; and collecting and recycling wastes.

In an effort to reduce toxic emissions from fuel-fired power plants, Kentucky announced in 2006 that it had applied for a cutting-edge billion-dollar FutureGen Project to build the first coal-fueled power plant with near-zero emission capability. The plan calls for the plant to generate electricity by capturing and storing electricity in geological formations. Hydrogen and byproducts produced by the plant are to be used by other industries in the state. The FutureGen Alliance, which oversees the project, will use the plant as a global research facility on clean coal technology and advanced energy development.

SEE ALSO: Agriculture; Education; Energy; Transportation.

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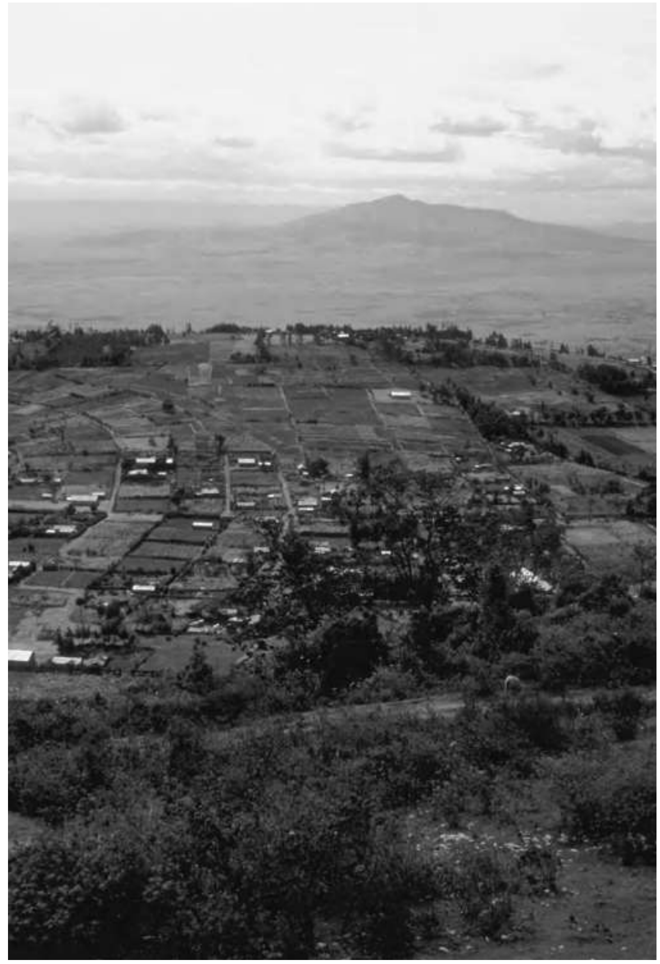
Kenya

THE REPUBLIC OF Kenya remains the center for east African trade and finance and is a world-renown destination for tourism. It is also beset by multiple, interrelated environmental concerns, including climate change, a rapidly growing human population, and a significant decline in flora and non-human fauna.

Straddling the Equator, Kenya is comprised of 225,000 sq. mi. (582,650 sq. km.) of diverse landscapes. These include wide, sandy beaches and coral reefs along the Indian Ocean coast in the southeast; the eastern African plateau and its semi-arid plains; the Rift Valley, with freshwater and saltwater lakes surrounded by fertile uplands; northern deserts flanked by Sudan, Ethiopia, and Somalia; southern grasslands that blend into neighboring Tanzania; and, in the west, a portion of Lake Victoria, as well as densely farmed highlands that run partly along the border with Uganda. Mt. Kenya's glacier-capped peaks top out at 17, 057 ft. (5,199 m.) above sea level, making it the second tallest mountain in Africa after Tanzania's Mt. Kilimanjaro.

Over the past century, both Mt. Kenya and Mt. Kilimanjaro have experienced marked recessions in the thickness of their glaciers, as well as the output of melt water absorbed by other landscapes and their inhabitants.



While nearly 75 percent of Kenya's labor force is engaged in agriculture, more than 80 percent of the land is arid or semi-arid.

According to the Intergovernmental Panel on Climate Change, sub-Saharan Africa is most vulnerable to projected changes due to global warming because widespread poverty and reliance on small-scale, rain-fed agriculture limit adaptation capabilities. Kenya has a population of 35 million, over half of whom live below the international poverty line. Although tourism and manufacturing contribute significantly to the Gross Domestic Product, the Kenyan economy relies heavily on export-oriented agriculture, with chief cash crop exports including water-intensive and climate-sensitive cut flowers, tea, and coffee. Nearly 75 percent of Kenya's labor force engages in agriculture and livestock production. More than 80 percent of Kenyan land is classified as arid or semi-arid, and 30 percent of its population and more than half of its livestock reside there. Only 5–8 percent of Kenya's land is considered suitable for horticulture. Other Kenyan exports include cement, petroleum products, and fish. The expanding industrial sector of Nairobi is home to a number of multinational corporations. Emissions standards are variably enforced.

Periods of drought and flooding have been typical across millennia in East Africa. Still, scientists note that human-induced climate change has led to erratic rainfall and land transformations that, since Kenya's independence in 1963, have been record-setting in terms of the severity of their impacts. Since 1963, Kenya's population has doubled twice, and the concomitant pressures on land, flora, and fauna are exacerbated by drought and flooding. Thus, climate change, along with population growth and a reduction in farmland and grazing land, is closely connected to armed conflicts. Efforts by 2004 Nobel Laureate Wangari Maathai and the Greenbelt Movement emphasize the link between environmental issues and peaceful governance.

From Kenya's agricultural base to national parks and reserves, there are likely to be substantial shifts in species diversity and community composition. The first sub-Saharan African country to do so, Kenya hosted the 2006 United Nations ministerial conference on climate change, comprised of the 12th Conference of the 189 Parties to the UN Framework Convention on Climate Change, and the 2nd Meeting of the 166 Parties to the Convention's Kyoto Protocol.

SEE ALSO: Drought; Floods; Intergovernmental Panel on Climate Change (IPCC); Kyoto Protocol; Population; Tourism.

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Kiribati

THE REPUBLIC OF Kiribati consists of 33 atolls in three island groups: the Gilbert, Phoenix, and Line groups, located between 1 degree north longitude and 173 degrees east latitude. The land area of 313 sq. mi. (810.5 sq. km.) is scattered over 1.4 million sq. mi. (3.5 million sq. km.) of Exclusive Economic Zone (EEZ), extending 2,485 mi. (4,000 km.) from west to east and about 1,243 mi. (2,000 km.) from north to south. The natural resource endowment is poor. Only Banaba is volcanic; the other 32 islands are low-lying coral atolls with soils of very poor quality and not useful for agricultural production. Soils are highly alkaline, calcareous, and shallow, with low water-holding capacity, little organic material, and few available nutrients. Drinking water is received from slightly brackish freshwater lenses, which collect rainwater and are part of the porous surface. With a growth rate 1995–2000 of 1.8 percent per year, an estimated 97,000 people lived in Kiribati in 2007.

Kiribati is facing increased urbanization, with densities of up to 2,581 people per sq. mi. (1,600 people per sq. km.) in Betio, Tarawa. Urbanization is problematic when considering a lack of infrastructure, especially regarding fresh water supply, sewage, and sewer options. Sea-level rise and the increased occurrence of high tidal waves has forced people to move away from lagoon and ocean-side coastal proximity, which is difficult on urban South Tarawa, where population pressures force people to live in closer proximity. As one of the consequences, people have built stone walls for protection. Coastal erosion has increased because of stone walls manipulating wave movements. This is similar to the effect of the construction of causeways. Sand extraction, which is needed for buildings and facilities, accelerates these effects.

With increased urbanization, families are also faced with changes in land tenure, which can cause cultural tension when considering that coastal erosion and sea level rise have led to different allocations, mainly land loss. The Kiribati government has repeatedly called on the international community to address the issue of climate change as, together with other low-atoll environments in the Pacific, Kiribati is threatened by sea-level rise. Kiribati, as well as Tuvalu, depends on international political empathy. There is fear that, in the future, the people of Kiribati could become environmental refugees. Existing migration schemes for Kiribati are small, with strongest links to Australia and New Zealand that allow only a limited number of people to temporarily migrate on a Pacific Access Category.

SEE ALSO: Australia; Global Warming; New Zealand; Salinity; Sea Level, Rising.

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Korea, North

THE DEMOCRATIC PEOPLE'S Republic of Korea (DPRK) is located in the northern part of the Korean peninsula, which lies between 33 and 43 degrees N, and extends southward in to the northeastern Asian continent. North Korea is a transitional zone between the continental landmass of Asia and the island arc rimming the western Pacific Ocean. About 80 percent of North Korea is mountainous or hilly. Elevations are generally low, because the mountain ranges have been subject to long-term erosion, with relatively stable tectonic movement. A number of high altitude—2,625–3,281 ft. (800–1,000 m.)—plateaus are found in the northeastern and eastern part of North Korea. Mountain ranges drop abruptly toward the East Sea with little coastal plain. Some extensive lowlands are found mainly at the mouths of rivers flowing into the Yellow Sea.

Its peninsular configuration and mid-latitudinal location lead continental influence on the East-Asian monsoon climate of North Korea. North Korea's climate is regarded as a continental climate from a temperature standpoint, and a monsoon climate from a precipitation standpoint. The climate of North Korea is characterized by four distinct seasons. Summer is sultry because of the hot and humid airflow from the North Pacific high pressure, while winter is bitterly cold due to the influx of cold, dry northwesterly winds from Siberian high pressure. The average annual temperature is between 46–54 degrees F (8–12 degrees C), with great regional and seasonal variations in temperature. The lowest annual average temperature and the greatest annual temperature range are found in the northeastern interior mountainous regions. Annual average precipitation is 41.5 in. (1,054 mm.). A noticeable seasonal variation in precipitation is, however, found because of the monsoon climate. About 60 percent of annual precipitation is concentrated from June to August. Winter is dry; less than 10 percent of annual precipitation occurs in winter. Heavy snowfalls are common in the northern, mountainous regions.

Few studies have been done on climate change in North Korea, because access to weather data and other climatic information is limited. A gradual increase in mean temperature is, however, reported over the last century and this warming trend is significant. Recent global warming is responsible for a substantial increase in the frequency and intensity of natural disasters, such as severe droughts in spring and regional heavy rainfalls in summer since the late 1980s. Human mortality from the growing numbers of natural disasters is substantial. In July 2006, Typhoon Bilis brought 19.6 in. (500 mm.) of rainfall in one day. Subsequent widespread devastation caused by floods and landslides caused thousands of deaths, and damage to both the natural and human environments. In North Korea, recent climate change and the ensuing reduction in total agricultural production have induced widespread starvation and prevalent epidemic diseases. Climate change models predict that global warming will increase temperatures in North Korea by 3.6–7.2 degrees F (2–4 degrees C), and precipitation 20–30 percent by 2050. Seasonal concentration of precipitation will be even more intensified; there will be a greater increase in winter precipitation, and severe spring and early summer drought.

SEE ALSO: Diseases; Floods; Monsoons.

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Korea, South

THE REPUBLIC OF Korea is located in the southern part of the Korean peninsula and associated islands that lie between 33 and 43 degrees N and extend southward into the northeastern Asian continent. Its peninsular configuration as an appendage of the Asian continent and mid-latitudinal location lead the continental influence on the East Asian monsoon climate of South Korea. South Korea has four distinct seasons. In summer, a hot, moist climate dominates South Korea, which is located in the western flank of the North Pacific high pressure system, while cold, dry northwesterly winds from the Siberian high pressure system take over the winter climate. In the transition periods of spring and fall, clear, pleasant weather occurs more frequently and the land-sea breeze becomes dominant with weakened monsoon wind.

The average annual temperature and the annual temperature range are 54 degrees F (12.3 degrees C) and 78.6 degrees F (25.9 degrees C), respectively. The lowest annual average temperature is found in the northeastern interior mountainous regions, while the highest occurs in Cheju Island, located in the South Sea. The temperature range is also much greater in the northeastern interior mountainous regions than in the south and along the coasts. These temperature patterns show influence of latitude, altitude, and the continent on temperature distribution. Summer is hot, with very little regional difference in temperature, while winter is very cold, but has great regional variation in temperature. The mean temperature of warmest month and coldest month is 76.8 degrees F (24.9 degrees C) and 30 degrees F (minus 1 degree C), respectively.

South Korea is a region of abundant precipitation, with an annual average precipitation of 51.5 in. (1,310 mm.). A noticeable seasonal variation in precipitation is, however, found because of the monsoon climate. In summer, heavy rainfalls are accompanied by a Changma front, a quasi-stationary front extending from Japan through Korea into southeastern China, and tropical cyclones are substantial and represent approximately 70 percent of annual precipitation. Heavy regional showers, often exceeding 12 in. (300 mm.) of rainfall in a day, or sometimes more than 32.5 in. (800 mm.), also characterize summer rainfall. As in much of Asia, winter in Korea is dry. Less than 10 percent of annual precipitation occurs in winter. Heavy snowfall is found on islands and in the eastern coastal regions. The spatial distribution of annual mean precipitation generally increases southward, but its spatial pattern is complicated because of complexity of topography.

Over the last century, a gradual increase (2.8 degrees F, or 1.6 degrees C, over 100 years) in mean temperature has continued, but a warming trend has become even more significant since the 1980s. The mean winter temperature has drastically increased, while no distinct increase in mean summer temperature is found. Both diurnal and annual temperature ranges, however, have been significantly reduced due to the noticeable increase in minimum temperatures. Since the late 20th century, considerable decrease in the frequency of frost days in spring and autumn has extended growing season length. The frequency and duration of heat waves and warm nights have notably increased. Although a gradual increase of annual precipitation is found, there is some controversy about the temporal trend of annual precipitation because of its considerable variation. Along with a gradual increase in annual precipitation, a significant decrease of annual rain days results in the increased rainfall intensity once rain occurs. The frequency of severe drought has also increased, especially in the southern part of South Korea.

Global warming is poised to substantially change both natural and human environments in northeast Asia. The environmental impacts of global climate change in South Korea include changes in average temperature, changes in precipitation and in the frequency and severity of storms, changes in the distribution of ecosystems, and changes in the socioeconomic environment. The frequency of weather disasters has decreased during the last 10 years, but their intensity and duration has significantly increased, as have human mortalities and economic damages. The South Korean climate is gradually turning from a warm temperate climate into a subtropical climate. Recent warming trends enable many broad-leaved evergreen tree species to grow near their northern range limit. Changes in the maritime environment are also noticeable. Due to the change in ocean circulation near the Korean peninsula, a large number of new warm water fish and other marine organisms have been identified, and their northern limit has extended northwards. Changing patterns of temperature and rainfall have caused a shift in the distribution of disease-carrying mosquitoes. The occurrence of epidemics, such as malaria and hantavirus pulmonary syndrome, has increased. In particular, malaria reappeared in the mid-1990s, after its disappearance for two decades.

SEE ALSO: Floods; Korea, North; Monsoons.

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Kuroshio Current

THE KUROSHIO CURRENT is the second largest ocean current in the world, and flows in the western Pacific from the east coast of Taiwan island, northwards to Japan, and then beyond Hokkaido past the Kuril Islands, where it merges with the North Pacific Current. In many ways, it is similar to the Gulf Stream in the Atlantic Ocean, which also carries warm tropical waters toward the polar region. The Japanese call it the Kuroshio Current, with some early English geographers translating this to the Black Stream, the name coming from the deep blue of the water; a few writers referring to it as the Japan Current. A branch of the Kuroshio Current, known as the Tsushima Current, passes through the Tsushima Straits between Japan and Korea, into the Sea of Japan.

The warm waters of the Kuroshio Current are largely responsible for the abundance of coral reefs off the east coast of Japan, bringing coral reef larvae from other coral reefs in the South China Sea and off the coast of the Philippines. As a result, the coral reefs off Japan are the northernmost coral reefs in the world; the waters off the coast of Japan are as warm as 68 degrees F (20 degrees C) off the Ryukyu Islands, and even reach 60 degrees F (16 degrees C) in winter off the southern coast of Honshu Island. It has been the center of the Japanese fishing industry since prehistoric times. Since the 1940s, there has been a significant decline in the fish in the Kuroshio Current; this can be attributed to over-fishing, or to global warming and climate change since the 1960s. In 1988, studies of the coral reefs showed heavy coral bleaching, which resulted in the deaths of many of the reefs. The pressure of population, with some waste dumped in the sea, has been a major contributory factor, as well as the rise in temperature of the Kuroshio Current.

This rise in temperature is the major actor in coral bleaching off the Osasawara Islands, which have 460 hectares of coral reefs, especially around Muko, Chichi, and Haha Islands. These losses cannot be simply attributed to overpopulation. The local fishing industry has been unable to sustain itself by fishing in Japan's territorial waters, leading to increasing numbers of Japanese fishing and whaling ships operating throughout the Pacific. Between 1993 and 1998, the fishing catch off Okinawa dropped by 21 percent. Off the Ryukyu Islands, although the number of fish has increased, the species diversity has dramatically fallen. The worst losses in coral reefs have occurred near Okinawa, where overpopulation has led to pollution. An aerial survey by the Environment Agency of Japan 1990–92 revealed that some 90.8 percent of the coral communities near Okinawa had less than 5 percent cover. In summer 1998, some 97 municipalities reported bleaching of coral reefs in their communities, especially of the Acropora species, which appears the worst affected.

SEE ALSO: Gulf Stream; Japan; Oceanic Changes.

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Kuwait

KUWAIT LIES ON the Arabian Gulf; its geography is made up of mostly flat desert on the mainland, and nine islands off the coast, some marshy and uninhabited. The climate of Kuwait can be extreme, with temperatures ranging from very cold to very hot, although the average annual temperature is 91 degrees F (33 degrees C). The highest temperature ever recorded was 126 degrees F (52 degrees C) in July 1978. The long, dry summer extends May through October, with August the hottest month, having an average temperature of 112 degrees F (44 degrees C). The winters are mild, with January the coolest month, with an average temperature of 45 degrees F (7 degrees C). Rain storms may occur, and the wind may cause dust storms.

Despite the harshness of the environment, Kuwait supports more than 2 million people. With valuable oil fields estimated at 10 percent of world oil reserves, or 99 billion barrels, the major industries revolve around oil (including refining, marketing, and distribution). Kuwait's poor, dry soil means less than 1 percent can be used for farmland. Kuwait is one of at least 11 countries consuming more than 100 percent of their renewable water resources, though the water is reportedly free of water-borne pathogens. Limited fresh water means desalination plants are needed to supply fresh water. These plants require energy to heat the salt water to boiling and energy to provide cooling to condense the steam into fresh water droplets.

In March 2005, Kuwait ratified the Kyoto Protocol (an international and legally binding agreement to reduce greenhouse gas emissions worldwide, which took effect on February 16, 2005). It took effect in Kuwait's entry in June 2005. As a participant in the United Nations Framework Convention on Climate Change, Kuwait is responsible for providing national communication, including assessment of potential impacts of climate change. To meet this challenge, the Environment Public Authority (EPA), with an administrator appointed by the Council of Ministers, oversees environmental testing and education for voluntary programs. In addition, the EPA acts in a resource capacity. It advises federal and governmental policy makers on developing regulations and has authority to enforce the regulations provided within Kuwait's environmental laws through monitoring and compliance enforcement.

As an oil producer, Kuwait contributes to global emissions. Kuwait experienced the effects of human-induced climate change following the Gulf War; Iraqis set oil wells on fire while retreating. The fires burned an average of 5 million barrels of oil, and 70 million cubic meters of gas per day, producing emissions of carbon dioxide (500,000 tons per day) and sulfur dioxide (40,000 tons per day). In addition to emissions, the regional climate impact from smoke caused the surrounding areas to cool (between 10 and 20 degrees) and damage to the land allowed the wind to blow away eroded soil. Future impacts from climate change may include: changes in the coastline, a decline in the water supply that is already poor, and an increase in temperatures causing higher incidence of heat stress. It may also impair air quality, primarily through increases in ground-level ozone pollution in heavily populated urban areas.

SEE ALSO: Oil, Consumption of; Oil, Production of; Salinity.

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Kyoto Mechanisms

UNDER THE KYOTO Protocol to the United Nations Framework Convention on Climate Change (UNFCCC), industrialized countries committed to reduce their greenhouse gas emissions by an average of minus 5.2 percent relative to their 1990 level emissions by 2008–12. To assist countries in attaining these reduction targets, the protocol created three flexible mechanisms. These mechanisms allow countries with reduction commitments to achieve their targets by acquiring credits from emissions reduced or avoided in other countries, where it may be more cost-effective to do so. The three mechanisms of the Kyoto Protocol are: Emissions Trading, Joint Implementation, and the Clean Development Mechanism. In this way, a country or a private or public entity within a country that reduces or avoids emissions more than it is required, may sell its emission reductions as credits to another country or entity that has not reduced its own emissions. Because greenhouse gases, in contrast to local pollutants, are uniformly distributed in the atmosphere within a week, it does not matter where the source of emissions is located. However, the cost of reducing or avoiding emissions may vary greatly.

Only countries with emission reduction targets under the protocol have "quantified emission limitation and reduction commitments," known as QELRCs, calculated and quantified as an "assigned amount." The total amount of emissions that each country with QELRCs can release 2008–12 (the first commitment period) must not exceed its assigned amount. Because emissions fluctuate from year to year, depending on the weather and economic cycles, an average over several years was chosen to check compliance with the reduction commitments. These are restrictions on a country's level of emissions, based on voluntarily adopted targets that collectively amount to a slightly more than 5 percent reduction relative to emissions in 1990. If a party exceeds its reduction target by cutting back on its emissions more than the amount specified in its QELRCs, it might sell its excess units or, under some circumstances, carry them over to the next commitment period. The QELRCs cover emissions of six greenhouse gases including: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), Hydrofluorcarbons (HFCs), Perfluorocarbons (PCFs), and Sulfur hexafluoride (SF_6).]

A total of 39 countries have QELRCs, and they are listed in Annex B of the protocol with their respective targets. They are referred to as Annex I parties because they are also listed in Annex I of the UNFCCC, including: Australia, Austria, Belgium, Bulgaria, Canada, Croatia, Czech Republic, Denmark, Estonia, European Community, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Liechtenstein, Lithuania, Luxembourg, Monaco, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Slovakia, Slovenia, Spain, Sweden, Switzerland, Ukraine, United Kingdom, and United States. The European Community as a group is also a party, and the countries that compose it have internally redistributed their assigned amounts to collectively achieve their targets. The United States and Australia have not ratified the protocol, even though they agreed to specific reduction targets like the other Annex I parties did in 1997 when the protocol was adopted. Therefore, they are parties to the UNFCCC, but are not parties to the Kyoto Protocol and cannot participate in its mechanisms.

Because global warming is a result of accumulated emissions in the atmosphere, and non-industrialized countries have historically contributed little to the problem, developing countries do not have reduction commitments under the protocol. This is inscribed as one of the fundamental principles of the UNFCCC, which acknowledges that countries should act "in accordance with their common but differentiated responsibilities and respective capabilities and their social and economic conditions." It was therefore agreed that industrialized countries, which have greater responsibility and capability, should take the lead in reducing emissions.

ACCOUNTING UNDER FLEXIBLE MECHANISMS

The Kyoto Protocol does not bestow any "right, title or entitlement" to emit, and requires that domestic action constitute a "significant element" of Annex I parties' efforts to achieve their reduction targets, with the use of mechanisms only "supplemental to domestic action." To ensure that emission reductions bought and sold through the flexible mechanisms are measurable and real, the protocol establishes specific rules and accounting procedures for each of the flexible mechanisms. Emission reductions under any of the three flexible mechanisms generate a specific kind of unit that may be added to or subtracted from a party's assigned amount. Each unit is equal to one metric ton of emissions. All units are fungible, but have different names so they can be traced in the International Transaction Log, kept by the UNFCCC secretariat.

Under Emissions Trading, Annex I parties may trade assigned amount units (AAUs) issued on the basis of their assigned amount, or Removal Units (RMUs) issued on the basis of land use, land-use change, and forestry (LULUCF) activities (also known as carbon sinks), with other Annex I parties. They may also trade units acquired under the other flexible mechanisms. Because trading in emissions may be highly profitable, and given that enforcement of compliance under an international environmental regime could be weak, countries agreed to maintain in their inventories a certain level of credits, called the commitment period reserve. Emissions-trading is set out in Article 17 of the Kyoto Protocol.

Joint Implementation (JI) refers to credits acquired from projects that reduce or avoid emissions or enhance removals by sinks undertaken mainly in countries with economies in transition (EITs), namely central and eastern European countries that were part of the former Soviet Union. These countries are also Annex I countries, and have reduction commitments under the protocol. Credits traded under JI are recorded as Emission Reduction Units (ERUs). Because both parties involved in the transaction have reduction commitments and are therefore required to report on their overall level of emissions, the rules applied are less complicated than for Clean Development Mechanism (CDM) projects, where the host country has no reduction commitments. The basic principles of JI are defined in Article 6 of the Kyoto Protocol.

The CDM is similar to Joint Implementation in that both involve undertaking specific project activities. However, the CDM allows countries with reduction commitments to invest in a developing country in projects that reduce or avoid emissions, or enhance removals by sinks, and to use the resulting credits to meet its commitments. The CDM, therefore, is the only mechanism with a worldwide reach, and its purpose is twofold: to contribute to sustainable development in developing countries, and to make it easier for countries with reduction commitments to achieve their targets. The CDM is supposed to orient the future development of the less industrialized countries down a more sustainable path, and to prepare developing countries to contribute to mitigation without undertaking binding commitments.

The credits acquired under the CDM are called Certified Emissions Reductions (CERs). If resulting from afforestation and reforestation projects (the only two sink activities allowed), they are either temporary or long-term CERs (tCERs or lCERS). A levy of 2 percent of the number of CERs issued for every project is to go to an adaptation fund for vulnerable countries. Projects undertaken in the Least Developed Countries (LDCs), as well as small-scale projects, are exempt from this levy. Because the market offer is potentially unlimited, and developing countries have no reduction commitments, both seller and buyer have an incentive to inflate the emission reductions achieved. Therefore, to ensure transparency and accountability, the mechanism is subject to control by the CDM Executive Board, which, in turn, responds to the governing body of the Kyoto Protocol, the Conference of the Parties serving as the Meeting of the Parties (COP/MOP).

To participate in the mechanisms, Annex 1 parties must meet certain eligibility requirements. These include: ratifying the protocol; calculating their assigned amount; having a national system for estimating emissions and removals of greenhouse gases within their territory; putting in place a national registry to record and track the creation and movement of tradable units; and reporting annually on emissions and removals to the UNFCCC secretariat. The Facilitative Branch of the Compliance Committee oversees conformity with these requirements. Most of the rules and modalities that govern the mechanisms were established in a package of decisions known as the Marrakesh Accords, which resulted after many difficult political issues were agreed on in Marrakesh in 2001. They were adopted, along with the Kyoto Protocol, at the first session of the COP/MOP in Montreal in December 2005.

SEE ALSO: Clean Development Mechanism; Emissions Trading; Framework Convention on Climate Change; Kyoto Protocol.

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Kyoto Protocol

WHEN THE GOVERNMENTS adopted the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCC), it was quite obvious that its commitments would not be sufficient to seriously tackle climate change. At Conference of the Parties (COP) 1 (Berlin, March/April 1995), in a decision known as the Berlin Mandate, parties therefore launched a new round of talks to decide on stronger and more detailed commitments for industrialized countries. After two and a half years of intense negotiations, the Kyoto Protocol was adopted at COP 3 in Kyoto, Japan, on December 11, 1997. The Kyoto Protocol was open for signatures on that day and took effect on February 16, 2005. As of June 2007, 172 countries have ratified the protocol and the treaty expires in 2012. But some of the major countries such as the United States and Australia have not ratified the Kyoto Protocol. Big, developing countries such as India and China are part of the protocol, but are not required to cut back any emissions under this treaty (based on the rationale that developing countries should be given a chance for development). This has made the treaty controversial and, so far, the targets have not been fixed. This is based on the principle of common, but differentiated responsibilities, as most of the emissions to be reduced (or blamed for today's climate change) were produced historically (during the industrialization era when most the developing countries did not produce emissions) or originate in developed countries. Per capita emissions in developing nations are still relatively low compared to the developed nations, and the share of global emissions originating in developing countries will grow to meet their developmental and growth needs.

The United States argued that the developing countries should also be bound by limiting their emissions, but the Protocol did not impose any restrictions on them. Developing countries, on the other hand, felt that their development was hampered because the colonial powers prevented their development by exploiting their natural resources and selling their finished products to the developing countries hence preventing development of industry there. Now that they are free to carry on their development, no limits should be imposed on their emission levels, because of their heavy dependence on fossil fuel. Another point of difference between the developed and developing nation was whether to consider the absolute value of emissions or the per capita value—there is a great difference between the two sides, and hence, the controversy still persists.

HISTORICAL MILESTONE

The Kyoto Protocol is a historical milestone, as it is the first international agreement to set targets to reduce greenhouse gas emissions to tackle climate change. The Protocol sketches out the basic features of its mechanisms and compliance system, but did not flesh out the all-important rules of how they would operate. The 1997 Kyoto Protocol shares the UNFCCC's objectives, principles, and institutions, but significantly strengthens the UNFCCC by setting targets to limit green house gases. Under the protocol the signatory countries are divided into two categories: Annex I and Non-Annex parties. Annex I Parties are committed to individual, legally-binding targets to limit or reduce their greenhouse gas emissions. The targets cover emissions of the six main greenhouse gases, namely: Carbon dioxide (CO_2); Methane (CH_4); Nitrous oxide (N_2O); Hydrofluorocarbons (HFCs); Perfluorocarbons (PFCs); and Sulphur hexafluoride (SF_6). It was agreed that developed countries would jointly reduce their net emissions (emissions from sources minus removals by sinks) of these six greenhouse gases by 5.2 percent in the period 2008–12 in relation to emission levels in 1990. The Protocol does not list separate targets for each individual gas but instead a combined target for all the gases, expressed in CO_2 equivalence. On the other hand Non-Annex countries do not have obligations to reduce or limit the greenhouse gas emissions but can voluntarily do so.

The maximum amount of emissions (measured as the equivalent in CO_2) that a Party may emit over the commitment period, in order to comply with its emissions target, is known as a Party's assigned amount. To achieve their targets, Annex I Parties must put in place domestic policies and measures. The Protocol provides an indicative list of policies and measures that might help mitigate climate change and promote sustainable development. Parties may offset their emissions by increasing the amount of greenhouse gases removed from the atmosphere by carbon sinks in the land use, land-use change and forestry (LULUCF) sector. However, only certain activities in this sector are eligible. These are afforestation, reforestation and deforestation (defined as eligible by the Kyoto Protocol) and forest management, cropland management, grazing-land management and revegetation. The main objective behind these reductions (as pointed out in UNFCC) is to stabilize the concentration of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate change.

THE THREE MECHANISMS

The Protocol also establishes three innovative mechanisms known as Joint Implementation, the Clean Development Mechanism and Emissions Trading.

The Kyoto Protocol marks the first time an international agreement has set targets to reduce greenhouse gas emissions.

These are designed to help Annex I Parties cut the cost of meeting their emissions targets by taking advantage of lower cost opportunities to reduce emissions, or increase greenhouse gas removals in other countries than at home. Under the Joint Implementation mechanism, developed countries can make investments in Eastern and Central European countries in return for emission reduction credits (when there are emission reductions in the host countries, the investing country receives credits). Thus, if a country is not able to cut down emissions in its own country it can invest in some Eastern and Central European country on project(s) that deal with greenhouse gas emissions and get credit for the same. Emission trading allows the emission targets to be tradable. This is more like a "cap and trade" system where a cap is set on the maximum emissions allowed and then the country that emits more can buy the credits from the country that emits less than the cap. In other words, if a country emits less than its assigned amount it can sell the remainder to another country that has exceeded its allowed or assigned amount of greenhouse gas emissions. The Clean Development Mechanism allows countries and companies from developed countries to invest in sustainable development (or cleaner technologies/development) projects in the developing world, in return for emissions credits. In addition to these three original mechanisms, another mechanism called Activities Implemented Jointly was launched in 1995, as a precursor to Joint Implementation and Clean Development Mechanism and allows countries to participate voluntarily in schemes during a pilot phase, in which no crediting is allowed.

All the parties who have ratified the Protocol have to develop national systems for calculating emissions and cost-effective programs to improve the quality of the national inventories, and to cooperate in technology, science, and the development of education and training programs (for cleaner technologies). Developed countries in Annex II (the countries that have committed financial contributions for meeting Kyoto Protocol commitments) are expected to provide additional funds to meet the agreed fixed incremental costs for developing countries to meet their specific obligations.

Under sustainable development, free utilization of Kyoto mechanisms is essential. Still, Kyoto Protocol Article 17 stipulates that international emissions trading must be "supplemental" to "domestic actions" to meet the quantified commitment of each country. Introducing the Kyoto mechanisms and not yet allowing their utilization unless supplementary, is itself a contradiction. This was the focus of post-COP3 negotiations where European Union (EU) was advocating "supplementary" and introduced the concept of "bubble." This essentially meant that EU's assigned amount is reallocated among its member countries, hence EU would have a lower reduction cost than would be the case if a definitive amount were assigned to each country individually. Depending on how many Eastern and Central European countries join the EU the cost drops quite significantly. According to some literature the cost margin can be quite large, for example even when EU is to implement emission reductions twice its total target of 8 percent reductions, EU has a marginal reduction cost of 20 €/CO_2 ton (about $70 per C ton, this is in

2004) as compared to Japan's $300–400 per C ton and the United States' 100–200 per Carbon ton. At the same time, EU also raised the question of liability in emissions permits, for the purpose of preventing noncompliance caused by overselling emissions permits to other countries. This would translate into the fact that a certain volume of assigned amount must not be sold to other countries, and the remaining part of the assigned amount must be reserved, hence restricting emission permit exports. This would present no harm to the EU but have an impact on countries such as Japan.

THREE CONCERNS ON DIRECTION

The Kyoto Protocol has also become a debate between North and South. According to some scholars (mainly from the South) there are a few concerns related to the direction global climate regime is taking, which can be categorized into three sections:

- Although the principle of equity was central to the discussions of global climate change and even till the adoption of UNFCC, it has not been part of most the discussions since, and particularly since the Kyoto agreement.
- The focus of the regime is heavily on minimizing the burden of implementation of Kyoto reductions on polluting countries (industries) rather than being on the vulnerabilities of the communities and countries at greater risk and disadvantage due to climate change.
- Somehow the limelight is now on the global carbon trade and how to manage it, rather than on reduction of greenhouse gases (the main objective of Kyoto Protocol).

It is interesting to note that although the United States was a leader in drafting the Montreal Protocol and to implement it, such is not the case with the Kyoto Protocol. The reason for this may be that for the key countries, including the United States, the payoff structure is fundamentally different for the two agreements. For most of the key countries, unilateral compliance with the Montreal Protocol requirements was justified and boosted industry, in the sense that better technology needed to be developed to deal with changing things such as refrigerators, and American industry took the lead. On the other hand, the Kyoto Protocol might mean some cut-backs in emissions with an inverse impact on industries (but can boost industry if innovative greener technology is utilized). The Stern Review (a United Kingdom government-sponsored report on the economic impacts of climate change) concluded that one percent of global gross domestic product (GDP) is required to be invested to mitigate the effects of climate change, and that failure to do so could risk a recession worth up to 20 percent of the global GDP. Although some companies in the United States have begun working towards reducing greenhouse gas emissions, as a nation, the United States is still not part of the Kyoto Protocol. It is reasonable to predict that, when it comes to climate change, the United States will only move to ratify an international agreement reducing greenhouse gases if the perceived domestic costs of reduction decrease, or the benefits increase, or both. Without the United States participating, the success of any agreement will most likely be limited, because such a large amount of the world's greenhouse gas emissions are coming from the United States.

SEE ALSO: Berlin Mandate; Greenhouse Gases; Greenhouse Effect; Kyoto Mechanisms.

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Kyrgyzstan

KYRGYZSTAN IS LOCATED in Central Asia, west of China, with which it shares its dominant geological feature: the Tien Shan mountain range. The former Soviet state has a varied climate, ranging from subtropical to polar, but most of the country is arid, high mountain terrain. Over 45 percent of Kyrgystan sits at elevations that make it uninhabitable to humans. Of the remaining 54 percent, only 19 percent of the land is considered comfortable for human habitation. Government researchers have found that, over the past 100 years, average temperatures in Kyrgyzstan rose by 2.8 degrees F (1.6 degrees C) (much higher than the global average of 1 degree F, or 0.6 degrees C). Precipitation rose only 6 percent during the same period. Scientists project temperature rises of between 3–8 degrees F (1.8–4.4 degrees C) by 2100, and projected precipitation increases of 6–54 percent, depending on the modeling program used.

In 2002, researchers announced that Issyk-Kul, the world's ninth-largest lake and second-largest saline lake, was showing a marked rise in water levels and temperature. This was shocking to many experts, who had seen the lake shrinking 1926–98, and expected that trend to continue. However, in 1998–2002, the lake level rose 10 in. (26 cm.).

This was deemed an extraordinary rise for a body of water that covers 2,317 sq. mi. (6,000 sq. km.). Temperature readings from across the lake showed increases of 6.6–7.5 degrees F (3.7–4.2 degrees C). Further study has shown that most of the rising water level is attributable to increased mountain precipitation and increased snowfall in the high mountains. The country's glacier fields are shrinking, but glacial melt is not believed to have played a significant role in Issyk-Kul's rise.

The government expects that, in the north and northeastern parts of the country, the desert belt will move up about 1,312 ft. (400 m.), the steppe belt about 820 ft. (250 m.), forest meadows 492 ft. (150 m.), and the subalpine belt 328 ft. (100 m.); other parts of the country will see less dramatic shifts of about 656 ft. (200 m.) for deserts and steppes, and 492 ft. (150 m.) for forest-meadows.

Kyrgyzstan's government is not concerned about energy use in the country, and is only moderately concerned about water availability. It believes most native flora and fauna will adapt to shifting climate zones, and forests will benefit from a greater range. It is slightly more concerned about the impact on human health, particularly an increase in vector-borne disease like malaria and dengue fever, which might flourish under warmer average temperatures. It believes this can be countered by improved standards of living and health care investments.

As a developing nation, Kyrgyzstan is not obligated to cut emissions under the Kyoto Protocol, but has stated a commitment to implement plans to reduce carbon emissions by encouraging sustainable agricultural practices, building energy-efficient housing, implementing environmental controls in industry, and investing in renewable energy sources.

SEE ALSO: Developing Countries; Diseases; Glaciers, Retreating.

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Land Component of Models

CLIMATE MODELS simulate the interactions between the atmosphere, and the ocean and land surface beneath it. The land properties that matter most to the atmosphere include land elevation; the the presence of mountains, for example, can strongly affect the flow of air, causing it to rise and fall, thus creating zones of high and low rainfall.

The albedo of the land, which determines how much of the incident sunlight is reflected, depends critically on the nature of the ground cover, whether it is snow, ice, sand, or vegetation. The moisture content of the soil has a strong effect on the hydrological cycle, for example, the amount of evaporation into the atmosphere, and the amount of run-off into rivers and lakes. The roughness of the land surface affects the flow of air, which can become very turbulent near the surface.

Since climate models have reached a new generation of sophistication, the type and scope of variables employed in models have also changed. Perhaps the most startling change in model specifications has been the replacement of single variables to represent the three principal components of land, ice, and atmosphere, with numerous variables to account for these parts.

In terms of the land component, the single variable used in early models, which did not distinguish between land and sea, has been replaced by a suite of variables that model not just land and sea, but as many as three layers of land, including overlays of snow or ice, and a vegetation layer. The elevation of the land has also been incorporated into models, together with its impact on the albedo of the land—that is, the degree to which solar energy is reflected back away from the surface. Recent work has focused on the interaction between component parts. For example, the pressure and temperature of the land and the air or sea adjoining it will have significant impacts on the horizontal and vertical fluxes of masses of air, water vapor, or water. The interaction between land and sea ice also has implications for the flow of salt to and from different components, and this is important because salinity leads to different forms of behavior, with respect to interactions. Seasonality has also been modeled, as its impact on temperature has important effects over many parts of the land, particularly for Eurasia.

In technical terms, improvements to the land component derive from more sophisticated handling of fractional processes and turbulence. The actions and behavior of non-solids in turbulence remains one of the most complex areas of mundane physics.

Nevertheless, advanced computational power has gone a long way to help understand this behavior and predict how it is going to take place in a variety of environments. A second area of improvement concerns the handling of run-off of various types of precipitation. These issues have been tackled by a joint project known as the Common Land Model (CLM), which aims to pool the knowledge and understanding of research communities in various locations.

The land component of climate models most readily shows the impact of humans. Rapid urbanization, deforestation, and changes in land cover all have significant effects on the other components of the model, and also directly impact the atmosphere and its circulation. Cities, for example, are noticeably hotter than the surrounding areas, and this introduces new forms of circulation into the system. These changes also occur much more rapidly than changes in the sea or atmosphere. The increasing heterogeneity of the land, which the changes generally bring about, increase the complexity of models and the difficulties involved in attempting to simulate climate systems.

SEE ALSO: Climate Models; Computer Models; Land Use.

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Land Use

THE CHARACTER OF the environment has been largely dictated by the uses to which humans have put the land. Nomadic man walked lightly on the land, roaming from place to place, taking only what was needed for survival, leaving the land largely as it was. As humans settled into more sedentary, agrarian pursuits, they began to physically transform the land to meet their needs. Transformations of the land were generally localized and environmental impacts minimal. The ascent of mercantilism saw the growth of villages and towns in which goods and services were produced and traded in a more highly-developed, social economy in which production methods began to have wider environmental impacts. The 19th century saw an unprecedented intensification of land use, industrial-scale agriculture, and manufacturing that has transformed the land and regional environments almost beyond recognition. More importantly, the introduction of carbon-based fuels—wood and coal to power early industrialization, and petrochemical fuels of the 20th century—began to have transformative effects on the global climate.

Regional and global climates transform, and are transformed by, a complex dance of culture and economic development with nature. Over the past 20 years, humans have become increasingly aware of the extent to which land development is directly or indirectly responsible for the emission of numerous greenhouse gases—primarily carbon dioxide and methane—that act as forcing agents for global warming. These influences derive not only from the combustion-related emission of greenhouse gases and their accumulation in the atmosphere, but also from the local warming of the atmosphere by the urban heat island effect.

Since the 1990s, increasingly sophisticated computer models have demonstrated the tight coupling of changes in land use to subsequent changes in atmospheric and ocean temperatures. As virgin and agricultural land is transformed, attendant greenhouse gas emissions contribute to climate change at the global scale. Locally, the land's albedo may decrease, resulting in the absorption of more of the Sun's radiant energy. In densely developed urban environments, this leads to a heat island effect, which directly modifies local and regional climates. The 2007 Fourth Assessment Reports from the Intergovernmental Panel on Climate Change have recognized land-use and land use change as significant, if not primary, contributors to global climate change.

After World War II, the United States—and to a lesser extent the rest of the developed world—experienced a rapid growth in per capita income and the development of mass-market economies. Driven also

In the 19th century, land use intensified with industrial-scale agriculture and manufacturing, transforming the land and regional environments. The introduction of carbon-based fuels began to transform the global climate as well.

by government policy (such as suburban mortgage subsidies, restriction of urban investment, urban flight, and the triumph of the automobile over transit in the United States) residential and commercial land-use development rapidly expanded outside existing urban boundaries to transform enormous swathes of undeveloped or agricultural land. The resulting low-density sprawl continues to drive—and, in turn, is driven by—the development of highway transportation infrastructure that encourages the seemingly endless growth of vehicle miles traveled and the attendant emission of carbon dioxide and other non-point source air pollutants.

As developing nations strive to join the global economy, their land-use choices also contribute significantly to global warming and climate change. Not only can these developing, largely agrarian, economies ill-afford the latest in power generation and pollution-control technologies (to limit greenhouse gas emissions), but the very survival of their populations often depends on the transformation—some say destruction—of natural landscapes that play a key role in climate protection. The large-scale deforestation of the Amazon Basin by Brazilian peasants and international corporations seeking to compete in global agricultural markets is gradually eliminating a globally-essential carbon dioxide sink. The chaos of unplanned urbanization and economic development are major contributors to the production and release of global warming gases.

Second-order land-use changes are motivated by first-order transformations. As populations respond to changing land uses—to urban development, suburban sprawl, and their attendant climatic effects—more land is ultimately transformed. Sprawl begets sprawl and amplifies local and global climate forcing. Intelligent reuses of previously developed land and those parcels left vacant as a result of leapfrog urban development (brownfield and infill development sites) can mitigate the resulting climate impact by limiting the development of new (highway) transportation infrastructure with its resulting climate impacts. In the long term, the increasing application of smart growth, traditional neighborhood development, and new urbanist principles may contribute to denser and more sustainable land use by encouraging mixed-use development.

SEE ALSO: Albedo; Anthropogenic Forcing; Climate Models; Deforestation; Global Warming; Greenhouse Gases; Sustainability.

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Laos

LOCATED IN SOUTHEAST Asia, and formerly part of the French Indochina, Laos has a land area of 91,429 sq. mi. (236,800 sq. km.), a population of 5,859,000 (2006 est.), and a population density of 66 people per sq. mi. (25 people per sq. km.). With only 3 percent of the country arable, and another 3 percent used for meadows and pasture, 55 percent of the country remains forested, although this is declining slowly with a large timber industry in parts of Laos.

Regarding the electricity production in Laos, 98 percent comes from hydropower, with the remaining 2 percent from fossil fuels. Laos is located on the Mekong River, and plans were first discussed in 1962, and drawn up in 1969, to build the Nam Ngum Dam to provide for the power needs of Vientiane, the country's capital. Although it already exports electricity generated from hydropower, the Laotian and Thai governments plan to build the controversial Pa Mong Dam. As a result of this heavy use of hydropower, Laos maintains one of the lowest per capita rates of carbon dioxide emission in the world, at 0.1 metric tons in 1990, rising to 0.22 metric tons by 2003.

The main effect of global warming and climate change on Laos is expected to be increased flooding of low-lying parts of the country, with a possible increase in the prevalence of insect-borne diseases such as malaria and dengue fever. Higher temperatures might also result in difficulty growing some crops in the country, resulting in lower yields. The government of the Lao Democratic People's Republic took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, and they accepted the Kyoto Protocol to the UN Framework Convention on Climate Change on February 6, 2003, which took effect on February 16, 2005.

SEE ALSO: Disease; Floods; Thailand.

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Latvia

THE REPUBLIC OF Latvia, located in the Baltic, and until 1991 a constituent part of the Soviet Union, has a land area of 24,937 sq. mi. (64,589 sq. km.), a population of 2,277,000 (2006 est.), and a population density of 93 people per sq. mi. (36 people per sq. km.). Twenty-seven percent of the country is arable, with a further 13 percent used for meadows and pasture, much of that for raising cattle or dairy farming, contributing to the high per capita methane emission level.

Latvia generates 67 percent of its electricity from hydropower, with the remaining 33 percent from fossil fuels. As a result of this heavy use of hydroelectricity, Latvia produced 4.8 metric tons per capita of carbon dioxide (CO_2) in 1992, falling to 2.9 metric tons per person by 2003. This was far below its northern neighbor Estonia (16.1 in 1992, 13.6 in 2003) and lower than its southern neighbor Lithuania (5.8 in 1992, 3.7 in 2003). Forty-two percent of the carbon emissions in the country come from electricity and heat production (Latvia having bitterly cold winters), 27 percent from transportation, and 16 percent from manufacturing and construction. In terms of its emissions by source, 62 percent comes from liquid fuels, reflecting the heavy use of privately-owned cars in the country, and 30 percent from gaseous fuels, with the remainder from the use of solid fuels and cement manufacturing. In recent years, the Latvian government has encouraged bicycling in the country to try to reduce dependence on cars for short journeys.

The main effects of global warming and climate change on Latvia have been a rise in the average temperatures in the country, which has allowed more land to be used for arable purposes. However, it has also led to degradation of some coastal lands, and the possibility of flooding in parts of the country. The Latvian government took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, and three years later ratified the Vienna Convention.

Latvia signed the Kyoto Protocol to the UN Framework Convention on Climate Change on December 14, 1998, and ratified it on July 5, 2002. It took effect on February 16, 2005. The Latvian government has undertaken to reduce CO_2 emissions by 8 percent by 2012.

SEE ALSO: Estonia; Global Warming; Lithuania.

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LDEO Climate Modeling Group

THE CLIMATE MODELING and Diagnostics Group at the Lamont-Doherty Earth Observatory (LDEO) of the Earth Institute at Columbia University includes more than 200 researchers studying the origin, evolution, and future of the natural world. The Climate Modeling Group carries out research in climate modeling and climate change, also taking into account important issues in the phenomenon of global warming, such as El Niño/Southern Oscillation. Climate Group builds on the data produced from general circulation models (GCMs) to answer fundamental science questions.

LDEO is developing several climate models. The Lamont Ocean-AML GCM (LOAM) is a recent recreation of the Gent-Cane Primitive Equation Ocean Model with many supplementary elements. It was developed for modeling the equatorial Pacific on a stretched longitude/latitude A-grid. Most of the horizontal features have been kept in the present version. The fourth order time and space (horizontal) discretization has been retained, the Shapiro filters (reduced, conservative, narrow passage modifications) are still used, and most of the old options remain. The only major exception is that the reduced-gravity setup (assuming no motion at depth) is not currently supported in this version, but could be reintroduced. The major changes from the original Gent/Cane model are the vastly improved I/O handling, a barotropic solver, a new ocean mixed-layer parameterization and an atmospheric mixed layer (AML).

The Coupler for the Atmosphere with Multi Element LOAM (CAMEL) was partly funded by the Lamont-Doherty Earth Observatory Investment Fund (LIF). The underlying idea of this project is to create a simple tool to combine atmosphere, land, ocean, and sea-ice models. CAMEL interpolates the surface fluxes computed in the atmosphere model to land, ocean, and sea-ice models. It also interpolates the surface temperature computed in these models to the atmosphere model.

The models can be kept as separate executables and the communication is done by reading/writing netCDF files. The interpolations and scheduling is all done by CAMEL, with the separate models waiting for updated information. If any of the components are already coupled into one model, as in CCM3(atmosphere) and LSM (land) , then CAMEL does not interfere, but does the coupling only between separate models. More generally, CAMEL can be used to patch together the surface conditions of multiple models. In addition, in any geographic area, climatological surface conditions may be combined with model output.

The Climate Model Data Documentation Project (CMDDP) was born of the need to analyze model data to support the scientific conclusions. This raised problems regarding archiving, accessibility, and documentation of the group's results, and relating to the integrity and reproducibility of the group's modeling experiments. Typically, the published data of modelers consists of figures, processed data, and tables of area averaged, depth-integrated, time-smoothed data. Due primarily to size constraints, the computer output is not available for further analysis. In addition, the source code for the models themselves is not easily reproduced. Even scientists based at the same institutions who repeat a model run frequently report different results from some unknown combination of code evolution, change in personnel, migration of computer platforms and data storage, or lack of proper documentation of parameters. To address this problem, which risks compromising the scientific effort, the Climate Modeling Group launched a comprehensive, web-based procedure for ensuring the integrity of local GCM runs. Data can be supplied over the internet through the Distributed Oceanographic Data System (DODS) to the whole community. In addition, all necessary documentation, source code, and initialization and forcing data can be stored in one place. The creation and maintenance of this Climate Model Data Documentation Project has achieved a new standard for this type of research. All new published modeling results in the group will be added to this project. Existing projects will also be added to this effort.

The Climate Modeling Group has created the "Reduced Space Optimal Analysis for Historical Datasets: 136 years of Global Sea Surface Temperatures." This analysis uses present-day temperature patterns to enhance the meager data available in the past. The group also manages the Climate Data Library, which includes over 300 datasets from a variety of Earth science disciplines and climate-related topics. Through this facility, users are granted access to any number of datasets, they can create analyses of data ranging from simple averaging to more advanced Empirical Orthogonal Function (EOF) analyses, they can monitor present climate conditions with maps and analyses in the Maproom, they can create visual representations of data, including animations, and they can download data in a variety of commonly-used formats, including Geographic Information Systems- (GIS) compatible formats.

The group also monitors the phenomena of El Niño/Southern Oscillation. Researchers expect drought to worsen in the Plains and the West of the United States over the next several years because of La Niña-like conditions. Using observations and models, LDEO scientists learned that all the major dry and wet events in the American West since the late 19th century were forced by slowing varying tropical Pacific sea surface temperatures (SSTs). Climate Modeling Group scientists have shown how decadal variations of these SSTs are predictable to a modest degree a few years in advance. According to them, the American West might be entering one of the most serious period of drought since European settlement. The group's research in the area also includes predicting if rising greenhouse gases will induce an El Niño-like response, causing increased precipitation over the American West, or a La Niña-like response, causing less precipitation over the American West in the tropical Pacific Ocean.

SEE ALSO: Climate Models; Climate Change, Effects; Columbia University; El Niño and La Niña.

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Lebanon

LEBANON IS SITUATED on the eastern coast of the Mediterranean Sea and has boundaries with Syria and Israel. Lebanon is a small country with diverse geographical regions, including a narrow coastal strip, the Chouf Mountains, the Mount Lebanon range, and the Bekáa Valley in the arid rain-shadow area. In the Chouf Mountains, a nonporous rock layer forces water to the surface, resulting in waterfalls, and makes high-altitude cultivation possible. There are over 30 areas of natural areas protected by ministerial decrees of the Protected Areas Directorate of the Ministry of Environments. The climate of Lebanon is Mediterranean, with warm, dry summers and cool, wet winters, with some variation across the more diverse geographic regions. The coastal plain is subtropical. The mountain areas experience lower temperatures and increasing precipitation as elevation increases.

Lebanon imports over 75 percent of its food to support a population of over 4.4 million, with a steady population growth. The impact of global warming is apparent in current environmental concerns, including degradation of forests and woodlands for urbanization, and excessive water use for both domestic water supply and agriculture. Much of the land is littered with landmines from war. Areas susceptible to the effects of climate change include water resources, higher elevations affected by warming, and coastal flooding with increased storm probability and rising sea levels. Higher temperatures could affect the native vegetation that may be unable to adapt, and may be replaced with vegetation that thrives at higher temperatures.

In December 1994, Lebanon ratified the United Nations Framework Convention on Climate Change and prepared and submitted, through funding from the Global Environment Facility, Lebanon's First National Communication Report in 1995 to the Secretariat in November of 2006. Lebanon ratified the Kyoto Protocol (an international and legally binding agreement to reduce greenhouse gas emissions worldwide, which took effect on February 16, 2005). It took effect in Lebanon on February 11, 2007. Countries that are parties to the UN Framework Convention on Climate Change are required to undertake national communication, which can include assessment of potential impacts of climate change.

There are more than 30 nongovernmental environmental organizations active in Lebanon. Proposed projects aimed at reducing greenhouse gas emissions include assessing energy requirements and possible use of solar and wind energy as well as imported natural gas, improving efficiency of electricity use with advanced technology, improving waste management practices, and methane gas recovery. In addition to research studies on feasibility, the chief components necessary for mitigation of human-induced climate change in Lebanon are raising public awareness, educating policy makers on cost-effective environmental conservation practices, and access to education and experience with advanced technology for professionals.

SEE ALSO: Food Miles; Food Production; Nongovernmental Organizations (NGOs).

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Lesotho

THE LANDLOCKED KINGDOM of Lesotho, totally surrounded by South Africa, has a land area of 11,717 sq. mi. (30,355 sq. km.), a population of 2,008,000 (2006 est.), and a population density of 153 people per sq. mi. (59 people per sq. km.). Most of the people in Lesotho work in subsistence agriculture, with 11 percent of the land arable, and a further 66 percent used for meadows and pasture, mainly for low-intensity grazing of cattle, sheep, goats, and pigs. Because it is relatively undeveloped, the carbon dioxide emissions from the country are low on a per capita basis. Exact statistics for the country have not been published for several years.

The effects of global warming on Lesotho involve a possibility of rising temperatures leading to a reduction in the amount of farmland, with increased desertification and soil erosion, and the possibility of drought. The Leostho government took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, and ratified the Vienna Convention in 1994. They also accepted the Kyoto Protocol to the UN Framework Convention on Climate Change on September 6, 2000,; it took effect on February 16, 2005.

SEE ALSO: Desertification; Drought; South Africa.

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Liberia

THE REPUBLIC OF Liberia, located in West Africa, an independent country since 1847, has a land area of 43,000 sq. mi. (111,369 sq. km.), a population of 3,750,000 (2006 est.), and a population density of 75 people per sq. mi. (29 people per sq. km.). The economy of the country came largely from rubber, but since 1989 there has been extensive fighting in much of the country, leading to the installation of President Charles Taylor, and later his ejection from the country.

Some 39 percent of the country is forested, with 1 percent of the land arable, and a further 29 percent used for meadows and pasture. All of the country's electricity production comes from fossil fuels, with only the capital, Monrovia, covered by the country's electricity grid. Liquid fuels make up 99 percent of the country's carbon dioxide (CO_2) emissions, and the remaining 1 percent comes from cement manufacturing. The overall CO_2 emissions per capita fluctuated from 0.1 to 0.2 metric tons 1990–2003. These changes reflect the fact that the central electricity supply system in the country stopped working during fighting in July 1990, causing most people to have gasoline-driven power generators. It was not until 1998 that the first traffic lights since 1990 were brought into operation in the capital. However, the civil war has had a major impact on the country's rainforests, with the illegal timber industry used to raise money for various sides in the conflict. This deforestation has had a major impact on the country's environmental problems, leading not only to increased greenhouse gases, but also to soil erosion.

Monrovia has the second highest rainfall rate in Africa, and, located on a peninsula, it is at risk of flooding if climate change and global warming lead to even a moderate rise in water levels in the Atlantic Ocean. The Liberian government of Amos Sawyer took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, and ratified the Vienna Convention in 1996. The subsequent government of Charles Taylor accepted the Kyoto Protocol to the UN Framework Convention on Climate Change on November 5, 2002, and ittook effect on February 16, 2005.

SEE ALSO: Carbon Dioxide; Deforestation; Oil, Consumption of.

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Liechtenstein

LOCATED IN CENTRAL Europe, the Principality of Liechtenstein is landlocked, with Germany as its northern neighbor, and Switzerland along its southern border. It has a land area of 62 sq. mi. (160 sq. km.), a population of 35,000 (2006 est.), and a population density of 557 people per sq. mi. (215 people per sq. km.). Twenty-four percent of the land is arable, with 16 percent used for meadows and pasture, and 20 percent of the country forested.

With a very high standard of living in the country, it has a relatively high level of per capita carbon dioxide emissions, largely because of its high per capita electricity production, and high private ownership of automobiles, in spite of having an efficient level of public transport in Vaduz, the capital. However, much of the automobile usage takes place outside of Liechtenstein.

In the foothills of the Alps, Liechtenstein is threatened by rising temperatures from climate change and global warming, noticeable in the lessening of the snow-covered Alpine peaks. The Liechtenstein government took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, and signed the Kyoto Protocol to the UN Framework Convention on Climate Change on June 29, 1998. It was ratified by the Landtag, the Liechtenstein parliament, on December 3, 2004, and it took effect on March 3, 2005.

SEE ALSO: Germany; Glaciers, Retreating; Switzerland.

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Life Cycle Analysis

LIFE CYCLE ANALYSIS (LCA) is a means of quantifying how much energy and raw materials are used and how much (solid, liquid, and gaseous) waste is generated at each stage of a product, process, service, or system's lifetime. An LCA is the environmental impact over the entire lifespan of the entity in question, and can be used to help reduce anthropogenic impacts on the climate. Life cycle analysis is also known as a life cycle assessment, life cycle inventory, eco-balance, net energy analysis, materials flow analysis, cradle-to-grave analysis, cradle-to-cradle analysis, well-to-wheel analysis, resource analysis, and environmental impact analysis. The environmental impact can be converted to a carbon footprint or land area in ecological footprint (or eco-footprint) analysis.

There is no agreed-upon methodology for LCAs. The most institutionalized LCAs methodology is the codification into the ISO (International Organization of Standards) 14000 environmental management standards, which assists organizations to minimize negative environmental impacts, comply with applicable laws and regulations, and to continually improve on these metrics. ISO 14040 to 14044 covers LCAs and pre-production planning and environment goal-setting. LCA can, however, be very complex, and reliable data are difficult to compile. Thus, studies on similar systems, products, and processes often vary considerably in their final results. In the literature covering the LCA of controversial technologies (such as nuclear energy), the results may be biased. Provided all reports state the methodology used and the assumptions made, LCAs do, however, provide a useful indication of where to concentrate work on essential improvement, and which technologies should be adopted to reduce the environmental impact of a product or process, in terms of energy and raw materials used and wastes produced.

LIFE CYCLE ANALYSIS AND THE ENERGY SECTOR

In the context of climate change and its largest contributor, the energy sector, LCAs generally focus on an energy LCA that includes both tangible and intangible costs of energy production from the initial project conception, to the final step of returning the land to its original or its next-use state. Tangible costs have always been included in the industry analysis and include such items as facility construction, fuel source development, post-extraction land remediation, and waste disposal. Because different forms of energy use have adverse impacts, not only on nonusers, but also the entire biosphere, intangible costs are important. These include the impact of the release of carbon dioxide into the atmosphere.

In the past, conventional energy proponents often overlooked costs (both economic and energy-related) due to plant decommissioning because of weak regulations and oversight. This allowed some energy producers to hide the true lifetime costs of energy production, thus projecting a false image of both economic and environmental benefit. Examples include ignoring nuclear waste storage, or the cost of reclaiming strip-mined land, or mountaintop removal mining in the Appalachian Mountains. Complete LCA's are difficult to perform, especially on emerging technologies, such as solar photovoltaic cells, whose fabrication is constantly undergoing improvements, and which has not been in mass production long enough for recycling or disposal to become established. Often in the energy sector, energy LCA is used because it is less complicated than a full LCA; energy consumption data are more reliable (often metered for individual processes). Ideally, an energy life cycle analysis would include: raw material production energy, manufacturing energy of all components, energy-use requirements, energy generation (if any), end of use (disposal) energy, and the distribution/transportation energies in between each stage.

LCA AND CLIMATE CHANGE

To utilize LCA in policy decisions on climate change, it is imperative to understand the boundaries of the operations that produce the process, because if any part of the system contained within the boundaries is changed, the other inputs and outputs will also change. Deciding what constitutes the cradle and what is the grave (or next cradle) for such studies has been one of the major points of contention in the evolving discipline of LCA. For example, in calculating the embodied energy for transportation as just one component of the LCA in the recycling of plastic, the simplest case would be limited to the fuel used for the recycling trucks. In more detailed LCAs, the embodied energy of the trucks would be included; particularly if the trucks were only used for plastic recycling (otherwise, the fractional use would be taken into account). Such a study would normally ignore second, third, and greater generation impacts, such as the energy required to fire the bricks used to build the kilns used to manufacture the truck components.

In addition, recycling itself lends considerable complexity to LCAs. For some materials such as aluminum, which can technically be recycled an indefinite number of times (with some melt losses), there is no longer a grave. In the case of paper, however, taking into account recycling is even more complex. Paper can theoretically be reprocessed four or five times before fibers are too short to have viable strength for paper, but even then it may still be useful in a downcycled product like cellulose insulation.

For these reasons, an LCA can never produce one simple result. The results are tables of ranges of figures showing quantities of resources used and wastes produced. Any comparison between similar processes or products will depend on subjective judgments on the relative importance of energy consumption, raw material use, and waste generation.

SEE ALSO: Carbon Footprint; Ecological Footprint; Energy.

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Lindzen, Richard (1940–)

RICHARD SIEGMUND LINDZEN is the Alfred P. Sloan Professor of Meteorology in the Department of Earth, Atmospheric, and Planetary Sciences at the Massachusetts Institute of Technology (MIT), where he has taught since 1983. Though extremely accomplished and respected in his field, he is perhaps best-known in non-academic circles for his arguments against anthropogenic climate change, that is, human-influenced or induced climate change known as global warming. Lindzen was born in Webster, Massachusetts, on February 8, 1940, and received his Ph.D. from Harvard University in Physics and Applied Mathematics in 1964 after earning an AB in 1960 and an SM in 1961 from Harvard. He taught at the University of Chicago (1967–72) and Harvard (1972–83) before moving to MIT.

Lindzen is a dynamic meteorologist and climatologist, applying mathematics, computational modeling, and hydrodynamics to the study of atmospheric motions. His research interests and contributions involve Hadley Circulation, planetary waves, upper atmospheric dynamics, mesoscale systems, clear air turbulence, ozone photochemistry, radiative transfer, climate sensitivity, atmospheric eddies, global heat transport, cumulus convections and the greenhouse effect, tropical meteorology, monsoons, and the heating and drying of the atmosphere. His Earth climate models are used to study the atmospheric sensitivity to carbon dioxide (CO_2), ice cap stability, regional climate maintenance, and glaciation.

He was honored with the American Meteorological Society's Meisinger and Charney Awards, as well as the American Geophysical Union's Macelwane Medal. He is a member of the National Academy of Sciences, the Science and Economic Advisory Council of the Annapolis Center for Science-Based Public Policy, the National Academy of Science Committee on Human Rights, and the Nuclear Regulatory Commission Board on Atmospheric Sciences and Climate. He is a Fellow of the American Association for the Advancement of Science and served on the 11-member Committee on the Science of Climate Change of the National Research Council.

He consults for the National Aeronautical and Space Administration's Global Modeling and Simulation Group, and has been a Distinguished Visiting Scientist at California Institute of Technology's Jet Propulsion Laboratory.

A hole in the ozone layer of the atmosphere was discovered in 1985, and the earlier detection of the warming of the Earth (1980) gave impetus to the idea that one of the causes is human-induced climate change from manmade ozone-depleting gases. In 1988, the United Nations responded by creating and tasking the Intergovernmental Panel on Climate Change (IPCC) with studying the hypothesized phenomenon. The IPCC determined that the Earth had warmed over the prior 150-year period, and that this warming was due, in part, to human activity. The executive summary of the report concluded that the most of the observed global warming experienced in the last 50 years is due to the increase in greenhouse gas concentrations. The IPCC and former U.S. Vice President Al Gore were jointly awarded the Nobel Peace on October 12, 2007, for their work on global warming.

REJECTING ANTHROPOGENIC CLIMATE CHANGE

Lindzen rejects anthropogenic climate change and asserts that, though others in the field agree with him, political and academic pressure to adhere to the accepted knowledge construct or paradigm of the climate research establishment keep them from speaking. Lindzen asserts that there is a bias against those who reject global warming by those who accept it and who control key publications and research funding. Lindzen argues that the climate models used by the IPCC do not correctly model the physics of cloud formation, and intentionally heighten the warming effect of CO_2 and other greenhouse gases. He argues that this modeling flaw is apparent when the same model is used to explain or predict shorter-term changes in the atmosphere.

He argues further that climate change is the historic norm, and that there are periods when the Earth was warmer and that in those periods the emission of human-induced CO_2 was minimal.

Lindzen does not dispute that there is global warming in the 20th and 21st centuries, that there is a concurrent increase in the concentration of greenhouse gases in the atmosphere, or that there is some anthropogenic heating.

What Lindzen disputes is that this warming trend is necessarily and substantially due to human activity, or the increase in the concentration of greenhouse gases in the atmosphere. Lindzen argues that the observed temperature data are massaged or curved by the models. This curve fitting is primarily due to the inability of contemporary computer modeling to integrate all of the known human and natural variables that must be part of the equation.For example, Lindzen asserts that the IPCC models as constructed are too sensitive to atmospheric CO_2. Additionally, Lindzen asserts that there are many variables that are as yet unknown.

Lindzen does estimate the Earth will continue to warm over the next century, but asserts that that this warming will be far less than contemporaneous models predict, and that those predictions are alarmist. Lindzen also asserts that changes in human activity will do little to mitigate the current cycle, and that the impact of the Kyoto Protocol on the climate is much smaller than its political and social impact.

Even though he was the lead author on, or contributor to, a number of the IPCC Assessment Reports, he was not involved in producing the executive summary that he believes was filtered through the accepted anthropogenic climate change paradigm by those scientists, environmentalists, government bureaucrats, and industry representatives responsible for creating the summary supplied to policymakers. He also asserts that the press, which exaggerated the problem and its potential effects, selectively reported this paradigmatically-curved summary. The fault was not with the Assessment Reports or the real findings of the IPCC, but rather with how those reports and results were interpreted for the world's decision-makers and disseminated to the global populace.

SEE ALSO: Anthropogenic Forcing; Climate Cycles; Climate Models; Climate Sensitivity and Feedbacks; Computer Models; Earth's Climate History.

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Lithuania

THE SOUTHERNMOST OF the three Baltic Republics, Lithuania has a land area of 25,173 sq. mi. (65,200 sq. km.), a population of 3,390,000 (2006 est.), and a population density of 142 people per sq. mi. (55 people per sq. km.). The economy of the country is heavily agricultural, and 39 percent of the land is arable. In addition, 6 percent is used for meadows and pasture, mainly for rearing cattle and pigs, both of which contribute to global warming through methane emissions. However, 31 percent of the country is forested, which alleviates some of the overall greenhouse gas emissions of the country.

In 1990, carbon dioxide (CO_2) emissions per capita were 5.8 metric tons, but these had fallen to 3.7 metric tons per person by 2003. Seventy percent of these emissions come from the use of liquid fuels, 23 percent from gaseous fuels, 4 percent from solid fuels, and three percent from the manufacture of cement. In terms of emissions by sector, electricity production in the country contributes 39 percent of CO_2, with only 20.2 percent of electricity production coming from fossil fuels, 76.8 percent from nuclear power, and 3 percent from hydropower. Transportation accounts for 26 percent of the country's CO_2 emissions, with manufacturing and construction accounting for 15 percent, and residential use accounting for 5 percent.

The effects of global warming and climate change on Lithuania are potentially quite serious, especially around Klaipeda (formerly Memel) and the Courland Spit, which is at risk from flooding. There is also risk from flooding in other parts of the country, such as in the Aukstaitija National Park. To try to combat the effects of global warming, Lithuania has continued to invest heavily in its public transport system, and parts of many cities such as Klaipeda are pedestrian precincts that discourage the use of cars, with heavy encouragement of bicycling.

The Lithuanian government took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, and ratified the Vienna Convention in 1995. They also signed the Kyoto Protocol to the UN Framework Convention on Climate Change on September 21, 1998, and ratified it on January 3, 2003. It took affect on February 16, 2005.

SEE ALSO: Automobiles; Floods; Kyoto Protocol; Transportation.

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Little Ice Age

THE LITTLE ICE Age does not cover a clear and well-defined climatic regime and time-period upon which climate scientists agree. Glaciologists, to describe the most recent major glacial advance of the Holocene period, originally used the phrase. Subsequently, the Little Ice Age was associated with a period of advances of European glaciers 1450–1850. It is now often associated with a climatic regime with relatively cold temperatures. However, current research does not support a globally-synchronous period of unusual cold over this approximate period.

The Little Ice Age was originally used to denote a period of moderate glaciation covering the past 4,000 years. In more recent and seminal work on the subject by J.M. Grove, the concept refers, not directly to climate, but specifically to a time, or times, of glacial advance; more precisely, to a period lasting several centuries within the last millennium, when glaciers extended globally and remained enlarged. Pioneers of the use of historical records to reconstruct past climate, such as H.H. Lamb, were drawn to suggest a cold phase in Europe on the basis of accounts of the extent of snow and ice on land and sea 1450–1850.

Based on a variety of different types of data from many parts of the world, suggestions for the period covered by this most recent meaning of the Little Ice Age have ranged from 1200–1400, 1200–1900, 1550–1700, 1550–1800 and 1550–1850. Since some of these dates were put forward, the availability of data on the climate of the past has increased. At one time, it was believed that the Little Ice Age was a global phenomenon, but this is now less apparent. Spatial climatic patterns of the past 1,000 years are beginning to be mapped for large parts of the world, and the early 21st century have seen the development of multiple climate-proxy averages providing year-by-year estimates of average temperatures. These new series challenge the idea of global synchrony, often assumed when terms such as Little Ice Age and Medieval Warm Period are used.

Climate model results using best estimates of forcing factors over the past 1,000 years also show no clearly-defined global-scale warm or cold periods during this time, suggesting that any signals that exist are largely masked by the noise of shorter timescale variability. Although the concept of a global-scale cold climatic regime in the later half of the last millennium, lasting for several hundred years, is now outdated, there were episodes of relatively cold climate in many parts of the world during the past millennium. That glaciers advanced in the 1650s, for example, in the Swiss Alps, is well-known. However, while continental Europe suffered cold temperatures in the 1600s, Iceland enjoyed a relatively mild period with infrequent sea ice 1640–80. Particularly cold periods occurred in Iceland in the 1780s and 1880s. In the United States, winter 1780 was notably cold, and New York harbor froze, allowing people to walk on the ice.

A cold Little Ice Age climate has been suggested as a causal factor in a number of episodes in human history. However, in these cases, it is likely that several elements were involved, not just climate. A case in point is the loss of the Norse settlements in Greenland (1350 and 1450), where it is clear that many factors contributed to their demise, including a possible reluctance on the part of the settlers to learn from their environment and their Inuit neighbors.

The concept of the Little Ice Age has now evolved from the idea of a simple, centuries-long period of lower temperatures, to a more complex view of temporal and spatial climate variability. There were, nevertheless, distinct phases of cold and variable climate

General George Washington crossing the Delaware on the evening before the Battle of Trenton, December 25, 1776. The American revolutionary period experienced the effects of colder temperatures, particularly during the winter of 1780.

that occurred in many parts of the globe, although not necessarily synchronously, from 1200–1850.

SEE ALSO: Climatic Data, Historical Records; Climatic Research Unit; Drift Ice; Earth's Climate History; Ice Ages; Iceland; Paleoclimates.

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Lorenz, Edward (1917–)

EWARD LORENZ IS an American mathematician and meteorologist who pioneered the chaos theory. Lorenz conceptualized the strange attractor notion and termed it the "butterfly effect." He is well-known for his work in the dynamics of atmospheric circulations, and the first to recognize what is now called chaotic behavior in the mathematical modeling of weather systems. In the words of the committee that presented him the Kyoto prize in 1991, Lorenz has established "the theoretical basis of weather and climate predictability, as well as the basis for computer-aided atmospheric physics and meteorology." The committee went on to compare the impact of Lorenz's discovery of "deterministic chaos" on a wide range of basic sciences to that of the ideas of Sir Isaac Newton. Lorenz's discovery of the sensitivity of weather predictions to the input is often invoked by global warming skeptics to challenge computer-based scenarios which continue to predict an exponential temperature increase on earth.

Born in West Hartford, Connecticut, on May 23, 1917, Lorenz received his undergraduate degree in mathematics from Dartmouth College in 1938, a master's degree in mathematics from Harvard University in 1940, the SM in meteorology from the Massachusetts Institute of Technology (MIT) in 1943 and the Sc.D. in meteorology in 1948. It was while serving as a weather forecaster for the U.S. Army Air Corps in World War II that he decided to do graduate work in meteorology at MIT. Upon his return from the war, he joined the staff of what was then MIT's Department of Meteorology in 1948. Seven years later he was appointed to the faculty as an assistant professor. He was promoted to professor in 1962 and was head of the department from 1977 to 1981. He became an emeritus professor in 1987.

In the early 1960s, in the course of his work on weather systems, Lorenz found that he was getting chaotic results from some of his calculations. Studying weather patterns, he realized that weather did not always change as predicted. He experimentally discovered that if he made two runs using the same initial conditions, but specified his input conditions in one to three decimal places, rather than two, or four rather than three, he always got different weather predictions. Small variations in the initial values of variables in his 12 variable computer weather model would lead to extremely different weather patterns. This sensitive dependence on initial conditions came to be known as the butterfly effect. In Lorenz's weather models, almost any two nearby starting points, indicating the current weather, will quickly diverge trajectories and quite frequently will end up in different "lobes," which correspond to calm or stormy weather. The shape this model took, with its twin-lobed outlook, gave rise to the somewhat ironic "butterfly effect" metaphor: the flapping of a butterfly's wings in Mexico today may cause a tornado in Kansas tomorrow.

Convinced that these inconsistencies were not caused by faulty data or computer errors, he began to study chaos itself. His early insights, published in his 1963 paper, "Deterministic Nonperiodic Flow," marked the beginning of a new field of study. Some scientists have since asserted that the 20th century will be remembered for three scientific revolutions: relativity, quantum mechanics, and chaos. The study of the rules of chaotic disorder is making an impact, not only on the field of mathematics, but in virtually every branch of science: biological, physical and social. In terms of the atmosphere, it has led to the conclusion that it may be fundamentally impossible to predict weather beyond two or three weeks with a reasonable degree of accuracy. For this conclusion, Lorenz is often a starting point for global warming critics. They point out that Lorenz's "butterfly effect" leads to predictions that may depart significantly over time from what happens in the real world, if the input conditions cannot be specified to arbitrary accuracy.

During leaves of absence from MIT, Lorenz has held visiting research or teaching positions at the Lowell Observatory in Flagstaff, Arizona, the Department of Meteorology at the University of California at Los Angeles, the Det Norske Meteorologiske Insitutt in Oslo, Norway, and the National Center for Atmospheric Research in Boulder, Colorado. He was elected to the National Academy of Sciences in 1975, and his groundbreaking research has won numerous awards, honors and honorary degrees. In 1983, he and former MIT Professor Henry M. Stommel were jointly-awarded the $50,000 Crafoord Prize by the Royal Swedish Academy of Sciences, a prize established to recognize fields not eligible for Nobel Prizes. His other honors include the Elliott Cresson Medal from the Franklin Institute in 1989, the Rossby Research Medal of the American Meteorological Society in 1969, and the Society's Meisinger Award in 1963. In 1991, he was awarded the Kyoto Prize in earth and planetary sciences.

SEE ALSO: Chaos Theory; Computer Models; Massachusetts Institute of Technology.

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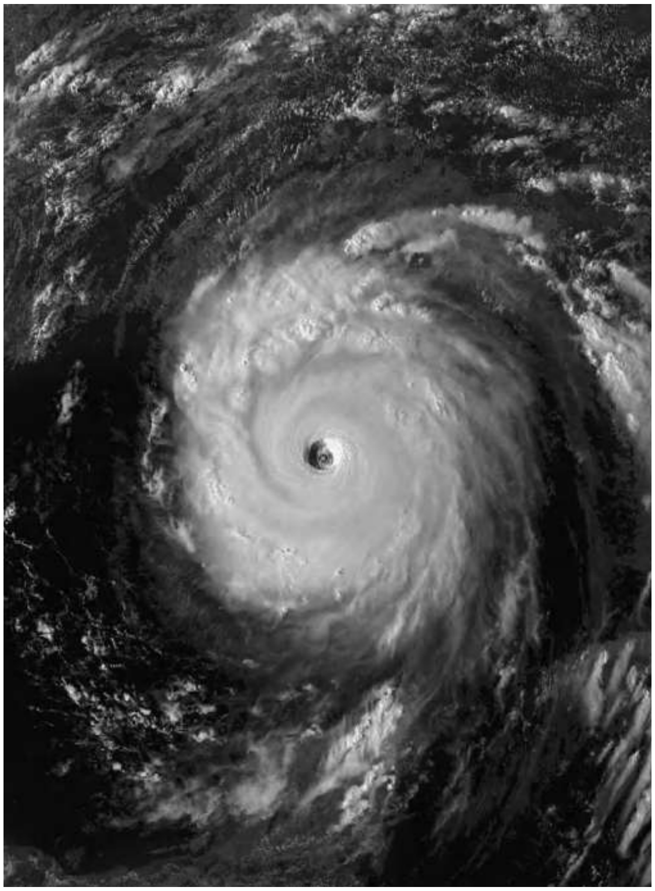
Louisiana

LOUISIANA IS A state in the south-central United States, bordered by the Gulf of Mexico, Texas, Arkansas, and Mississippi. Major physical features include the Mississippi River, which forms part of the state's eastern boundary and crosscuts southeastern Louisiana, and its Atchafalaya River distributary; extensive but rapidly diminishing coastal wetlands; and hogbacks and cuestas of the north. The uplands and terraces of the Gulf Coastal Plain of northwestern and east-central Louisiana are interrupted by the vast Mississippi River bottomlands, which fan southward to include the entire coastal lowland region. The highest elevation is only 535 ft. (163 m.), making Louisiana's highest point third lowest in the United States. Over 18 percent of Louisiana's area lies below 4.9 ft. (1.5 m.) above sea level. Much of the New Orleans metropolitan area lies below sea level.

The entire state has a humid-subtropical climate, with long, hot, rainy summers and cool, wet winters interrupted by mild-to-warm conditions. July temperatures average in the high 60s degrees F (20s degrees C) statewide, with January averaging approximately 43–55 degrees F (6–13 degrees C). Statewide, precipitation ranks among the highest of the states, but with a considerable gradient, ranging from nearly 48–71 in. (122–180 cm.) from northwest to southeast. Much of the rainfall, especially in summer, falls in short, intense downpours. The average number of thunderstorm days at a location exceeds that in any state except Florida, and tornado frequency per sq. mi. ranks sixth among the states. Louisiana is among the few places on Earth that frequently experiences tropical cyclones, tornadoes, rainfall rates exceeding 2 in. (5 cm.) per hour, floods, and winter storms.

Owing to its low-lying terrain, sultry climate, susceptibility to severe weather impacts, and high per capita rates of fossil fuel production and consumption, Louisiana is perhaps more vulnerable than any other state to environmental and economic impacts of long-term warming. These changes can be felt most directly in eustatic sea level increases from rising global temperatures, which could inundate the coastal zone and accelerate the already-rapid rate of coastal erosion. Continued warming would accelerate saltwater intrusion, which would remove the salt-intolerant coastal vegetation currently anchoring land in place. Drying conditions in much of the Mississippi River basin, as suggested by some general circulation models, would accelerate this effect of saltwater intrusion.

If global warming increases precipitation totals locally and across much of the Mississippi basin, as



Hurricane Katrina approaches the Louisiana coast in 2005. Questions remain about global warming's effect on the storm.

other models suggest, flooding hazards would be more problematic than increasing saltwater intrusion.

Although a causative link between global warming and severe/extreme weather has not been clearly established, Louisiana's susceptibility to such weather dictates that any climate change in frequency or intensity is likely to have a significant cumulative effect on environmental and social systems. In particular, if global warming increases the frequency and/or intensity of tropical cyclones as many climatologists suggest, acute loss of wetland habitats, human life, and property will accelerate. More chronic and insidious changes, such as in thunderstorm frequency and drought intensity, will also be important. Increased attention to emergency and disaster management, particularly in land-use planning and levee protection, is warranted. The degree to which the effects of Hurricanes Katrina and Rita of 2005 were exacerbated by global climatic change is still being debated.

Louisiana is also vulnerable to increased impacts on public health resulting from global climatic changes. Owing to its location near the poleward margin of the domain of tropical diseases, small increases in frost-free season length may be accompanied by significantly more cases of encephalitis, West Nile virus, dengue fever, and other tropical diseases. Increased impacts of heat waves will affect the disadvantaged and elderly disproportionately. Moreover, as summer temperatures rise under clear skies, tropospheric ozone is likely to become an increasing problem in the U.S. Environmental Protection Agency-designated Baton Rouge non-attainment zone and elsewhere. Effects of tropospheric ozone include respiratory illness, damage to plant membranes, and increased oxidation rates on physical structures. Rising temperatures will also increase the bacterial contamination of shellfish. Rises in water tables induced by additional precipitation and/or sea level rise would also place contaminants from dump sites and viruses and bacteria from septic systems closer to the surface, magnifying the impact on humans and livestock.

Agriculture and forestry in Louisiana will also be affected by global warming-induced climatic changes. Although some impacts may be positive, owing primarily to increases in growing season length, others place Louisiana in a more precarious situation. Pest populations would probably increase under longer frost-free seasons, and the additional "fertilization" by elevated carbon dioxide (CO_2) may benefit weeds more than crops, increasing expenses for pest and weed control. If precipitation decreases, the percentage of Louisiana farmland that is irrigated will increase from the current 25 percent, as will irrigation costs per acre. Landscape desiccation would also increase forest fire frequency, as in other states.

The costs of national and international policy changes regarding fossil fuel production and consumption may be felt more in Louisiana than in any other state except Alaska. Research on alternative energy sources and on reducing environmental impacts of fossil fuels may provide solutions that will preserve Louisiana's role as an energy producer while minimizing environmental impacts. Plans may involve using natural gas or methane hydrates from the Gulf of Mexico floor to produce hydrogen for fuel cells, sequestering the solidified carbon waste in the thousands of abandoned oil and gas wells throughout

Louisiana, and transporting hydrogen fuel via the vast network of existing pipelines.

SEE ALSO: Diseases; Hurricanes and Typhoons; Louisiana State University; Salinity; Sea Level, Rising.

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RESEARCH IN CLIMATIC change and variability at Louisiana State University (LSU) in Baton Rouge, Louisiana has been ongoing since the 1930s when coastal geomorphologist Richard J. Russell completed maps showing spatial variation through time in the Koeppen climatic boundaries across the United States. Since that time, climatic change research at LSU has focused on synoptic-to-global-scale atmospheric circulation, hydroclimatology, paleoclimatology, and surface/atmosphere interactions. Researchers affiliated with the Department of Geography and Anthropology accomplished the majority of the work, but other scientists on campus also make contributions, from the Department of Oceanography and Coastal Sciences, Department of Geology and Geophysics, Hurricane Research Center, LSU AgCenter, and Earth Scan Lab.

Most of the work on atmospheric circulation trends has been at the multi-decadal timescale. The study of the long-term nature of atmospheric circulation at LSU was begun by Robert Muller, whose contributions to atmospheric circulation research over five decades have centered on manual synoptic typing and, more recently, long-term changes to tropical cyclone frequencies in the Atlantic/Gulf of Mexico basins. LSU climatologists have applied manual synoptic typing to New England and automated typing techniques to the Great Lakes region.

The work on temporal trends in cyclones has also been expanded to include extratropical coastal storms and winter storms in New England. Muller also introduced hydroclimatology to LSU through his work on long-term changes in the water balance of the United States.

Work since that time has expanded to include trends in heavy rainfall, precipitation in general, water balance-modeled streamflow and runoff, and dew-point variability in the southeastern United States.

Other work by LSU scientists has investigated decadal-scale changes to such features as surface anticyclones, the Northern Hemispheric circumpolar vortex, teleconnections and their relationship to the circulation and precipitation of the Gulf of Mexico region, and circulation impacts on east-African precipitation.

Other examples of recent work directly related to global climatic circulation changes have involved assessment of model representation of the North Atlantic Oscillation, and the association of the North Atlantic Oscillation to the Arctic Oscillation.

A third research emphasis has emerged since the 1990s, under the leadership of Kam-biu Liu, in paleoclimatology. One major focus is on Quaternary paleoenvironmental reconstruction using pollen and phytolith proxies. Thematic examples include palynological evidence for long-term changes in the Asian monsoon and Amazonian ecosystems, and high-resolution pollen records of El Niño-Southern Oscillation (ENSO) and monsoon changes from Andean and Tibetan ice cores. Another focus of this group has involved the use of coastal lake-sediment proxy records to infer the Holocene history of tropical cyclone landfalls—the new field of paleotempestology.

To date, Liu's research group has conducted paleoenvironmental and paleotempestological reconstructions throughout the Gulf-Atlantic coast of the United States, Central America and the Caribbean, the Amazon basin, the Bolivian Altiplano, East Africa, the Tibetan Plateau, Mongolia, and East Asia.

The impact of climatic changes on the lithosphere and ocean has also been the subject of recent research at LSU, in the tradition of R.J. Russell, James P. Morgan, and J.M. Coleman. For example, Mike Blum has investigated responses of large river systems to climate and sea-level change. Patrick Hesp's research on changes to barrier-island ecosystems under climatic forcing mechanisms also falls within this realm. Likewise, Gregory Stone has analyzed the effects of tropical cyclones and winter storms on coastal morphosedimentary dynamics and post-storm adjustment, and Masamichi Inoue observes deepwater circulation changes by a mooring deployed in the eastern Gulf of Mexico.

In addition to the research and teaching mission of LSU climatologists, service has traditionally played an important role. Four state climatologists (George Cry, Robert Muller, John "Jay" Grymes, and Barry Keim) have distributed climatic data for the state that has been used in research on climatic change. In addition, since 1990, staff associated with LSU's Southern Regional Climate Center, directed by Muller and later, Kevin Robbins, has archived and distributed data for the six-state region of Arkansas, Louisiana, Mississippi, Oklahoma, Tennessee, and Texas. Several papers have been published on the applicability, utility, and limitations of climatic data.

SEE ALSO: Hurricanes and Typhoons; Louisiana; Weather.

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Luxembourg

THE LANDLOCKED GRAND Duchy of Luxembourg, which has land borders with Belgium, Germany and France, has a land area of 999 sq. mi. (2,586 sq. km.), with a population of 467,000 (2006 est.), and a population density of 469 people per sq. mi. (171 people per sq. km.). Approximately 58 percent of the electricity used in Luxembourg comes from fossil fuels, with 25.6 percent from hydropower. With a very high standard of living, Luxembourg has the sixth highest per capita levels of carbon dioxide (CO_2) emissions in the world, the highest rating for a country that is not reliant on petroleum for its economy. This was calculated at 26.3 metric tons per person in 1990, rising to a peak of 30.5 metric tons per person in 1992 (the second highest in the world in that year, after Qatar), falling to 17.4 metric tons by 1998, and rising again to 22 metric tons in 2003. Sixty-seven percent of the CO_2 emissions coming from liquid fuels, 19 percent from gaseous fuels, 10 percent from solid fuels, and 4 percent from the manufacture of cement. The high level of liquid fuels is because 50 percent of the emissions, by sector, come from transportation. In spite of excellent public transport in the country, there is still heavy use of privately owned automobiles. Manufacturing and construction make up 19 percent of CO_2 emissions, with 18 percent from residential use. These figures exclude the CO_2 generated by electricity and heat production.

Since the 1990s, green parties have been elected. The Luxembourg government ratified the Vienna Convention in 1988, and took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992. It signed the Kyoto Protocol to the UN Framework Convention on Climate Change on April 29, 1998, which was ratified by the Luxembourg Chamber of Deputies on May 31, 2002, on the same day as the other member states of the European Union; it took effect on February 16, 2005.

SEE ALSO: Belgium; France; Germany.

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Macedonia (FYROM)

THE FORMER YUGOSLAV Republic of Macedonia (FYROM) has a land area of 9,779 sq. mi. (25,333 sq. km.), a population of 2,038,000 (2006 est.), and a population density of 205 people per sq. mi. (79 people per sq. km.). With a strong agricultural base, 24 percent of the country is classified as arable, with a further 25 percent used as meadows and pasture, and 39 percent is forested. Much of the pasture is for raising sheep, with large flocks reared on the Bistra Mountains.

In terms of carbon dioxide emissions, the per capita rate for Macedonia has been relatively stable, at 5.5 metric tons per person in 1992, falling slowly to 5.2 metric tons by 2003. As for the country's electricity production, 82.3 percent comes from fossil fuels, with 17.7 percent from hydropower. The result has been that 76 percent of emissions by source come from solid fuels, 22 percent from liquid fuels, and the remaining 2 percent from the manufacture of cement. By sector, electricity generation and heat production account for 71 percent of all carbon dioxide emissions, with 11 percent from transportation. The country has a relatively poor system of public transport, with a small railway network, only a third of which is electrified. Climate change and global warming are likely to have a severe effects on Lake Doiran, where fishermen from Macedonia source much of their fish stock.

The Macedonian government took part in the United Nations Framework Convention on Climate Change in May 1992, which they ratified in 1998. Macedonia also ratified in the Vienna Convention in 1994.

SEE ALSO: Agriculture; European Union; Transportation.

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Madagascar

THE MOST RECENT effect of climate change and global warming in Madagascar has been an increase in El Niño effects, which are associated with drought conditions and increased wildfires. In addition, there has been an increase in the intensity and number of cyclones, which displaces human communities and leads to local famine and cholera outbreaks. Madagascar's western coast, mangrove forests are particularly susceptible to any increase in sea levels. Although warmer ocean temperatures caused by global climate change have been recorded in northern Madagascar, the effects of this change on the coral reefs in the region have been mitigated, at least temporarily, by cooler water from deep ocean currents. Madagascar's unique flora and fauna are also susceptible to climate change. For example, reduced rainfall has negatively affected endangered sifaka lemur populations. The impact of climate change and global warming in Madagascar is exacerbated by deforestation resulting from increased population and unsustainable swidden farming and logging that has reduced forest cover and increased desertification, causing higher temperatures, lower humidity, and diminishing annual rainfall.

Efforts to reduce the effect of climate change and global warming on Madagascar's flora and fauna include the U.S. Agency for International Development's attempt to reduce brush fires, which, in addition to destroying vegetation, release carbon into the atmosphere. The Wildlife Conservation Society, Conservation International, and the government of Madagascar's Makira Forest Project seek to protect over 300,000 hectares of rainforest in northeastern Madagascar. It is hoped that the Makira Forest will offset 9.5 million tons of carbon dioxide (CO_2) over 30 years through carbon sequestration, preserve habitat for threatened species, and provide economic opportunities for local indigenous communities.

SEE ALSO: Carbon Sequestration; Cyclones; Deforestation; Desertification; El Niño and La Niña; Indian Ocean; Sea Level, Rising.

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Maine

LOCATED AT THE northeastern tip of the United States, Maine is known chiefly for its wood and seafood products. Nearly 90 percent of its land area is forested, and 21,000 acres (85 sq. km.) are designated as state forests. Maine has 3,478 mi. (597 km.) of tidally influenced shoreline. These forests and coastlines are particularly vulnerable to climate changes caused by global warming. The U.S. Environmental Protection Agency reports that rainfall in parts of Maine has decreased by 20 percent over the last century. In the future, the sea level in Rockland is predicted to rise as high as 14 in. (36 cm.), leading to coastal flooding, beach erosion, and the loss of valuable wetlands. As a result of this vulnerability, Maine has taken decisive action in establishing policies, priorities, and actions designed to modify human behaviors associated with global warming and climate change.

PROGRESS

Between 1990 and 2001, the population of Maine increased by 5 percent. During that same period, carbon dioxide (CO_2) emissions rose by 20 percent to a total of 22.7 million metric tons. In 2005, Maine established new standards for motor vehicle emissions based on those already in place in California. As a result of these efforts, Maine now has the eighth lowest level of CO_2 emissions in the United States. The Public Utilities Commission acted in 1999 to move Maine toward renewable energy, requiring that 30 percent of all power come from renewable sources, such as fuel cells, tidal power, solar, wind, geothermal, hydroelectric, biomass, and solid-waste fueled generators.

In 2001, the New England governors and Eastern Canadian premiers began developing plans to reduce the levels of greenhouse gas emissions throughout the area. In addition to establishing a Greenhouse Gas (GHG) Emissions Inventory, the plan called on members to develop specific plans for reducing GHG emissions and for energy conservation, educating the public, leading by example, reducing GHG emissions from electric power plants, conserving energy, and reducing the overall impacts of climate change. In 2006, Maine received an overall grade of "B" for actions taken on accomplishing these goals. The report card cited progress in purchasing hybrid vehicles for the state, establishing LEED standards in

A Maine moose in wetlands. The state is also known for its extensive shoreline, but the sea level in Rockland is predicted to rise, leading to coastal flooding, beach erosion, and the loss of wetlands.

new and renovated state buildings, reducing travel miles of state employees, reducing energy consumption, increasing the use of clean energy, developing strict vehicle emission standards, and focusing on renewable energy and carbon-neutral generators. The report card stated that improvements were needed in the areas of fuel efficiency, education, research, and mandated building codes.

The responsibility for overseeing environmental factors that lead to global warming and climate change is divided among several departments in Maine. The Department of Environmental Protection encompasses the divisions of Air Quality, Land and Water Quality, and Remediation and Waste Management, as well as the Board of Environmental Protection. The Bureau of Health, which operates under the auspices of the Department of Human Services, manages the Health and Environmental Testing Laboratory, the Environmental Health Unit, and the Division of Health Engineering. Other agencies with environmental responsibilities include the Department of Agriculture, which includes the Board of Pesticide Control, the Department of Conservation, the Department of Inland Fisheries and Wildlife, the Department of Marine Resources, and the State Planning Office, which oversees land use, coastal management, natural resources, waste management, and recycling.

PROGRAMS

In 2003, Maine became the first state in the United States to set a specific target for reducing GHG emissions. Established by an act to provide leadership in addressing the threat of climate change, the Greenhouse Gas Reduction Target Program mandates that emissions be restored to 1990 levels by 2010, and reduced an additional 10 percent by 2020. Long-term plans entail drastic reductions that may reach 75 to 80 percent of 2003 levels. The new standards work in conjunction with Maine's Clean Car Program, which was established in 1999. The program encourages residents to commit to reducing vehicle emissions, the greatest source of pollution in the state. Vehicles that meet established standards are allowed to display a "Cleaner Cars for Maine" sticker. To cut down on toxic emissions, consumers are advised to make sure that all car purchases are green, and drivers are encouraged to reduce driving time, avoid idling engines, accelerate gradually, avoid speeding, fill gas tanks during cooler periods of the day, refrain from spilling gas and topping off tanks, and reduce use of air conditioning. Since maintenance habits may also affect the environment, Maine drivers are requested to use energy-conserving motor oils, get regular check-ups, replace filters and oil frequently, keep tires properly inflated and aligned, and repair all leaks.

Maine's State Planning Office began working on the issue of climate change in the mid-1990s. When the working grant from the U.S. Environmental Protection Agency was exhausted, some members reformed as Maine Global Climate Change, Inc., for the purpose of educating the public about human behaviors that affect global warming and climate change. The group was successful in convincing the legislature to appoint a state climatologist. In 2004, Maine established a Climate Action Plan, targeting the transportation, industrial, commercial, institutional, and residential sectors as a means of controlling the emission of greenhouse gases by protecting the state's resources. The Department of Environment Protection announced 54 specific actions that had been proposed by working groups from all sectors, including forestry, land use, and transportation. Reporting and assessments were considered essential to keeping policies and responses up-to-date.

In 2007, Maine launched the Whole House pilot plan designed to provide homeowners with a one-way stop to transform their homes into energy-saving dwellings capable of reducing energy costs, fuel consumption, and greenhouse gas emissions. Using a plan developed by Energy Star, the Whole House project initially targeted 1,500 homes in southern and central Maine. Proponents of the plan promise the residents of Maine that, by working with a certified Home Performance contractor, they will be able to reduce energy costs, improve family health and safety, increase comfort, lower carbon footprints, and increase equity.

Maine's Smart Tracks for Exceptional Performers and Upward Performers (STEP-UP) program offers recognition and incentives to businesses that become involved in sustainable practices designed to mitigate the results of global warming and climate change. Actions taken are dependent on the type of businesses involved in the endeavor. For instance, Pratt & Whitney, which manufactures aerospace engine parts in North Berwick, pledged to reduce total energy consumption by 10 percent, total air emissions by 20 percent, water discharge by 30 percent, and the total amount of transported solid waste by 30 percent by 2008.

SEE ALSO: Automobiles; Greenhouse Gases; Energy; Transportation.

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Malawi

THE LANDLOCKED REPUBLIC of Malawi, formerly the British colony of Nyasaland, has a land area of 45,747 sq. mi. (118,484 sq. km.), a population of 13,925,000 (2006 est.), and a population density of 282 people per sq. mi. (109 people per sq. km.). About 34 percent of the country is arable, with a further 20 percent used for meadows and pasture. In addition, 50 percent of the country is forested.

As for the production of electricity in Malawi, 97 percent comes from hydropower, with only 3 percent from fossil fuels. The introduction of hydropower was remarkably recent, with the first water turbine and generator brought into the country in 1966 and installed at Nkula Falls on the Shire River in 1966, with plans having been drawn up for it as early as 1942. As a result of this reliance on hydropower, and the country remaining largely undeveloped, per capita carbon dioxide emissions were 0.1 metric tons in 1990, falling to 0.07 metric tons by 2003, far lower than most other countries in sub-Saharan Africa. Eighty-two percent of the total carbon dioxide emissions in the country are from liquid fuels, 6 percent from solid fuels, and 12 percent from the manufacture of cement.

By 1995, the population had reached the limit at which it could be sustained on the existing arable land of the country, and from then on, parts of the country experienced occasional shortages of firewood. The effects of global warming and climate change are expected to impact heavily on Malawi, which has already experienced periods of drought throughout its history, leading to migrations around Lake Nyasa. However, there are extensive underground water resources in the country, and these have been tapped since the 1950s, providing a water source that could help Malawi through a short period of drought.

The Malawi government ratified the Vienna Convention in 1991 and took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, which they ratified in 1994. It accepted the Kyoto Protocol to the UN Framework Convention on Climate Change on October 26, 2001, which took effect on February 16, 2005.

SEE ALSO: Deforestation; Desertification; Drought; Framework Convention on Climate Change.

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Malaysia

THE FEDERATION OF Malaysia, located in Southeast Asia, has a land area of 127,355 sq. mi. (329,847 sq. km.), with a population of 27,278,100 (2007 est.), and a population density of 213 people per sq. mi. (82 people per sq. km.). Three percent of Malaysia's land is arable, and 58 percent is covered in forests, although there has been a rise in the rate of deforestation from the 1980s.

With a large increase in industrialization, and the enlarging of manufacturing industry, the demand for electricity in Malaysia has increased considerably since the 1970s, with 88 percent of its electricity coming from fossil fuels, and only 12 percent from hydropower. As a result, electricity contributes to 28 percent of the country's carbon dioxide emissions, with 23 percent from manufacturing, and 28 percent from transportation. The latter figure comes from a high rate of private ownership of cars which, since the development of the Proton, has become more affordable for many people in the country, in spite of a relatively good system of public transport, mainly buses, covering much of the country. This has helped contribute to the fact that 54 percent of carbon dioxide emissions come from liquid fuels, 30 percent from gaseous fuels, and 6 percent from gas flaring (Malaysia has its own petroleum and natural gas industries). Solid fuels account for only 6 percent of emissions, with cement manufacturing making up the remaining 4 percent.

EFFECT OF GLOBAL WARMING

Malaysia has been affected in a number of ways by global warming and climate change. Rising temperatures have resulted in the bleaching of coral reefs along Malaysia's coasts, and have raised potential problems for marine life, especially fish and turtles (the latter nesting on some beaches in Terengganu, on Malaysia's east coast). Penang, off the west coast of Peninsular Malaysia, was affected by the Boxing Day 2004 Tsunami, and there has been increased risk of flooding in Sarawak and Sabah, leading to the possibility of a rise in insect-borne diseases such as malaria and dengue fever.

The Mahathir government of Malaysia ratified the Vienna Convention in 1989, and took part in the United Nations Framework Convention on Climate

Change signed in Rio de Janeiro in May 1992, which they ratified two years later. The Malaysian government signed the Kyoto Protocol to the UN Framework Convention on Climate Change on March 12, 1999, which was ratified on September 4, 2002, and took effect on February 16, 2005.

SEE ALSO: Deforestation; Developing Countries; Oil, Production of.

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Maldives

LOCATED IN THE Central Indian Ocean, the Maldives is a country composed of more than 1,190 low lying coral islands, many of which contain a large number of endemic species. With no coal, oil, or natural gas reserves, the country is reliant on imported oil and domestic wood resources to meet the majority of its energy needs. As a result, the Maldives is not a major producer of greenhouse gases and is not a significant contributor to climate change. Despite this, the Maldives, like other small island developing states, is likely to be greatly affected by climate change.

The Maldives faces many of the development challenges confronting other small island states. These include geographic isolation, dependence on tourism, and reliance on coastal and marine resources. In addition, though the country's population is small in absolute terms, many of the islands have high population densities and the country's population is distributed among various islands. While these characteristics represent obstacles to economic development, they also render the country vulnerable to the impacts of climate change, particularly as the country has limited resources with which to offset its impacts.

Given its relatively large coastline, the Maldives is vulnerable to an array of marine threats such as wave surges, tropical storms, and coastal erosion. These natural phenomena are expected to increase in severity or frequency as a result of climate change and are therefore a source of growing concern. However, it is sea-level rise that poses the greatest threat to the Maldives. With a maximum elevation of 7.8 ft. (2.4 m.) above sea level, small fluctuations in sea level could render much of the country uninhabitable as a result of inundation and saltwater infiltration into agricultural soils and groundwater resources, necessitating the relocation of many of the country's inhabitants.

THREAT TO ITS EXISTENCE

The population and government of the Maldives have long been aware of the threat that climate change and sea-level rise in particular pose to their country. In numerous statements, the president of the Maldives, Maumoon Abdul Gayoom, has pleaded with the international community to reduce greenhouse gas emissions. For example, in his 1992 speech at the United Nations Conference on Environment and Development in Rio de Janeiro, Maumoon Abdul Gayoom highlighted that global climate change threatened the very existence of his country and that global concerted action was required to save the Maldives and other low lying countries. However, given the Maldives's modest political influence, the government's ability to bring about such reductions is limited. In addition, the Maldives has been actively involved in the Alliance of Small Island States (AOSIS), a lobbying and negotiating body representing the needs of small island developing states at the level of the UN. Through AOSIS, the Maldives has continued to lobby for reductions in greenhouse gas emissions globally.

SEE ALSO: Alliance of Small Island States (AOSIS); Hurricanes and Typhoons; Sea Level, Rising.

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Mali

THE REPUBLIC OF Mali is located in western Africa, covering 478,767 sq. mi. (1,240,000 sq. km.), equivalent to an area twice the size of Texas. Mali has a population of 12,291,529 people (2005 est.) with about 80 percent of the labor force engaged in agricultural production and processing. Mali is among the poorest countries in the world, with a per capita gross domestic product of $900 (2004 est.). 64 percent of the population lives in poverty. Significant agricultural products include cotton, cereal crops, vegetables, peanuts, and livestock. Three geographic and meteorological zones characterize Mali: Saharan (desert/arid), Sahelian (shrub savanna/subtropical); and Sudanese (wooded savanna/tropical). Likewise, there are three distinct seasons: hot and dry (March to May); rainy (June to October); and cool and dry (November to February). Temperatures in Mali can drop as low as 41 degrees F (5 degrees C) at night in January and then reach 104–113 degrees F (40–45 degrees C) during the day from April to June.

Five environmental issues facing the country are deforestation, soil erosion, desertification, inadequate supplies of drinking water, and the poaching of wildlife. Mali is a party to the following International Environmental Agreements: Biodiversity, Climate Change, Climate Change-Kyoto Protocol, Desertification, Endangered Species, Hazardous Wastes, Law of the Sea, Ozone Layer Protection, and Wetlands. Given that Mali is periodically prone to droughts, the general population does have some sense of climate change awareness, as older generations have witnessed significant changes within their lifetimes. The development priorities of the Malian government also include addressing climate change.

The contributions that Mali makes to human-induced climate change are minimal compared to the rest of sub-Saharan Africa and the world. For example, per capita carbon dioxide emissions in 1998 were only 100 metric tons, compared to an average of 800 tons for the sub-continent, and the global average of 4,100 metric tons. Likewise, sulfur dioxide emissions in 1995 totaled 14,000 metric tons (less than one-third of 1 percent of the entire total for sub-Saharan Africa), while nitrogen oxide and carbon monoxide emissions (also in 1995) represented just 0.006 percent and 0.007 percent, respectively, of the total for all of sub-Saharan Africa.

Climate change could have significant consequences for the people, environment, and development of Mali. Climatic change, leading to a shorter rainy season and higher average temperatures, would lead to desertification of currently farmed areas in the central part of the country. Less rainfall would also impede the country's ability to produce hydroelectricity, which is already a problem during the dry season. Also, the intensification of rainfall could have serious effects on soil erosion. Finally, changes in rainfall patterns may also lead to changes in cropping patterns and, ultimately, changes in people's livelihoods, as both farmers and herders retreat toward the south in search of arable land and grazing areas.

SEE ALSO: Deforestation; Desertification; Drought.

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Malta

THE REPUBLIC OF Malta consists of three main islands in the Mediterranean Sea, and has a land area of 121 sq. mi. (316 sq. km.), consisting of the islands of Malta (246 sq. km.), Gozo (67 sq. km.), Comino (2.7 sq. km.) and the uninhabited islets of Cominotto, Filfla, and St. Paul. It has a population of 407,000 (2006 est.), and a population density of 3,339 people per sq. mi. (1,282 people per sq. km.), making it the 7th most densely populated country in the world. Although officially, 32 percent of the land is arable, with wheat and potatoes grown widely, the soil is poor.

Because of its hot temperature and extensive tourist industry, Malta has a relatively high per capita rate of carbon dioxide emissions, with 6.2 metric tons per person in 1990, rising to 8.7 metric tons per person in 1997, and then falling steadily to 6.2 metric tons by 2003. With 53 percent of all emissions in the country from electricity, heavily used for air conditioning, the entire electricity production in the country comes from fossil fuels, accounting for 40 percent of all carbon dioxide emissions coming from solid fuels. The remaining 60 percent of the carbon dioxide emissions is from liquid fuels, with transportation making up 15 percent of the country's entire emissions. In spite of its small size, there is a high private ownership of automobiles, many of which are increasingly old and inefficient in their use of fuel, resulting in heavy congestion and noticeable smog coming not only from traffic, but also from coal-fired power stations and factories.

The effects of global warming and climate change on Malta will be dramatic. The country already suffers from low agricultural production, and has shortages of water, resulting in Malta needing to build several large desalination plants, further increasing the strain on the power grid. It is also expected that rising temperatures in the Mediterranean might result in a decline in the number of fish, further hurting an already declining fishing industry. The Maltese government ratified the Vienna Convention in 1988 and took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992. The government signed the Kyoto Protocol to the UN Framework Convention on Climate Change on April 17, 1998. It was ratified on November 11, 2001, and took effect on February 16, 2005.

SEE ALSO: Italy; Salinity; Tourism.

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Manabe, Syukuro (1931–)

AS A JAPANESE meteorologist generally regarded as the world's leading scientist in the field of numerical modeling of climate and climate change, Syukuro Manabe pioneered the use of computers to simulate global climate change and natural climate variations. Manabe was one of the first scientists to study the phenomenon of global warming in the 1970s, when he investigated the possibility that the emissions of great quantities of carbon dioxide and other greenhouse gases from the combustion of fossil fuels such as coal, oil, and natural gas could affect climate.

Born in 1931, Manabe graduated from the University of Tokyo in 1958. The post-war period was a difficult time for scientists in Japan. Manabe was among those who, like Akio Arakawa, found better career opportunities in the United States, where the Cold War kept steady government funding for fields such as geophysics and computer science. Manabe was hired as a researcher by Joseph Smagorinsky, then the director of the U. S. Weather Bureau near Washington, D.C. Smagorinsky wanted to develop the insights of John von Neumann and Julie Charney into a general circulation model of the entire three-dimensional global atmosphere, built directly from the primitive equations.

PIVOTAL MODEL

Smagorinsky and Manabe put into their model details that would be influential for the discovery of global warming. Their model accounted for the way rain fell on the surface and evaporated, how radiation passing through the atmosphere was impeded, not only by water vapor but also by ozone and carbon dioxide gas (CO_2), how the air exchanged water and heat with simplified ocean, land, and ice surfaces, and much more. Manabe had always been interested in the effects of CO_2, and the impact of CO_2 on the future climate. Manabe's interest stemmed from the consideration that the gas at its current level was a significant factor in balancing the planet's heat. When Fritz Möller theorized that even mild perturbations and human actions could cause a global catastrophe, Manabe decided to work on a model that might account for how the climate system might change. He came to the conclusion that the entire atmosphere had to be studied as a tightly interacting system. In his model, Manabe took full account of water in all its forms. It included the feedback between the air's temperature and the amount of moisture the air would hold. In particular, Manabe calculated the way rising columns of moisture-laden air conveyed heat from the surface into the upper atmosphere.

In 1967, Manabe used a one-dimensional model to test what would happen if the level of CO_2 changed. He targeted the climate's "sensitivity," a feature that would eventually become a central preoccupation of modelers. Together with his group, he set out to calculate how much the variation of incoming and outgoing radiation would alter temperature. The answer they reached was that if the levels of CO_2 doubled by the end of the century, as seemed possible, global temperature would rise roughly 3–4 degrees F (around 2 degrees C). This was the first time a greenhouse warming calculation included enough of the essential factors, including the correct estimate for water vapor feedback, to seem reasonable to many scientists. Many of them who were to play an influential role in global warming debates, such as Wallace Broecker, recalled that it was these data that made them embrace research into the phenomenon.

In 1968, Smagorinsky and Manabe's group, which had been renamed the Geophysical Fluid Dynamics Laboratory in 1963, moved from the Washington, D.C., area to Princeton, and it eventually came under the wing of the U.S. National Oceanic and Atmospheric Administration. Manabe continued to work, together with fellow meteorologists, on general circulation models of the atmosphere, trying to make them more complex and comprehensive. In 1967, he and Richard Wetherald demonstrated that increasing atmospheric CO_2 absorptions would increase the height at which the Earth radiated heat to space. In 1969, Manabe and Kirk Bryan published the first simulations of the climate which combined ocean and atmosphere models. This was the first time that the role of oceanic heat transport was taken into account in determining global climate. Throughout the 1970s and 1980s, Manabe's research group published influential papers using these models to explore the sensitivity of the Earth's climate to the variations of greenhouse gas concentrations. These papers formed a major part of the first global assessments of climate change, published by the Intergovernmental Panel on Climate Change (IPCC), established in 1988.

From 1997 to 2001, Manbe went back to Japan at the Frontier Research System for Global Change serving as Director of the Global Warming Research Division. In 2002, he returned to Princeton University as a visiting research collaborator at the Program in Atmospheric and Oceanic Science. During his distinguished career, Manabe has received many honors and awards. He is a member of the United States National Academy of Sciences, and a foreign member of Academia Europaea and the Royal Society of Canada. In 1992, he was the first recipient of the Blue Planet Prize of the Asahi Foundation. In 1997, Manabe was awarded the Volvo Environmental Prize from the Volvo Foundation. Manabe has also been awarded the American Meteorological Society's Carl-Gustaf Rossby Research Medal, the American Geophysical Union's Revelle Medal, and the Milutin Milankovitch Medal from the European Geophysical Society.

SEE ALSO: Arakawa, Akio; Computer models; Geophysical Fluid Dynamics Laboratory; Global Warming; Historical Development of Climate Models; Japan; National Oceanic and Atmospheric Administration (NOAA).

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Marine Mammals

MARINE MAMMALS ARE members of the Class Mammalia possessing significant adaptations to allow them to live in an aquatic environment (to a greater or lesser extent) and derive all (or most) of their nutritional needs from the sea. Some marine mammals are entirely aquatic, while others may spend part of their lives on land. The polar bear, for example, is considered a marine mammal, as it typically inhabits pack ice (up to 807 mi., or 1300 km. from shore); it will attack prey in the water and relies almost entirely on marine species for prey; it has adaptations for a marine environment; and is able to swim long distances. Most significantly, the polar bear is dependent upon the marine environment ecologically.

Other marine mammals include two species of otter (Order Carnivora; family Mustelidae): the marine otter (*Lontra felina*) and sea otter (*Enhydra lutris*). *Myotis vivesi,* the marine-dependent fishing bat (Order Chiroptera), might also be considered to be a marine mammal. Less debatable marine mammals are the manatees and dugongs (Order Sirenia), whales, dolphins, and porpoises (Order Cetacea) and the various species of seal (Order Pinnipedia). The pinnipeds include true seals (family Phocidae), walruses (family Odobenidae), and eared seals (family Otariidae), the last of which, in turn, contains sea lions (sub-family Otariinae) and fur seals (sub-family Arctocephalinae).

There has been much concern about the impacts of climate change on marine mammals, particularly polar bears, cetaceans, and pinnipeds. Likely effects include shifts or depletion of important prey species, changes in distribution, exposure to new diseases and predators, and habitat loss. Several arctic-dwelling seal species haul out onto ice to give birth, and may be vulnerable to reductions in area, or thinning, of sea ice. Loss of ice as a haul-out substrate and fierce storms have led to several seasons of high harp seal pup (*Pagophilus groenlandicus*) mortality in the Gulf of St. Lawrence, Canada. As humans cull juveniles of this population, this adds an additional stressor to the population. Pinnipeds are also very well-adapted to cold temperatures and global warming may lead to heat stress.

SEE ALSO: Polar Bears; Sea Ice.

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Marshall Institute

THE GEORGE MARSHALL Institute (GMI) is a nonprofit organization founded in 1984. The mission of the Institute is to improve the use of science in making public policy about important issues for which science and technology are major considerations. Current research programs focus on such issues as national security and the environment.

The Marshall Institute seeks to counter this trend by providing policymakers with rigorous, clearly written and unbiased technical analyses on a range of public policy issues. Through briefings to the press, publication programs, speaking tours and public forums, the Institute seeks to preserve the integrity of science and promote scientific literacy. The Marshall Institute is located in Washington, D.C., and run by President Jeff Kueter as well as governed by a board of directors. Among the many programs at GMI is the climate change program. This program involves a critical examination of the scientific basis for global climate change policy. The intent is to promote a clear understanding of the state of climate science and assess the implications for public policy. A major component of this effort is communicating the findings to policy makers, the media, and the public policy community.

CONTROVERSY AND UNDERSTANDING

There has been an ongoing debate about the contribution of human activities to the global warming of the past century and how they may contribute to warming that may occur during the 21st century. International efforts to reach agreement on inferences about human influence on the climate system that can be drawn from science and policy prescriptions for addressing the climate change risk have been controversial.

Effective climate policy flows from a sound scientific foundation and a clear understanding of what science does and does not tell us about human influence and about courses of action to manage risk. Much of the data collected from temperature probes and computer models used to predict climate change are themselves uncertain. Reducing these many uncertainties requires a significant shift in the way climate change research is carried out in the United States and elsewhere.

The Institute has compiled a list of commonly asked questions and answers regarding global warming and climate change. These have been posted on the institute website to further educate the public and direct policy. GMI works on a range of issues, including civic environmentalism, climate change, national defense, bioterrorism, and missile defense. GMI publishes papers and holds roundtables. Many of these roundtables have featured climate change skeptics such as Roger Bate, Willie Soon, Margo Thorning, and GMI's own Sallie Baliunas.

In 1989, GMI released a report arguing that "cyclical variations in the intensity of the sun would offset any climate change associated with elevated greenhouse gases." Although it was refuted by the IPCC, the report was used by the George H.W. Bush Administration to argue for a more lenient climate change policy. GMI has since published numerous reports and articles attacking the Kyoto protocol and undermining climate science. GMI is a former member of the Cooler Heads Coalition.

Between 1985 and 2001, the institute received $5.5 million in funding from five foundations, including the Earhart Foundation, Sarah Scaife Foundation, and Lynde and Harry Bradley Foundation. In 2003, GMI's climate-change program received $95,000 from the Exxon Education Foundation, and $60,000 from the American Petroleum Institute. GMI's CEO, William O'Keefe, formerly an executive at the American Petroleum Institute and chairman of the Global Climate Coalition, is a registered lobbyist for ExxonMobil. The GMI was described in a 2007 report by the Union of Concerned Scientists as an ExxonMobil-funded "clearinghouse for global warming contrarians". ExxonMobil still continues to provide funds to the Marshall Institute.

SEE ALSO: Bush (George H.W.) Administration; Global Warming; Greenhouse Gases; Kyoto Protocol.

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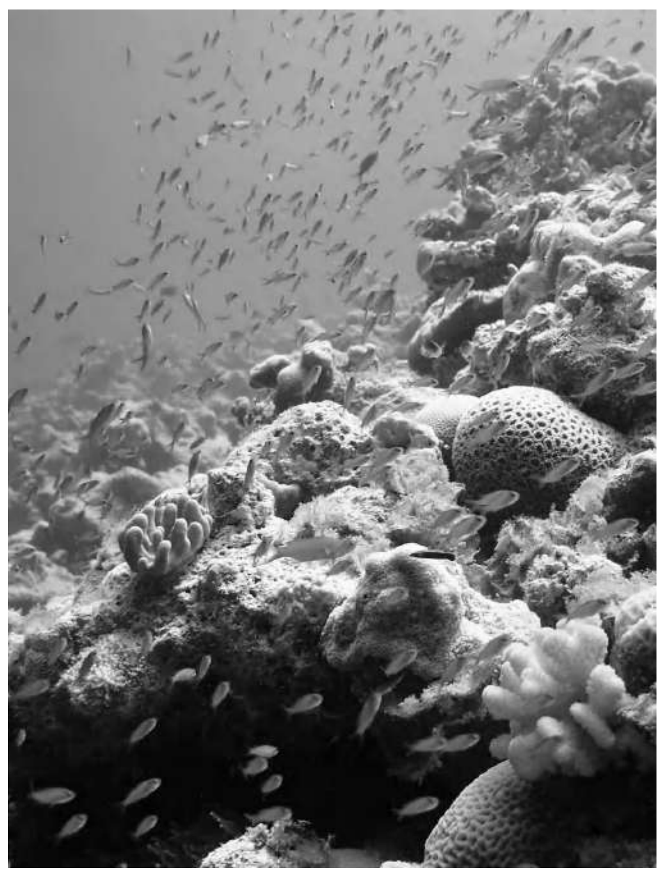
Marshall Islands

THE REPUBLIC OF the Marshall Islands (RMI) is a Pacific island nation that inhabits a fragile atoll ecosystem with no significant elevation above sea level. Susceptibility to tropical storms and economic dependence on coral reef ecology combine to produce a high risk that climate change will threaten the nation's survival. RMI can do little to ameliorate or reduce potential impacts. It is likely that land mass will be reduced, storm damage will increase, and the coral reef ecosystem will disintegrate with increasing ocean temperature, rising sea level, and atmospheric disturbances. RMI has been among the leading nations advocating a planetary response to these issues, most notably through testimony before the United Nations Climate Change Conference and UN Security Council, and active involvement in the Alliance of Small Island States. RMI consists of 29 coral atolls organized into the Ratak and Ralik chains in the western Pacific Ocean



Damselfish swarm around a coral reef in the Republic of the Marshall Islands, which consists of 29 Pacific coral atolls.

located between 2–14 degrees north and 160–173 degrees east. Total land area of RMI is 69.5 sq. mi. (180 sq. km.), with an average elevation of less than 6.5 ft. (2 m.). RMI population is 59,071 (2005 est.), with 38.2 percent of the population under age 15. The Marshallese are Micronesians who migrated from Asia several thousand years ago. More than half of the population is concentrated in two locations: Majuro, an atoll containing the capital city of Majuro; and Ebeye, an islet adjacent to the U.S. military base on Kwajalein Atoll.

RMI became an independent nation in 1986, but remains economically dependent on the United States due to historic and current military installations. Most commercial fishing is by licensed foreign fisheries. Small farms produce coconuts, tomatoes, melons, and breadfruit. Small-scale industry is limited to handicrafts, fish processing, and copra. Cultural integrity has historically been tied to land- and ocean-based food production. Environmental degradation accelerated by nuclear testing and military uses of some atolls complicates the challenge of developing sustainable lifestyles on these overpopulated, resource-poor atolls. The undeveloped economy results in low greenhouse gas emissions by the RMI.

Global climate change effects on RMI will include sea level rise, coral bleaching, saltwater intrusion, and the increased frequency of tropical storms. Solid waste disposal, availability of potable water, fisheries depletion, and overpopulation reduce the ability of the nation to react to climate change. For example, on March 21, 2007, the RMI government declared a state of emergency after a prolonged drought. Erosion of the extensive ocean/land interface, already escalating with a relatively small sea level increase, presents a serious challenge. Bleaching and coral death have interrupted the natural cycle of coral replenishment and may cause the collapse of the coral reef ecosystem. Prevailing wind patterns have largely protected these islands from severe tropical storm damage, but shifts in storm movement patterns are allowing more frequent and direct storms.

SEE ALSO: Alliance of Small Island States (AOSIS); Drought; Sea Level, Rising.

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Maryland

MARYLAND HAS AN area of 12,407 sq. mi. (32,134 sq. km.), with inland water making up 680 sq. mi. (1,761 sq. km.) and coastal water making up 1,843 sq. mi. (4,773 sq. km.). Maryland's average elevation is 350 ft. (107 m.) above sea level, with a range in elevation from sea level on the Atlantic Ocean, to 3,360 ft. (1,024 sq. km.) at Backbone Mountain. Chesapeake Bay is an estuary (were salt water and fresh water meet). The Chesapeake region is a flat coastal plain, and the western edge has the Appalachian Mountains. The Chesapeake Bay divides Maryland in half. Maryland's three major land regions are the Appalachian Mountains, the Piedmont Plateau, and the Atlantic Coastal Plain.

The climate of Maryland is characterized by generally hot, humid summers and cool winters. In comparison with the eastern shore and other lowland areas, the upland sections in the west have colder and longer winters, and cooler and shorter summers. Baltimore's average annual temperature is about 55 degrees F (13 degrees C), with an average January temperature of 32 degrees F (0 degrees C), and an average July temperature of 76 degrees F (24 degrees C). The highest temperature recorded in the state was 109 degrees F (43 degrees C) on July 10, 1936 and the lowest temperature recorded in the state was minus 40 degrees F (minus 40 degrees C) on January 13, 1912. The average annual precipitation is 43 in. (109 cm.). The Atlantic Coastal Plain, warmed by the Gulf Stream, has a high humidity, with the majority of precipitation in the form of rain. Winter snowfall potential in the Appalachian Mountain region is 80 in. (203 cm.), but in the Piedmont Plateau it is only 10 in (25 cm.).

Tobacco is grown in the southern region. Much of the state grows corn, especially the Piedmont region. Soybeans are grown in the eastern region along with peaches, strawberries, and melons. Maryland's economy also relies on livestock and poultry, greenhouse products, and dairies. Manufacturing includes chemicals and scientific instruments, and mining is primarily for crushed stone.

IMPACT OF CLIMATE CHANGE

Maryland has already experienced rising sea levels (7 in. or 18 cm. per century in Baltimore) and beach erosion. Climate models vary on temperature increases for Maryland, from 1–7 degrees F (1.8–12.6 degrees C) in spring, and from 2–9 degrees F (3.6–16.2 degrees C)in summer, autumn, and winter by the end of the century. Potential risks include rising sea levels (affecting barrier islands, developed ocean front, the eastern shore of the Chesapeake Bay with freshwater and salt marshes, causing flooding, loss of coastal wetlands, beach erosion, saltwater contamination of drinking water, and damage/decreasing stability of low-lying property and infrastructure), decreased water supplies, population displacement, changes in food production with agriculture improving in cooler climates and declining in warmer climates, and change in rain pattern to downpours with the potential for flash flooding and health risks of certain infectious diseases from water contamination or disease-carrying vectors such as mosquitoes, ticks, and rodents. Warmer temperatures can cause heat-related illnesses and lead to higher concentrations of ground-level ozone pollution, causing respiratory illnesses (diminished lung function, asthma and respiratory inflammation), especially in cities with smog, like Baltimore and the suburbs of Washington, D.C.

HUMAN-INDUCED CONTRIBUTIONS

Based on energy consumption data from the Energy Information Administration, Maryland's total carbon dioxide emissions from fossil fuel combustion in million metric tons for 2004 was 81.36, made up of contributions by source from: commercial, 5.00; industrial, 7.80; residential, 7.13; transportation, 31.01; and electric power, 30.42. Maryland passed legislation to join the New England and some mid-Atlantic states in the Regional Greenhouse Gas Initiative (RGGI), a mandatory cap-and-trade program. Carbon emissions from power plants will be capped at current level, 2009–15, and will be incrementally reduced by 10 percent before 2019.

The governor of Maryland established the Climate Change Commission (MCCC) on April 20, 2007 by executive order. The commission is made up of members of the Maryland Department of the Environment, the Maryland Energy Administration, and others affected by potential initiatives (such as businesses and energy providers) to assess climate change impact, develop a strategy for greenhouse gas and carbon footprint reduction, and recommend actions for reducing vulnerability to risks associated with climate change. Maryland joined the Climate Registry, a voluntary national initiative to track, verify, and report greenhouse gas emissions, with acceptance of data from state agencies, corporations, and educational institutions beginning in January of 2008.

Maryland provides tax credits for commercial developers meeting certain energy-efficiency standards, for generating and selling electricity from biomass, and for purchasing electric or hybrid vehicles. Additional legislation new in 2007 includes the Maryland Clean Cars Act, requiring stronger emissions regulations. The Maryland Green Council is tasked with advising policy makers on using environmentally friendly technology in future construction projects, and the Stormwater Management Act of 2007 will improve management of storm water runoff. On a local level, the city of Annapolis has created several environmental initiatives, including a commitment to replace the city vehicle fleet and public transit vehicles with alternative fuel vehicles and to search for renewable energy options.

The University of Maryland is setting an example for public and private sectors; the president of the university joined other college presidents and chancellors around the country in taking a community leadership role in minimizing global warming emissions. In addition to the Center for Integrative Environmental Research, the university is assisting regionally in understanding the complex challenges of global warming and developing information and research to supply to policy makers like the MCCC for creating strategies to mitigate global warming.

SEE ALSO: Salinity; Sea Level, Rising; University of Maryland.

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Massachusetts

MASSACHUSETTS HAS AN area of 10,555 sq. mi. (2,737 sq. km.), with inland water making up 423 sq. mi. (1,095 sq. km.), and coastal water making up 977 sq. mi. (2,530 sq. km.), and access to territorial water of 1,314 sq. mi. (3,403 sq. km.). Massachusetts's average elevation is 500 ft. (152 m.) above sea level, and most of the state is quite level. Massachusetts has several river systems, and many lakes, ponds, and reservoirs.

Massachusetts has a humid, continental climate, with long, hot summers and cold winters. New England weather and climate are influenced by latitude (warm, moist air from the south and cold, dry air to the north), coastal orientation (position within the zone of the westerlies), and elevation changes. The sea breeze circulation, particularly along the east coast, tends to mitigate frequencies and intensities of thunderstorms in the coastal zone, while bringing relief in the form of mild temperatures in the peak summer heat. In winter, these waters remain warm relative to land. Cape Cod and the islands of Martha's Vineyard and Nantucket experience cooler summers and warmer winters because of the moderating effects of the Atlantic Ocean. Annual average precipitation is 40–46 in (16–18 cm.) per year.

Massachusetts's agriculture includes diverse crops of cranberries, apples, corn, potatoes, and dairy products. Massachusetts has extensive commercial fishing, both in coastal waters and in the colder currents of more distant fishing banks, including the Grand Banks of Newfoundland and Georges Bank off Cape Cod.

IMPACT OF CLIMATE CHANGE

Massachusetts already experiences the effects of higher temperatures and rising sea levels with eroding coastlines. On average, 65 acres of land are submerged each year due to a combination of rising seas and subsiding land in the state, with much of the loss occurring along the state's south-facing coast, including along Nantucket and Martha's Vineyard. A blizzard in 1996 caused severe flooding.

Climate models vary for the Northeast on the amount of temperature increase during the 21st century, from 5–12 degrees F (2.7–6.6 degrees C) during the winter months, to 3–14 degrees F (1.6–7.7 degrees C) during the summer months. Anticipated rising sea level (7–14 in. [18–36 cm.] on the low-end, and 10–23 in. [25–58 cm.] on the high-end) is projected to increase shoreline erosion and wetland loss. Using these estimates, the city of Boston might expect a coastal flood equivalent to today's 100-year flood every two to four years on average by mid-century, and almost annually by the end of the century under either scenario. Sea-level rise is also projected to increase shoreline erosion and wetland loss, particularly along the vulnerable coasts of Cape Cod, and will exacerbate flooding in the Charles River basin from storm surges stretching the limits of Boston's aging wastewater infrastructure.

The commercial fishing industry will suffer with rising ocean temperatures, with a northward habitat shift of many fish and shellfish species like cod and lobster. Under either high-end or low-end emissions scenarios, cod are expected to disappear from the region's waters south of Cape Cod during this century, and lobster populations south of Cape Cod are expected to dwindle by mid-century. With higher emissions, the fishing grounds of Georges Bank will likely lose their cod stocks. Impact is more severe under the higher-emissions scenario, with heat stress in cows decreasing milk production and the climate no longer suitable for cranberries and some apple varieties. Weeds and pests would proliferate. Under the lower-emissions scenario, changes would be less severe. Higher temperatures are expected to increase the frequency of summer heat waves. Health risks associated with rising temperatures include a potential increase in certain infectious diseases from water contamination or disease-carrying vectors such as mosquitoes, ticks, and rodents, and heat-related illnesses.

ADDRESSING HUMAN-INDUCED CONTRIBUTIONS

Based on energy consumption data from Energy Information Administration, Massachusetts's total carbon dioxide emissions from fossil fuel combustion in million metric tons for 2004 are 83.21, made up of contributions by source from: commercial, 6.54; industrial, 4.65; residential, 14.94; transportation, 33.41; and electric power, 23.67.

Massachusetts was the lead petitioner in a case on global warming that went to the U.S. Supreme Court. In this case, *Massachusetts, et al., v. EPA*, Massachusetts challenged the federal Environmental Protection Agency's refusal to regulate greenhouse gases under the Clean Air Act. On April 2, 2007, the court ruled in favor of Massachusetts. In May 2007, President George W. Bush announced that federal agencies, including the EPA, would develop regulations to reduce motor vehicle gasoline consumption and greenhouse gas emissions. Massachusetts's Greenhouse Gas reduction target is to meet 1990 levels of six greenhouse gases by 2010, be 10 percent below 1990 levels by 2020, and 75–85 percent below 2001 levels in the long term. Massachusetts adopted California's law requiring vehicle tailpipe emissions reductions of approximately 30 percent below 2002 levels by 2016, beginning with the 2009 model year. Current state regulations also allow the purchase of tax-deductible wind energy certificates from a wind company with a turbine in Hull, and Massachusetts Electric offers a renewable energy option for consumers to purchase renewable electricity from small hydro, wind, biomass, and solar sources in New England.

Massachusetts joined the Climate Registry, a voluntary national initiative to track, verify, and report greenhouse gas emissions, with acceptance of data from state agencies, corporations, and educational institutions beginning in January of 2008. Massachusetts has joined all the states in New England (as well as others in the mid-Atlantic area) in the Regional Greenhouse Gas Initiative (RGGI), the first multiple-state, market-based mandatory cap-and-trade program to reduce heat-trapping emissions from power plants. Carbon emissions from power plants will be capped at current level, 2009–15, and will be incrementally reduced by 10 percent before 2019.

SEE ALSO: Climate Models; Greenhouse Gases; Massachusetts Institute of Technology.

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Massachusetts Institute of Technology

THE MASSACHUSETTS INSTITUTE of Technology (MIT) is a private, coeducational research university located in Cambridge, Massachusetts. MIT has five schools and one college, containing 32 academic departments, with a strong emphasis on scientific and technological research. MIT is one of two private land-grant universities, as well as a sea-grant and space-grant university. The mission of MIT is to advance knowledge and educate students in science, technology, and other areas of scholarship that will best serve the nation and the world in the 21st century.

William Barton Rogers founded MIT in 1861, in response to the increasing industrialization of the United States. Although based upon German and French polytechnic models of an institute of technology, MIT's founding philosophy of "learning by doing" made it an early pioneer in the use of laboratory instruction, undergraduate research, and progressive architectural styles. As a federally-funded research and development center during World War II, MIT scientists developed defense-related technologies that would later become integral to computers, radar, and inertial guidance. After the war, MIT's reputation expanded beyond its core competencies in science and engineering into the social sciences, including economics, linguistics, political science, and management. MIT's endowment and annual research expenditures are among the largest of any American university. MIT graduates and faculty are noted for their technical acumen (63 Nobel Laureates, 47 National Medal of Science recipients, and 29 MacArthur Fellows), entrepreneurial spirit (a 1997 report claimed that the aggregated revenues of companies founded by MIT affiliates would make it the 24th largest economy in the world), and irreverence (the popular practice of constructing elaborate pranks, or hacking).

The Department of Earth, Atmospheric, and Planetary Sciences offer several undergraduate and graduate courses of study in the geophysical sciences: geology, geophysics, geochemistry, geobiology, atmospheric science, oceanography, climate, planetary science, and astronomy. More specifically, the Program in Atmospheres, Oceans, and Climate oversees a broad curriculum, with emphasis in three areas of study: Atmospheric Sciences, Climate, and Oceanography.

PROGRAMS AND INITIATIVES

The MIT Joint Program on the Science and Policy of Global Change is as an interdisciplinary organization, founded in 1991, that conducts research, independent policy analysis, and public communication on issues of global environmental change. The Joint Program combines the capabilities of two pre-existing MIT research centers: the Center for Global Change Science (CGCS) and the Center for Energy and Environmental Policy Research (CEEPR). It brings together an interactive group of faculty, staff and student researchers. Resources of the parent centers are strengthened by links to the Marine Biological Laboratory's Ecosystems Center in Woods Hole, Massachusetts, the MIT Climate Modeling Initiative, and other MIT environmental programs.

The MIT Joint Program's work is focused on the integration of natural and social science aspects of the climate issue, to produce analyses relevant to ongoing national and international discussions. Cooperative efforts engage it with leading research institutions and nonprofit organizations worldwide. Financial support is provided by an international group of sponsors from government organizations, foundations, and industry. The Program's cornerstone is the MIT Integrated Global System Model (IGSM) of economic and environmental change. The IGSM is a comprehensive research tool for analyzing potential anthropogenic global climate change and its social and environmental consequences. The IGSM includes consideration of climate science, technical change, and economic and social science, in an interacting set of computer models designed for study of the sensitivities and uncertainties that are crucial to policy evaluation.

MIT's Climate Modeling Initiative (CMI) is a collaborative effort among scientists in the Center for Global Change Science of MIT, to develop a state-of-the-art model of the atmosphere and ocean for study of Earth's climate. CMI is developing a new generation of climate model utilizing improved process models, which exploit our latest understanding of ocean, land, atmospheric and bio-geochemical processes, and new developments in algorithms, computing technology, and software design.

The Center for Global Change Science (CGCS) at MIT was founded in January 1990, to address fundamental questions about climate processes with a multidisciplinary approach. In July 2006, the CGCS became an independent center in the School of Science. CGCS's goal is to improve the ability to accurately predict changes in the global environment. The CGCS seeks to better understand the natural mechanisms in ocean, atmosphere, and land systems that together control the Earth's climate, and to apply improved knowledge to problems of predicting climate changes. The Center utilizes theory, observations, and numerical models to investigate climate phenomena, the linkages among them, and their potential feedbacks in a changing climate. CGCS builds on existing programs of research and education in the Schools of Science and Engineering at MIT. The interdisciplinary organization fosters studies on topics as varied as oceanography, meteorology, hydrology, atmospheric chemistry, ecology, biogeochemical cycling, paleoclimatology, applied math, data assimilation, computer science, and satellite remote sensing. The CGCS sustains a program of basic scientific research on the natural processes controlling global climate, with a concentration on the cycles, circulations and interactions of water, air, energy, and nutrients in the Earth system. The Center's research effort is focused primarily on five fundamental components of the global climate system.

CLIMATE AND ENVIRONMENTAL STUDIES

There are several suggested academic undergraduate programs leading to Bachelor of Science (S.B. or B.S.) degrees at MIT that can effectively accommodate interests in climate and environmental studies. The Department of Earth, Atmospheric and Planetary Sciences (EAPS), and its Program on Atmospheres, Oceans and Climate (PAOC) offer degrees in Physics of Atmospheres & Oceans and Environmental Science, both of which expose students to a wide range of Earth science topics, while allowing the flexibility to choose a specific area of focus. Similarly, the Department of Civil and Environmental Engineering (CEE) degree in Environmental Engineering provides a solid understanding of, and ability to apply the fundamentals of, the physical, chemical and biological sciences, treatment and control, economics, and public policy, as they relate to environmental engineering. A bachelor's degree from either EAPS or CEE provides an excellent foundation for graduate study and research in both basic and applied environmental science and engineering disciplines. Terrascope provides opportunities for first-year students to explore basic science and engineering concepts through the study of Planet Earth. Both major and minor degree programs are offered by CEE, EAPS, and PAOC. Several undergraduate research opportunities for hands-on field studies and laboratory work are also available. All MIT undergraduate students are strongly encouraged to become involved in research through the Undergraduate Research Opportunities Program (UROP).

SEE ALSO: Harvard University; Woods Hole Oceanographic Institution.

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Mauritania

LOCATED IN WEST Africa, and a former French colony, Mauritania has a land area of 397,954 sq. mi. (1,030,700 sq. km.), a population of 3,124,000 (2006 est.), and a population density of 7.8 people per sq. mi. (3 people per sq. km.). It is one of the most sparsely populated countries in the world. The Sahara Desert covers much of the country, with less than 1 percent of the land arable, and 38 percent used for low-intensity meadows and pasture. Some 5 percent of the country is forested, mainly with gum arabic, which is the major cash crop of the country.

Regarding electricity production in the country, some 84.4 percent comes from fossil fuels, with the remainder from hydropower. However, electricity usage in the country is extremely low, and per capita carbon dioxide emissions also remain low, ranging from 1.3 metric tons per person in 1990 to 0.87 metric tons per person by 2003. Overall, 98 percent of the carbon emissions in the country come from liquid fuels, with the remainder from solid fuels and cement manufacturing.

Mauritania has suffered much from deforestation, and there is the likelihood that climate change and global warming will lead to further desertification, leading to a decline in agricultural production. Rising sea levels could lead to the flooding of Nouadhibou (formerly Port Étienne, the country's former capital). The deliberate stranding of ships off the coast of Nouadhibou has only added to the environmental problems there. The Mauritanian government of Maaouya Ould Sid'Ahmed Taya took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, ratifying the Vienna Convention two years later. The government accepted the Kyoto Protocol to the UN Framework Convention on Climate Change on July 22, 2005; it took effect on October 20, 2005.

SEE ALSO: Deforestation; Desertification; Framework Convention on Climate Change; Global Warming; Kyoto Protocol; Sea Level, Rising.

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Mauritius

THE REPUBLIC OF Mauritius, located in the Indian Ocean, has a land area of 787 sq. mi. (1,860 sq. km.), a population of 1,262,000 (2006 est.), and a population density of 1,564 people per sq. mi. (616 people per sq. km.). About 49 percent of the country is arable, with a further 3 percent used for meadow and pasture. An additional 31 percent of the island is wooded, with extensive forest plantations.

Regarding electricity production in the country, 91 percent of it comes from fossil fuels, with the remaining 9 percent from hydropower. In 1990, Mauritius had a per capita carbon dioxide emission rate of 1.4 metric tons per person, rising to 2.6 metric tons per person by 2003. Ninety percent of these emissions come from the use of liquid fuels, with the remainder from solid fuels.

The effects of global warming and climate change will have a major impact on Mauritius. The rise in the temperature of the Indian Ocean is likely to have a serious adverse effect on the coral reefs located around the island, with those to the north of the island particularly popular with tourists. There is also the possibility of increased flooding of low-lying parts of the country, especially around Grand Baie.

In 1990, the World Bank was critical of the lax environmental laws in Mauritius, and the government responded by quickly establishing a Ministry for the Environment. The government took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, and ratified the Vienna Convention in the same year. On May 9, 2001, it accepted the Kyoto Protocol to the UN Framework Convention on Climate Change, which took effect on February 16, 2005.

SEE ALSO: Indian Ocean; Oceanic Changes; Tourism.

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Maximum Sustainable Yield

MAXIMUM SUSTAINABLE YIELD is a term population ecologists and economists use to define the theoretical top catch or yield of a species that can be taken indefinitely without depleting the population. The maximum sustainable yield is assumed to be half of the carrying capacity of a species. Commonly, the maximum sustainable yield is more than the optimum sustainable yield, which ends when yield is no longer economical.

Maximum sustainable yield is a long-term management approach, not a crisis recovery method. The European Union (EU), for instance, uses it for all stocks, not just those that are approaching unsustainability. According to the logistic model of growth, population in a new habitat, or one that is depleted will initially experience a slow growth rate, but will grow rapidly once it reaches a foothold level. Rapid growth will slow when the population nears the carrying capacity of the habitat. The goal of maximum sustainable yield is to raise or lower population to the level where the highest growth rate is most likely. The new population level should be capable of indefinite maintenance. Maximum sustainable yield is highly variable, depending heavily on weather-influenced factors. Global warming affects maximum sustainable yield by altering the weather.

BACKGROUND

A sixth of the Earth's population depends on the sea for over a third of its animal protein (the world average is 16 percent). Fishing and processing employs 200 million people worldwide. The current annual catch is about 88 million U.S. tons, or 80 million metric tons. The total is down from 1989, the peak year with 86 million metric tons. The 1989 catch culminated a 50-year process in which the catch rose by a factor of four. However, the world total conceals the disparities in different parts of the world—the Indian Ocean catch continues to rise, while 13 of the 15 major areas have shown declines (the Atlantic cod catch is down by a factor of almost three since 1970.)

In November 1992, a collection of scientists warned that nature and humanity were on a collision course because of the damage human activity was doing to the environment and resources. They warned that unless change occurred, humanity risked creating a world incapable of sustaining life as we know it. They said that Earth had too many people. The scientists warned of atmospheric damage from ozone depletion, air pollution, and acid rain. They noted critical depletion of the water supply, putting world food production at risk. They cited soil depletion that degraded land and cut food production. They decried the loss of tropical rainforests. They also talked of the destruction of ocean life, particularly the world's supply of food fish. They noted that the world's farmers, industrialists and urbanites were sending pollutants into the oceans, that fishermen were taking more than the maximum sustainable yield, and some fisheries were showing signs of collapsing. They calculated that by 2100, upwards of one-third of all extant species might disappear. Among other steps to prevent the disaster, humanity needed to find alternatives to fossil fuels, become more efficient in using nonrenewable resources, and manage critical resources more effectively. The developed world had to help the undeveloped world to make these changes.

The earlier approach to fisheries management was to keep stocks from falling too low. At the World Summit on Sustainable Development in Johannesburg, in September 2002, EU members agreed to limit fishing to sustainable levels, and to maintain or restore stocks to maximum sustainable yield levels. The goal was to replenish depleted species by 2015. The attendees also committed to act against illegal, unregulated, or unreported fishing, another priority. Four years after the agreements, the EU reported that it had many species outside safe limits. According to an International Council for the Exploration of the Sea (ICES) analysis, 81 percent of the stocks in the northeast Atlantic and adjacent waters were over-fished, some as much as five times maximum sustainable yield. The EU implementation of maximum sustainable yield sought to maximize the catch without endangering the stock. The EU noted that small stocks could provide only small yields, because too few adults were available to replenish the stock. When stock was too great, reproduction slowed because of lack of food and decreased competition. The maximum sustainable yield lies between too small, and too large.

NATURAL CAUSES AND HUMAN IMPACT

Maximum sustainable yield is common in fisheries management. In modern fisheries, maximum sustainable yield is around 30 percent of the unexploited population, but it varies depending on the life history of the species and the fishing method chosen.

The stock of a given type of fish varies over time, from natural causes and human impacts. A fishing fleet that has doubled in the past 25 years suffers when the variation is adverse, and as the catch trends down for commercially valuable varieties, concern arises that the ocean may not be able to supply the protein need of an ever-growing population without conservation and management. There are increasing disputes over who gets to fish for how much in which waters at which time of year—jurisdictional rights versus open access. There are disagreements over how many fish are left. Estimates are notoriously unreliable, because too many uncontrollable factors affect the total. Particularly important are environmental changes, which can affect mortality in larval fish and significantly impact the grown population. Factors include the number of predators, the available nutrients, and the temperature of the water. Water temperature is critical because fish can not regulate their own body temperature. Warming and cooling encourage populations to move to more suitable waters. Turbulence also affects the supply by putting the larvae at a disadvantage against larger and less susceptible predators. Turbulence changes reflect, among other factors, changes in regional climate.

The EU implemented maximum sustainable yield through long term plans prescribed by the Common Fisheries Policy, plans that define the fishing rate and the rate of annual adjustment. The approach was gradualist to avoid short-term harm to the fishing industry, while the changes took place. The EU also authorized closing fishing areas and restricting types of fishing gear on a case-by-case basis. Before implementing any plan, the EU prepared a

Scientists have warned for over a decade of a critical depletion of food fish production due to the destruction of ocean life.

social and economic impact statement. Maximum sustainable yield was assumed to keep stocks from collapsing, reducing discards of too small/too low value/caught beyond quota fish. It was also expected to reduce by-catches and cut down on impact on the environment. After the initial reduction to allow fish to grow, fishing could resume with presumed lower costs and greater profit, as catches of larger/better fish cut down fishing time and fuel consumed. The EU, in 2006, was dependent on imports for 60 percent of its fish products.

CLIMATE CHANGE

The Intergovernmental Panel on Climate Change (IPCC) released a study on probable impacts of greenhouse warming. Acknowledging that impacts vary from species to species, and that climate change models are only approximate, the IPCC predicted that global warming will have a small impact if global warming impacts are restricted to changes in surface temperature.

Warming will have a greater impact if local economic impacts of shifting fisheries are taken into account. The global total catch should remain about the same because the fish can move easily. The regions where fishing is viable will change, as will the species available, because some species are more susceptible to warming than others. A more significant impact could be the climate change that could alter winds, thereby changing currents and modifying the flow of nutrients and larval fish. Warming's rising waters would alter the area near shore or in river mouths, changing the ecosystem and modifying the types of marine life.

Determining maximum sustainable yield can be inaccurate when insufficient data are available. Miscalculation of the sustainable yield of roughy occurred in New Zealand when initial quotas assumed that the species lived a relatively short life and bred quickly. In fact, the roughy lives 30 years and breeds slowly. By the time this was known, the available roughy stock was mostly gone. That climate change affects maximum sustainable yield is indisputable, but exactly what the impacts will be is disputed, because sufficient data are not yet available.

SEE ALSO: Marine Mammals; Oceanic Changes; Ocean Component of Models; Oceanography; Pollution, Water.

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Measurement and Assessment

MEASUREMENT AND ASSESSMENT issues are central to debates about the nature and impact of global warming. Global warming models require information about the parameters in these models (measurement) and exploration of the meaning of the predicted results (assessment). Inference, lack of replicability, cyclical variables, and parameter attributes all shape these models and their predictions. Models can be attacked or defended, based primarily on their underlying measurements and assessments; thus, it is vital to understand the role measurement and assessment have in building and understanding these models.

The essence of science is the development of ideas that produce predictions to explain measurable phenomena. Measurement and assessment are central components of this process. The difference between these two concepts is tied to the modeling concept: measurement refers more to the evaluation of phenomena, and assessment refers more to the evaluation of models. Another link is the quality of the measured data: it is impossible to produce detailed assessments if the measurements are not detailed.

THREE ATTRIBUTES

It is axiomatic that any parameter has three attributes, only two (any two) of which can be simultaneously maximized. Furthermore, the more the third is minimized, the more the other two can be maximized. These three parameters are precision (minimizing the variance of the parameter), accuracy (the congruence between the calculated value of the parameter and the actual value of the parameter), and generality (the degree to which the parameter can be applied to a wide range of scenarios).

Two complications in the development and assessment of global predictive models are the nature of both reductionistic and experimental approaches. First, science is particularly good at a reductionist approach, that is, to isolate a situation as much as possible and manipulate or explore it to understand it better. However, the planet is not particularly amenable to attempts to isolate one segment of its atmosphere. Second, experimental approaches use multiple subjects to test the effects of changes in variables. Experimental approaches produce models that most confidently assess the predictive power of the model being tested because other variables are controlled. Situations in which experimental manipulation of variables is impossible or unethical (for example, many medical questions) are normally solved by the application of multivariate statistical techniques to extremely large groups of subjects. Planetary questions, such as global warming, are not desirable questions to be answered experimentally; the sample size is currently set at one planet.

Experimental approaches are not ethical or feasible, nor is it feasible to obtain multiple planets (unless additional planets are assigned to experimentation). However, situations such as these are still within the realm of scientific investigation, particularly through the use of inference and model assessment and calibration. The precision, accuracy, and generality of such results are both more difficult to determine and more likely to be challenged by skeptics. Evolution, global warming, and various factors influencing human health are all examples.

CLIMATE MODEL MEASUREMENT, ASSESSMENT

The modeler's ideas about relationships among variables need to be specified as precisely as possible. The actual variables have to be measured, the model implemented, and the results determined. Then, model assessment requires: the systematic testing of the degree of influence each parameter put into the model has upon the output. Typically, modeling is an iterative process, in which the assumptions of the model are sequentially considered and more powerful models that reduce the stochasticity or the probable impact of assumptions on precision, accuracy, or generality are reduced. Just as with other variables, assumptions can maximize two of the three attributes; typically, as with other aspects of the scientific method, modelers prefer to reduce generality. Thus, for example, more complicated models that consider each tree separately have replaced models of forest dynamics that treated forests as blocks of area. Models of global climate divide the globe into different areas. Each area has its own dynamics driven by the various parameters modeled, and each area impacts adjacent areas. The size of these areas within climate models has steadily decreased, and the number of parameters and the complexity of the interactions between areas have increased.

Because of lack of computing power, the tension among the three parameter attributes, and the amount of stochastity within complex systems, models themselves cannot be precise, accurate, and generalizable. Models are usually wrong in some way, but even a "wrong" model can still have substantial conceptual and scientific value. Models are especially good at identifying areas of weakness in understanding, areas that will be productive avenues for further research.

Within the context of global warming models, an additional challenge is the incorporation and assessment of cyclical variables. Cyclical variables are difficult to understand because they are constantly changing. A clear understanding of a cyclical variable should include a reasonable mechanistic explanation for the cycle, the periodicity, and the magnitude of variation. Global warming models are particularly complicated because there are multiple cyclical variables, each with its own mechanism, periodicity, and variation. For instance, sunspots, carbon dioxide, and climatic variation (both annual and era) have some degree of cycling. A comprehensive model, thus, needs to incorporate both stochastic variation and periodic variation for each of these variables. It is particularly hard to effectively incorporate a cyclical variable when the periodicity is much greater than the range of time during which measurements have been obtained.

These difficulties do not invalidate attempts to model global climate patterns. Science is not just the art of exploring easy problems. Computational power, the collection of more and better measurements, and richer forms of assessment (such as comparisons between different models through the development of metamodels) all contribute to a deeper understanding of the planet. Measurement and assessment are important issues and are not insurmountable obstacles.

SEE ALSO: Climate Models; Climatic Data, Nature of the Data; Climatic Data, Proxy Records; Computer Models.

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Media, Books and Journals

ISSUES RELATED TO climate change and global warming have been an important part of scientific literature. These questions have been brought from academic circles to the public sphere. For example, an article on global warming appearing in a newspaper such as the *Wall Street Journal* is likely to reach an immediate audience, even though this newspaper is not an academic science publication.

BOOKS AND ENCYCLOPEDIAS

In the 21st century, books have posed emerging theories of climate change, in some cases beyond basic debates about the existence of global warming. Many contemporary scientists claim to have published the "first book on climate change," however, French mathematician Jean Baptiste Fourier (1768–1830) first theorized the greenhouse effect in 1827. In 1989, Bill McKibben wrote what is often regarded as one of the first modern books on climate change, titled *The End of Nature: Humanity, Climate Change and the Natural World*. Before he released his famous book, *An Inconvenient Truth* (with the same title as his popular documentary), Al Gore published a similar lesser-known book, *Earth in the Balance: Ecology and the Human Spirit*.

Among prior encyclopedias produced on climatology are John Oliver's *The Encyclopedia of Climatology*, and the 1996 illustrated *Encyclopedia of Climate and Weather*, edited by Professor Stephen Henry Schneider. Among the new interdisciplinary encyclopedias is Paul Robbins' *Encyclopedia of Environment and Society*.

JOURNALS ON CLIMATE CHANGE

Scientific journals about climate have existed for centuries, but in the 21st century, some have focused solely on climate change and global warming. Among these are the *Journal of Climate*, the interdisciplinary journal *Climatic Change*, and the journal *Global Environmental Change*. The journal *Climate Policy* is published in the United Kingdom. In France, scientific journals and popular magazines often carry articles on global warming, such as in *Science et Vie*, and *Pour La Science*. Such journals do not include sensationalistic media coverage on global warming that has been recently labeled "climate pornography," because of its alarmist language and impressive, sometimes graphic images of catastrophic climate change.

BOOKS FOR CHILDREN

A bestseller book on global warming written for children is Laurie David's and Cambria Gordon's *Down-to-Earth Guide to Global Warming.* Another book for children, *Who Says Kids Can't Fight Global Warming?*, by Patrick Harrison and Gail Bunny McLeod, explains everyday efforts that children can make in order to reduce consumption, waste, and therefore pollution and global warming.

CHALLENGING THE IDEA OF GLOBAL WARMING

Many books, not always written by scientists or experts, bring a divergent theory or highlight contradictory arguments to the concept of global warming, such as S. Fred Singer's and Dennis Avery's *Unstoppable Global Warming: Every 1,500 Years*. The authors express doubts that the 1,500-year climate cycle can be changed or controlled. In the French book titled *Ecologie, La Grande Arnaque* (translated as *Ecology, the Big Hoax*), the president of the French Automobile Club, Christian Gerondeau, argues that ecological problems and global warming are real, but the solutions and ongoing strategies made by the French state are neither adaptive nor efficient.

RECENT THEORETICAL FRAMEWORKS

Many academics in social sciences agree that these issues related to environmental threats will remain for a long while. For instance, in his book, *Postmodern Climate Change*, Leigh Glover argues that the ongoing climate crisis will never be resolved, but will remain an environmental issue for decades, as it has since 1970, mainly because we seem to live in an "international climate change régime."

In the book *The Social Construction of Climate Change: Power, Knowledge, Norms, Discourses*, the contributors do not propose responses, but argue that climate change is socially made and remains a matter of knowledge and power.

Unless they have great interest in the topic, most people are not likely to read books on climate change and global warming, so they may be reliant on what they read in popular magazines and the mass media. Therefore, they might only get a partial view of this complex phenomena.

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Media, Internet

THE SCIENTIFIC COMMUNITY has considered media coverage about science, in general, as inadequate, and coverage about global warming and climate change, in particular, as distorted. Scientists have maintained that their consensus about the causes and consequences of global warming has been overshadowed by coverage that portrays global warming as a source of scientific controversy and debate. The peer-reviewed findings of the Intergovernmental Panel on Climate Change represent more than 2,000 scientists from 100 countries who have reached the joint conclusion that the burning of fossil fuels is causing significant climate shifts, findings that have been substantiated by the National Academy of Sciences, among other prestigious scientific bodies.

Nonetheless, the media have tended to give importance to climate change skeptics. For example, the Western Fuels Association, a cooperative that supplies coal to consumer-owned electric utilities, hired such detractors, including scientists Robert Bailing, Patrick Michaels, and S. Fred Singer, as spokespersons in the early 1990s, as part of a strategy to shift the focus of global warming from fact to speculation. By 1997, only 22 percent of respondents in a *Newsweek* poll indicated that they worried a large amount about climate change, down from 35 percent in 1991, before the Western Fuels campaign began. Although mass media are not the only avenues which shape public opinion, it affects public perceptions, and, in turn, public policy. Western Fuels ultimately sued environmental groups for publicly linking global warming to the burning of fossil fuels, but the U.S. federal district court in Wyoming dismissed the suit.

A comparison in 2000, climate change coverage in major newspapers found that global warming received three times more coverage in the United Kingdom than in the United States. In the United States, Andrew Revkin of the *New York Times* has been praised as one writer who has covered global warming steadily. Additionally, it was not until 2004 that the Weather Channel began citing global warming in relationship to its projections. In recent years, however, awareness of global warming has grown and the media have begun to cover climate change more expansively. In those countries with greater media coverage, the public are more concerned about the effects of global warming. A 2007 study found that citizens in Brazil, where media coverage of global warming is regular, are among those most concerned about global warming in the developing world; South Korea's citizens are among the least concerned.

INTERNET COVERAGE

In January 2007, following a report by the United Nations, global warming ranked in the top 5 percent of news stories for the first time. In addition to traditional news sources, technology has significantly increased the number of options for obtaining news and information. Among these options are blogs, online journals that are frequently updated and published in reverse chronological order. Blogs have been in existence since the late 1990s. Numbers suggest that each day, more than 12 million American adults contribute to blogs, and more than 7 million Americans read them. In a situation that parallels other news media formats, however, much of the content is not original, less than 5 percent in the case of blogs.

In 2004, blogs became increasingly commonplace. In an effort to combat the failure of the media to effectively cover the common consensus about global warming shared by scientists worldwide, nine climate scientists launched RealClimate in December 2004. RealClimate was designed as a climate science site by working climate scientists for journalists and members of the public. The site has won a number of awards, including a 2005 Science & Technology Web Award by *Scientific American*, and recognition by the *Guardian Unlimited* as a Top 10 Environmental Site. The scientists' goal is to provide rapid rebuttals to distortions about climate change, often made by American-based, industry-sponsored think tanks.

Music Television (MTV) generated interest in global warming by implementing a yearlong, daily public service announcement campaign, "Break the Addiction," on Earth Day in 2006. The campaign included daily suggestions on changes viewers could make to lead more environmentally friendly lives, coupled with educational messages about the reasons for, and consequences of, climate change and the political context in which climate change issues are addressed.

Additionally, MTV included a monthly online segment featuring young people making a difference in environmental issues. MTV estimated nearly 90 million households had potential contact with the campaign each day, and one million people turned to www.think.mtv.com as an additional resource about global warming. In 2007, *CNN News* further demonstrated the significance of the internet on American politics by selecting those questions that would be used in a televised presidential debate from among almost 3,000 questions posted to YouTube, a video-sharing website created in 2005, and ranked as one of the top sites in 2006, attracting close to 20 million visitors per month. An analysis of data by Hitwise, the leading online competitive intelligence service, found that online searches for environmental information increase alongside greater media coverage about environmental issues. During the most recent two-year period studied, online searches for information about global warming by internet users in the United Kingdom increased by 22 percent. Much of the online searching directed users to websites based in the United States, which suggests that U.S. sites potentially have greater influence on the public, and subsequently on policymaking, than do UK sites.

Paralleling earlier findings in the United Kingdom, Hitwise data indicated that Australian internet users visited former U.S. Vice President Al Gore's website at a significant rate when he was making media appearances in Australia in September 2006 to promote his documentary, *An Inconvenient Truth*, which later won the Academy Award for best documentary film. Hitwise also determined that Australian internet users searching for climate change information are more likely to be redirected to media and government websites, while those searching for global warming tend to visit environmental and educational sites. The question raised by these data is whether or not climate change is now viewed as the more emotionally charged term, which, when thought to be more benign, was the term of choice by U.S. President George W. Bush, and, subsequently, viewed as representing the interests of industry and political conservatives.

In late 2006, ACNielsen, the world's leading marketing-information company, surveyed more than 25,000 internet users in almost 50 markets about global warming. Of those questioned, 91 percent were aware of global warming, and more than half considered global warming to be a critical issue. Internet users most aware and concerned about global warming were those from countries most affected by the consequences of climate change. The three countries that ranked the lowest in awareness were the United Arab Emirates, where 18 percent of consumers said they had not heard of global warming, followed by the United States, with 13 percent, and Malaysia with 11 percent. Latin Americans ranked with those consumers most likely to believe that global warming is the direct result of human activity, and the users from Eastern Europe, the Middle East, and Africa followed closely. Research suggests that greater media coverage and increased awareness by individuals, however, do not inevitably lead to changes in individual behavior.

EVALUATING ONLINE INFORMATION

With the increasing availability of websites that focus on global warming, the complexity of scientific issues, and the presence of climate change skeptics disputing the consensus of the scientific community, a critical issue for internet users searching for reliable information is the evaluation of online resources. Accuracy and objectivity are critical to sound information. Graduate programs in library and information science routinely incorporate website evaluation and analysis as components of their curricula. Additionally, public and academic libraries post evaluation criteria on their own websites and teach patrons how to assess online information through individual user instruction or group orientation sessions. Johns Hopkins University, for example, offers not only website evaluation criteria, but an introduction to information counterfeits, including: propaganda, misinformation, and disinformation, on its library's website.

According to this overview, propaganda is frequently misused because of its pejorative historic context. Propaganda is often thought of as information with no basis in truth, when, in actuality, it is the representation of the facts in a manner to solicit a specific response that defines propaganda as such. Misinformation, on the other hand, is not based in facts. Misinformation is not an intentional effort to mislead, but is simply incorrect information passed from one person to the next. Urban legends, which are untrue tales, comprise much of the misinformation online. Disinformation is the intentional propagation of false information, often with the purpose of influencing the media and the public to gain support for a political or policymaking position. The internet may be fertile ground for disinformation, but it is most likely the propaganda found online that scientists and scholars have attempted to debunk.

The number of factors recommended for analyzing a website can be as few as five or more than 20. Generally, however, criteria can be reduced to 10 categories: the publisher, author, currency, audience, perspective, content, quality, style, organization, and stability. The publisher of the website is critical, particularly if the site does not credit authors for their content. The publishing body should be recognizable and reputable.

Online searches for environmental information increase alongside greater media coverage about environmental issues.

There should be a link on each page of the site back to the home page and a link to email the webmaster. The authors' credentials are also central in determining whether or not a site should be used as a reliable, authoritative source. There should be information about the authors or links to other documents about and by the authors. The perspective of the site should represent an objective, balanced presentation of information. If there is an intended bias, then it should be clearly stated on the site. Government sites reflect the positions and policies of government leaders, just as industry sites represent the positions of corporate interests, although the perspectives of each may not be clearly defined. The user must sift through information to determine bias on these sites, as well as those representing other public and special interests.

The currency of the site refers to the frequency of updates. Dates of revision to the site as a whole and to the site's individual web pages should be posted.

Frequent updates are important if the site provides time-sensitive information. If a page or site has not been revised for some time, then it is possible that it is an orphaned page, or a site that has been superseded. The audience refers to the primary users of the site and the target audience. The intended users should be readily apparent on the site.

The stability of the site and its overall quality, including obvious faults, known errors, or inconsistencies, also play a central role in determining whether or not the site is credible. Finally, the site should be well organized, user-friendly, and easy to navigate. These factors influence the decisions by users on whether or not to return to sites. Sites with valuable reliable information are not useful if the users cannot find what they need.

RECOMMENDED WEBSITES

There is a profusion of websites about climate change and global warming. Even with evaluation criteria, choosing among them can be difficult for internet users. There are a number of portal sites that provide links to information on a wide range of topics, including environmental science. These sites link to other sites that have been reviewed by information professionals and subject specialists.

For example, Intute, created by a network of universities and partners in the United Kingdom, contains more than 300 pages with information about global warming. Multiple pages may be found on the same site, so the number of websites is actually lower. Bulletin Board for Libraries (BUBL), prepared by and maintained at Strathclyde University in Glasgow, Scotland, links to nine individual websites about global warming, including those of the U.S. Environmental Protection Agency, the World Wildlife Fund, and the Public Broadcasting Service. BUBL links to 30 sites about climate change, but there is some duplication of these sites and the sites about global warming.

The Internet Public Library, founded by the University of Michigan School of Information, and now maintained by the College of Information Science and Technology at Drexel University, with support from the College of Information at Florida State University, includes approximately 200 entries about global warming and 133 about climate change, with some repetition among the sites. The Librarians' Internet Index, a publicly-funded, librarian-maintained website with more than 20,000 entries, includes more than 70 sites about global warming and 70 about climate change, but includes duplication of sites.

Each year, the Reference and User Services Association (RUSA) publishes a list of Best Free Reference Websites. RUSA is a division of The American Library Association, the oldest library association in the world, and the largest, with more than 65,000 members. RUSA's combined index includes Earthtrends: the Environmental Information Portal by the World Resources Institute (2004); GrayLit Network: A Science Portal of Technical Reports by the United States' Department of Energy's Office of Scientific and Technical Information (2005); the Internet Public Library (1999); Librarians Index to the Internet (2000); U.S. National Aeronautics and Space Administration (2003); National Weather Service of the U.S. National Oceanic and Atmospheric Administration (2006); The *New York Times* on the Web (2003); and *Science Daily* Magazine (2004).

In the late 1990s, the environmental resources librarian at Harvard College Library identified a number of websites representing campus initiatives online, many of which are still viable sites today. Among those listed were the National Wildlife Federation, Second Nature, and the Institute for Sustainable Development. Stanford University's recommended internet resources also include the National Wildlife Federation, in addition to EcoNet, National Institute of Environmental Health Services, and Earth Trends.

The State University of New York at Buffalo has a comprehensive list of recommended sites about global warming that encompass domestic policy issues, international policy issues, New York State, data relevant to specific sites, materials for teachers and students, and guides to additional information. The list is thoroughly annotated and included among its recommendations are: Community Planning and Development: Environment, the U.S. Department of Housing and Urban Development; Office of Community Viability; Congressional Research Service Reports, National Council for Science and the Environment; the U.S. Environmental Protection Agency, which includes links to 250 documents about climate change, representing a broad range of local, national, and international websites; the National Library of the Environment, National Council for Science and the Environment; Environment: United Nations (UN) System Pathfinder, UN Dag Hammarskjöld Library; the World Bank, and the World Resources Institute.

The Petroleum and Energy Resources Division of the Special Library Association (SLA) published its own list of recommended online resources in August 2007. Al Gore was a keynote speaker at the SLA's annual conference. Suggested publications could be found at websites by the Intergovernmental Panel on Climate Change; The Climate Institute, based in Washington, D.C.; RealClimate; Massachusetts Institute of Technology; the ResourceShelf, a site that includes librarians and researchers among its contributors; and the National Academies Press. Websites recommended by other sources, including members of the State & Local Climate Change Program, are the U.S. Environmental Protection Agency, the National Science Teachers Association, the Climate Action Network, the Climate Institute, Environmental Defense Fund, the Natural Resources Defense Council, the National Environmental Trust, Physicians for Social Responsibility, the Union of Concerned Scientists, and the Pew Center of Global Climate Change. A number of factors, technological and human-driven, determine whether or not internet traffic is successfully directed to any of these recommended resources. The Western Fuels Association website has been cited as representing aggressive interests to downplay the impact of global warming and climate change.

SEE ALSO: Media, Books and Journals; Media, TV; Technology.

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Media, TV

IN MOST COUNTRIES, there are at least two kinds of television programs that carry news about environmental issues and climate change. First, there are the general, daily news reports, which, on occasion, might introduce scientific matters into the broad agenda, whenever something new happens: either a catastrophe related to the weather, or any public event that centers on a decision related to climate change. On the other hand, there are many scientific series (or programs about popular science) specially made for television, usually in a one-hour format that can address some selected aspects of climate change and global warming, in general terms.

For instance, in the United States, there is *NOVA* and *Journey to Planet Earth* on PBS; in Canada, there is *Découverte* produced weekly by Radio-Canada; in England, there are many programs that are produced by the BBC. Many non-experts who have an interest in nature would consider television their main source of information about scientific matters, rather than scientific magazines or academic journals.

CLIMATE CHANGE IN THE EVENING NEWS

In most Western countries, television news segments need two elements, no matter what the topic is: an event that has just happened, and actual images that prove that it is true, such as a tornado or a handshake, depending on topic. Sometimes, a complement, such as an analysis of the issue by an expert can be a plus, in order to give meaning to the news, or at least a context, but it is not essential. Most journalists try to present both sides of every issue; so whenever there is a press conference, a decision by authorities, a new law, a demonstration, or a political event related to the environment, the media will report the issue in order to cover what has been announced in a previous press release or memorandum on a press wire.

For instance, when presenting an ongoing debate or a new controversy, journalists will try to get comments and opinions from an official voice of the administration (or government), who will be criticized (or contradicted) by a politician from the opposing party, an expert from civil society, or some representative from an environmental movement such as Greenpeace. Greenpeace receives the full attention of many news teams when they organize a spectacular event, fulfilling the media's quest for breaking news with striking images.

In some exceptional cases, the media will present events that are not new, but rather a part of history. On special occasions, for instance during the 10-year anniversary of the signing of the Kyoto Protocol, or a number of years following the *Exxon Valdez* disaster, the media might review the years that have passed, but only if there are significant events that are organized by groups or associations regarding that timeframe. This would be an opportunity for evaluating the progress and consequences that might have been witnessed during that period.

Television news is one of the most common ways to communicate scientific issues to a general audience. In that context, reporters who are neither scientists, nor experts, but just communicators who report what they have witnessed, translate scientific news into ordinary terms. Although experts and scientists are often consulted and quoted, journalists have the capacity to interpret, edit, quote outside the context, holding the ability to have the last word on the subject. On these occasions, some hypotheses, models, intuitions, or trends explained in detail and with much nuance by scientists can be misinterpreted or misunderstood by facts being stated by inexperienced journalists, who at times need to cover the entire subject in under a minute. That is the price scientists have to pay to find a wider audience, quite different from a university chair, a conference for scholars, or a scientific article. However, some devoted journalists specialize in scientific news and will often join various networks of colleagues who share the same interests in science, nature, and environmental issues. Associations such as the Society of Environmental Journalists allow such cooperation, although there is still much debate about climate change and related issues in these circles.

THE FUTURE OF CLIMATE CHANGE

There are many programs and special features related to environmental risks, climate change, and global warming. Laboratory life and science are not exciting as such; but for most producers, stories about science made for television have to be. Most of these programs are often produced and structured according to the same patterns. First, there must be a few experts who confirm the main arguments that are brought to the table. But to avoid showing a series of talking heads of scientists on television, most television directors try to borrow some stylistic elements from fiction feature films in order to create an original narrative that is easy to follow, with all the common ingredients: a strong intrigue, some background music that dramatizes the problem, plus illustrations and moving images. However, because events about climate change and global warming are complex and evolving quickly, programs that discuss these matters tend to become obsolete in a short period of time. New-media and specialized networks can offer other sources, for instance, the National Aeronautics and Space Administration (NASA) Television (NTV), in the United States.

CLIMATE CHANGE AS A MERCHANDISE

Programs about the environment and related issues have become merchandise that can be bought and sold by producers to distributors and television networks. As with any other program, the value of a one-hour feature on climate change will depend, among other factors, on the audience it gathered when it was first aired. Other elements are the year it was produced, the cost of its rental, and its original language (if a translation is needed). Some television programs are sold on videocassette or DVD for further uses, for example, as instruments of environmental education for use in classrooms.

Other events promoting awareness about climate change and global warming are specially conceived for television, like Al Gore's Live Earth Concert on July 7, 2007, which attracted an audience of two billion on radio, television, and over the internet. On that occasion, more than 100 groups and artists performed live in diverse locations, on all seven continents, including Antarctica. Many news reports mentioned the event and focused on the most unusual dimension, which was the musicians playing in Antarctica in front of cameras. The whole event was staged to attract media awareness and target a new audience for the cause of climate change.

ADVOCACY

While it is easy for audiences to be reached by the media (for example, by listening to the radio, watching television, or picking up a newspaper); the access for an individual to go inside the media, on the other hand, is harder, and often impossible, especially with national media and large television networks, for an unknown citizen to discuss an issue, a problem, or an opinion of his/her own. In most cases, groups and associations have more opportunity to be heard than a single individual.

Every day, most journalists receive phone calls from people defending a cause, who want media coverage, and, thus, journalists have to select according to what is relevant, to societal norms, the opinions of their colleagues or bosses, and regarding how audiences might react, according to Lawrence Wallack and colleagues.

When activists want to have access to television to express their position, for example, about environmental issues, climate change, and global warming, they often face the same institutional barriers: lack of time, no specific program to host them, and too many topics to cover. Often, the local media become the easiest entry to present a point. National networks and global networks like CNN (or Al-Jazera in Katar and for the Middle East) are among the most difficult media to reach. Some community media, often run by persons who do not get paid, can add another dimension. In his book about advocacy communication, John P. McHale recognizes both local and cable television as the most efficient media for people who want to advocate environmental causes and topics, because these channels are easier to access and have an audience that is often overlooked by their competitors. In some cases, these parallel media can become a first step in a strategy toward creating a broader media presence.

SEE ALSO: Media, Books and Journals; Media, Internet; Public Awareness; Technology; United States.

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Meridional Overturning Circulation

THE MERIDIONAL OVERTURNING circulation is an oceanic system driven by physical forces related to temperature, salinity, and momentum. The circulation is a generally closed system with an important role in redistributing heat on a global scale. Regions of intense heat loss at high latitudes produce cold (dense) water that sinks to the oceans' depths. This abyssal water spreads toward the equator, while the sinking water is replenished by warmer water flowing poleward near to the ocean surface. The upper level waters link the circulation, fed in regions of upwelling from the oceans' depths. Although other areas of subduction exist, especially in the Waddell Sea in Antarctic waters, a key source of the cold abyssal water is in the North Atlantic Ocean. It is the Atlantic Meridional Overturning Circulation (AMOC), which has garnered the largest amount of attention from researchers.

The usually stratified ocean surface layers in the North Atlantic may become disturbed by a weather system, allowing the particularly cold surface water in this region to sink, adding to the North Atlantic deep water, driving the circulation. In the return flow, the heat flux into the North Atlantic carried by the North Atlantic Drift (a part of the meridional overturning circulation, as opposed to the wind-driven Gulf Stream) makes a substantial contribution to keeping the region warmer than at comparable latitudes in the North Pacific. Because the circulation involves the movement of surface waters to abyssal depths and vice versa, it also plays a key role in the redistribution of dissolved carbon dioxide and inorganic carbon in oceanic waters. The role of this in modulating or enhancing climate change is an area of active investigation.

The accumulation of evidence from studies of past climates provides one of the most persuasive links between the meridional overturning circulation and climate change. Studies of deep sea sediments, glacial ice cores, varves, and peat sediments show that, as the North Atlantic region emerged from the Pleistocene glacial period, the general warming process was punctuated by periods of intense cold (such as the Heinrich, and the Younger Dryas cold events). The transition between events was very rapid. In the case of the Younger Dryas, temperatures may have declined by 9–18 degrees F (5–10 degrees C) in as little as 10 years. Although there are alternative hypotheses, the most compelling explanation for these oscillations in climate is a disruption in the North Atlantic circulation. Evidence suggests that the circulation was entirely, or almost completely eliminated during these events. The periods of a strengthening meridional overturning circulation also experienced the most rapid warming. Variations in the meridional overturning circulation in the North Atlantic have been significant in driving abrupt climate change.

The meridional overturning circulation exhibits considerable variability. In recent years, the upper layers of the North Atlantic appear to be warming, and the fluxes associated with the meridional overturning circulation appear to be diminishing. It is not yet clear if the observations are part of a process of natural variability or represent a longer-term trend. However, a majority of computer models suggest a general weakening of the circulation during the coming century as a result of climate change.

In a warming world, any melting of the Greenland Ice Sheet could enhance ocean layering, thereby impeding the processes of convection and reducing the warming flow of the North Atlantic Drift. Increased precipitation in the region could produce a similar effect. In models, if the meridional overturning circulation is shut off, results indicate a significant cooling of several degrees C in the surrounding continental areas. However, indications are that the region has been warming. Also, a complete shutdown of the circulation in the North Atlantic in the coming century is unlikely.

SEE ALSO: Atlantic Ocean; North Atlantic Oscillation; Thermohaline Circulation.

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Mesosphere

THE EARTH IS surrounded by an atmosphere which is the blanket of gases that has no definite outer edge. Over 80 percent of the gases in the atmosphere are held by gravity within 12.4 mi. (20 km.) of the earth's surface. The physical and chemical structure of the atmosphere and the interactions occurring there make the atmosphere an integral part of the earth system. It is held near the surface of the planet by the earth's gravitational attraction.

Without the atmosphere there would not be life on earth. The atmosphere contains the air people breathe, protects life from harmful radiation from the Sun and helps keep the planet's heat from the Sun from escaping back into space. The atmosphere is made up of a mixture of gases, especially nitrogen, oxygen, argon and carbon dioxide. It reaches over 310 mi. (500 km.) above the surface of the planet. There is no exact boundary between the atmosphere and outer space. Atmospheric gases, however, become thinner the higher up the space.

TWO LAYERS OF THE ATMOSPHERE

Based on chemical composition, the atmosphere is divided into two broad layers: the homosphere and the heterosphere. The homosphere extends up to the height of 56 mi. (90 km.) and is characterised by uniformity in chemical composition. It consists of three thermal layers, namely, the troposphere, the stratosphere, and the mesosphere. Each sub-layer is separated from the adjoining layer by a shallow transitional zone. The heterosphere has heterogeneous chemical composition, with layered structure, of nitrogen, oxygen, helium, and hydrogen, respectively. Generally, the atmosphere consists of five layers, namely, the troposphere, the stratosphere, the mesosphere, the thermosphere, and the exosphere. The thickness of these layers is slightly different around the globe, and also varies with respect to temperature and season. These five layers of the atmosphere act as safety blankets, regulating the Earth's temperature and maintaining life forms in it.

The mesosphere is the third highest layer and is separated from the stratosphere by the stratopause and from the thermosphere by the mesopause. The top layer of the mesosphere is called the mesopause. The regions of the stratosphere and the mesosphere, along with the stratopause and mesopause are called the middle atmosphere. The mesosphere is the layer of the earth's atmosphere that is immediately above the stratosphere and below the thermosphere and is located from about 31 mi. (50 km.) to 50–56 mi. (80-90 km.) altitude above the earth's surface. Within this layer, temperature decreases with increasing altitude. The mesosphere spreads above the stratosphere from 31–50 mi. (50–80 km.). Temperatures in the upper mesosphere fall as low as minus 148 degrees F (minus 100 degrees C), varying according to latitude and season. Millions of meteors burn up daily in the mesosphere as a result of collisions with the gas particles contained there, creating enough heat to vaporize the falling objects before they reach the ground, resulting in a high concentration of iron and other metal atoms. The meteors, which fall to the Earth withgravitational force, burn due to the friction with the wind at this level. This layer protects the Earth from the falling meteors. It is characterized by a broad temperature maximum (near 32 degrees F, 0 degrees C) at its base, from which the temperature decreases to a minimum of about minus 130 degrees F (minus 90 degrees C) at the mesopause level. Mesosphere displays high wispy clouds in high latitudes during summer because of reflected sunlight from meteriotic dust particles.

The mesosphere is the coldest layer of the atmosphere, where the temperature drops rapidly with altitude. Temperatures are warmest at the lowest level of the mesosphere and become colder at its highest level. The mesosphere is that region of the atmosphere where the air masses are relatively mixed together and the temperature is constant with altitude. The region receives balanced heating from below and above, and cools off about as fast as it warms up. Elevated temperatures can sometimes cause a molecule to become ionized; therefore, the ionosphere and thermosphere can overlap. The main dynamic features in this region are atmospheric tides, internal atmospheric gravity waves, and planetary waves. In the mesosphere, gravity-wave amplitudes can become so large that the waves' dissipation transmits so much energy that it largely drives the global circulation of the mesosphere. Because it lies between the maximum altitude for aircraft and the minimum altitude for orbital spacecraft, this region of the atmosphere has only been accessed through the use of sounding rockets. As a result, it is the least understood part of the atmosphere.

SEE ALSO: Carbon Dioxide; Evolution of the Atmosphere; Stratosphere; Thermosphere; Weather.

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Mesozoic Era

THE MESOZOIC ERA is one of three geologic eras of the Phanerozoic eon. Lying between the Paleozoic and the Cenozoic these three eras comprise the Phanerozoic eon. The Mesozoic was a time of tectonic, climatic, and evolutionary activity. The continents gradually shifted from a state of connectedness into their present configuration. The climate was exceptionally warm throughout the period, also playing an important role in the evolution and diversification of new animal species. By the end of the era, the basis of modern life was in place. The Mesozoic era extended roughly 180 million years, from 251 million years ago (Mya) to when the Cenozoic era began 65 Mya. This Era is further separated into three geologic Periods. From oldest to youngest: Triassic (251 Mya to 199 Mya), Jurassic (199 Mya to 145 Mya), Cretaceous (145 Mya to 65 Mya).

The lower (Triassic) boundary is set by the Permian-Triassic extinction, during which approximately 90–96 percent of marine species and 70 percent of terrestrial vertebrates became extinct. It is also known as the Great Dying because it is considered the largest mass extinction in history. The upper (Cretaceous) boundary is set at the Cretaceous-Tertiary (KT) extinction, which may have been caused by the meteor that created the Chicxulub Crater on the Yucatán Peninsula. Approximately 50 percent of all genera became extinct, including all of the non-avian dinosaurs.

DRAMATIC RIFTING

After the vigorous convergent plate mountain-building of the late Paleozoic, Mesozoic tectonic deformation was comparatively mild. Nevertheless, the era featured the dramatic rifting of the supercontinent, Pangaea. Pangaea gradually split into a northern continent, Laurasia, and a southern continent, Gondwana. Laurasia became North America and Eurasia, while Gondwana split into South America, Africa, Australia, Antarctica and the Indian subcontinent, which collided with the Asian plate during the Cenozoic, the impact giving rise to the Himalayas. The Triassic was generally dry, a trend that began in the late Carboniferous, and highly seasonal, especially in the interior of Pangaea. Low sea levels may also have exacerbated temperature extremes. Because much of the land that constituted Pangaea was distant from the oceans, temperatures fluctuated greatly, and the interior of Pangaea probably included expansive areas of desert. Abundant evidence of red beds and evaporites, such as salt, support these conclusions. Sea levels began to rise during the Jurassic, probably caused by an increase in seafloor spreading. The formation of new crust beneath the surface displaced ocean waters by as much as 656 ft. (200 m.) more than today, which flooded coastal areas. Furthermore, Pangaea began to rift into smaller divisions, bringing more land area in contact with the ocean by forming the Tethys Sea. Temperatures continued to increase and began to stabilize. Humidity also increased with the proximity of water, and deserts retreated.

WIDELY DISPUTED

The climate of the Cretaceous is less certain and more widely disputed. Average temperatures were higher than today by about 18 degrees F (10 degrees C). In fact, by the middle Cretaceous, equatorial ocean waters may have been too warm for sea life, and land areas near the equator may have been deserts, despite their proximity to water. The circulation of oxygen to the deep ocean may also have been disrupted. Large volumes of organic matter accumulated because they were unable to decompose and were eventually deposited as black shale.

The extinction of nearly all animal species by the end of the Permian period allowed for the radiation of many new lifeforms. Large archosaurian reptiles that appeared a few million years after the Permian extinction dominated animal life during the Mesozoic era.

The climatic changes of the late Jurassic and Cretaceous provided for further adaptive radiation. The Jurassic was the height of archosaur diversity, and the first birds and placental mammals also appeared. Angiosperms radiated sometime in the early Cretaceous period. As the temperatures in the seas increased, the larger animals of the early Mesozoic gradually began to disappear, while smaller animals of all kinds, including lizards, snakes, and perhaps the ancestor mammals to primates, evolved. The large archosaurs became extinct, while birds and mammals thrived.

During the early Mesozoic era, researchers do not conclusively predict high-latitude ice-free environments during the Cretaceous period. Various explanations have been proposed for the discrepancy, and subsequently incorporated into further modelling studies. Two of these include ocean circulation changes and the role of CO_2. Of these, only an elevated atmospheric CO_2 concentration could come close to reconciling the models with geological evidence. High levels of CO_2 seem reasonable, considering the high global sea level and ensuing break-up of Pangea. In addition to increased outgasing of

CO_2, the reduced continental area would result in a decreased rate of weathering of silicates and removal of CO_2 from the atmosphere.

Unfortunately, there is little reliable evidence to support the CO_2 model. M.A. Kominz and colleagues have estimated that average rates of the velocities of major tectonic plates were higher in the late Cretaceous and ocean ridge volumes were greater. In addition, Cretaceous sea-beds were dominated by calcite minerals, implying higher aqueous, and, consequently, atmospheric, CO_2 concentrations.

SEE ALSO: Cretaceous Era; Jurassic Era; Triassic Era.

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Methane Cycle

METHANE HAS MANY sources, both natural and human-related, but just two major sinks: its destruction in the atmosphere, and its use by certain soil bacteria. Methane is a powerful greenhouse gas, each kg. emitted to the atmosphere having a global warming potential (GWP) 23 times greater than that of a kg. of carbon dioxide over a 100-year time horizon. Since the pre-industrial era, the concentration of methane in the atmosphere has more than doubled, rising from around 715 parts per billion (ppb) in 1800, to more than 1,770 ppb today—higher than at any time in the preceding 650,000 years. Methane emissions resulting from human activities now exceed those from natural sources, comprising around 60 percent of the 600 million metric tons of methane emitted globally to the atmosphere each year.

Methane (CH_4) is the main component of natural gas, first discovered in 1776, by Alessandro Volta. It has a relatively short lifetime in the atmosphere, most molecules having been destroyed within 10 years of release. Despite this limited lifespan, it is a powerful greenhouse gas, having a global warming potential (GWP) of 23. This means that every kg. of methane emitted to the atmosphere has the equivalent forcing effect on the Earth's climate of 23 kg. of carbon dioxide over a 100-year period.

The global methane cycle is comprised of a wide range of sources and sinks. Major natural sources include wetlands, termites, the oceans, and release from hydrates (lattice-like structures of ice and methane, also known as clathrates, occurring in polar regions and in oceanic sediments). Recently, living vegetation has also been suggested as an important natural source of methane. Of known sources, wetlands dominate natural emissions, with between 100 and 200 million tons of methane emitted from these waterlogged soils each year. Wetland methane emissions arise from methane-producing bacteria known as methanogens, which are active in the anaerobic, carbon-rich environments common to wetland soils.

Human activities are to blame for around 60 percent of global methane emissions into the atmosphere each year.

The rate of wetland methane production increases rapidly with increasing temperatures, raising concerns that human-induced climatic warming, particularly at high latitudes, may increase global methane emissions and amplify warming.

While the methanogens in the anaerobic soils of wetlands are major producers of methane, soils also represent significant sinks for methane. Methane-utilizing bacteria, called methanotrophs, oxidize much of the methane produced in wetland soils before it can escape to the atmosphere. In well-aerated soils, such as those common to forested areas, the methanotrophs are also able to remove methane from the atmosphere. Globally, soil methanotrophs are estimated to remove around 30 million tons of methane from the atmosphere each year. By far the largest sink for atmospheric methane is that of destruction in the troposphere by the hydroxyl (OH) radical, this process removes around 500 million tons of methane each year. Additional destruction of methane OH radicals in the stratosphere is thought to remove 40 million tones of methane per year.

At around 320 million tons per year, methane emissions related to human activities are estimated to exceed those from all natural sources. The bulk of these emissions come from losses occurring during fossil fuel extraction and transport, from ruminant livestock and waste treatment, from landfill sites, from rice cultivation, and from biomass burning. Mitigation policies designed to reduce human-induced methane emissions include the capture of methane produced during fossil fuel extraction and by landfill sites, for flaring or use as an energy source; the use of feed additives to reduce methane production by ruminants; changes in rice cultivation methods to reduce the length of time that rice paddy soils are in a waterlogged, methane-producing state.

Concentrations of methane in the atmosphere have more than doubled since the pre-industrial period, rising from around 715 parts per billion (ppb) in 1800, to the current level of around 1,770 ppb. This concentration is higher than at any time in the last 650,000 years, and has arisen due to an imbalance between methane sources and sinks. Since the early 1990s, the rate of increase has slowed markedly, with atmospheric methane concentrations remaining relatively constant since 1999. Analyses indicate that this recent stabilization may be the result of transient reductions in emissions from wetland areas from unusually low rainfall. If rainfall in these areas returns to normal, atmospheric methane concentrations may increase still further, unless emissions from human activities are reduced.

SEE ALSO: Carbon Cycle; Greenhouse Effect; Greenhouse Gases; Greenland Cores; Radiation, Absorption.

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Mexico

THE REPUBLIC OF Mexico has a land area of 758,249 sq. mi. (1,972,550 sq. km.), a population of 106,535,000 (2006 est.), and a population density of 142 people per sq. mi. (55 people per sq. km.). About 12 percent of the country is arable, with a further 39 percent used for meadow or pasture (often for low-intensity grazing), and 24 percent of the country is forested. The climate of Mexico varies considerably; while some of the northern parts are arid desert, the central plateau is much colder, especially in winter, and the southern part of Mexico is largely tropical jungle. As well as the regional variations in climate, there have also been studies of Mexico's climate over recent centuries. Many historians now believe that the Mayan civilization collapsed in about 950 C.E. as a result of lack of food supplies, possibly through an earlier episode of climate change. It coincided with a period of prolonged drought. This has led some global warming skeptics to suggest that both global warming and climate change are historical cycles, rather than solely a result of human activity.

Largely because of its heavy industry and the size of its population, Mexico has a high rate of carbon dioxide emissions per capita, at 4.5 metric tons per person in 1990, reduced to 3.9 metric tons per person by 1991, after which it rose slightly, to 4.24 metric tons in 1993. The vast majority of Mexico's carbon dioxide emissions (73 percent) come from the use of liquid fuels, and 17 percent come from gaseous fuels. This is not just from the use of automobiles (transport makes up 27 percent of the country's carbon dioxide emissions), but also from the proliferation of gasoline-driven generators. Approximately 75.9 percent of electricity in Mexico is generated from fossil fuels. For the remainder of the electricity production in the country (accounting for 31 percent of carbon dioxide emissions), 16.8 percent of the power comes from hydropower, and 4 percent from nuclear power. Mexico's other major contributions to global warming are from cement manufacturing (4 percent) and gas flaring (1 percent).

The effects of global warming in Mexico have been marked in parts of the country. The Pacific coastline of Mexico has seen an increase in the numbers of tornados, and there is clear evidence of coral reef bleaching. In 1998, the country recorded its worst fire season on record up to that point, with fires destroying 1.25 million acres (505,857 hectares). The smoke from this triggered a statewide health alert in Texas. Pollution in Mexico City also remains particularly bad, with 4 million automobiles, 200,000 buses, 35,000 taxis, and 60,000 factories responsible for considerable carbon dioxide and sulfur emissions. Traffic congestion is serious throughout the day, and the city is located in a 70-mi.- (113-km.-) wide basin, which prevents the fumes from dispersing. In some parts of the country, there has been an increase in the number of rainstorms, which in turn has led to the prevalence of insect-borne diseases such as dengue fever, which had previously been limited to an elevation limit of 3,300 ft. (1,006 m.), but has now been found at 5,600 ft. (1,707 m.). Concern about climate change and global warming has led to more publicity for the Green Party in Mexico.

The Mexican government took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992. They signed the Kyoto Protocol to the UN Framework Convention on Climate Change on June 9, 1998, with was ratified on September 7, 2000, with it entering into force on February 16, 2005.

SEE ALSO: Climate Cycles; Climate Change, Effects; Diseases; Thunderstorms.

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Michigan

MICHIGAN LIES IN the northern United States and is located between 41 degrees N and 49 degrees N in latitude and between 82 degrees W and 88 degrees W in longitude. Michigan's area is 253,793 sq. km. (97,990 sq. mi.); its population is 10.1 million (2006 est.); in comparison, in 1950, the population was about 6.4 million. Its largest cities are Detroit and Grand Rapids. Lansing is Michigan's capital.

The territory consists of two peninsulas. The southern peninsula is between Lakes Huron and Erie on the east, and Lake Michigan on the west. The northern peninsula is between Lakes Huron and Michigan on the south, and Lake Superior on the north. The Michigan topography is mostly hilly uplands, with many lowlands in the eastern portion of both peninsulas. The central part of southern Michigan is a plateau, surrounded by a chain of ancient shore terraces. On the western sections of the northern peninsula, the landmasses are up to 1,968 ft. (600 m.) in height. The highest point in Michigan is Mount Arvon 1,981 ft. (604 m.). The Ontonagon River, which flows into Lake

Superior, is the largest river in Michigan. Ancient soft sandstone, limestone, and lake and glacial deposits compound the landmasses.

Michigan is located in the Great Lakes Region and has a shoreline with Lakes Superior, Michigan, Huron, and Erie. The Great Lakes Region is geographically located at the edges of the Northern Hemisphere polar vortex, and thus Michigan lies in the path of traveling cyclones and anticyclones. On a global scale, the Michigan climate is affected by three air masses: the Continental Polar air mass, with dry, cold winters and summers; the Marine Polar air mass, with cold, snowy winters and cool wet summers; and the Marine Tropical air mass with humid and hot summers. Which combination of air mass or masses dominates at a particular time of the year depends on the Earth's general circulation and its global teleconnection patterns. The El Niño–Southern Oscillation (ENSO) phenomenon dominates, both phases of which—the ENSO warm phase (El Niño) and cold phase (La Niña)—have been linked to anomalous climatic patterns in the areas adjunct to the Great Lakes Region. The warm phase of ENSO brings heavy snow in winters to northern Michigan.

At the local scale, the Michigan climate is influenced by the lakes and local topography and, in general, has mild winters and cool summers. The climate in northern Michigan is cooler than the climate in the south. In southeastern Michigan, the average January temperature is 25 degrees F (minus 4 degrees C). In the northwestern part, it is as low as 14 degrees F (minus 10 degrees C); the July temperature ranges are from 64–74 degrees F (64–74 degrees C). Michigan annual precipitation ranges within 2–33 in. (50–850 mm.), with the highest amounts at the southern shore of Lake Superior and at the southwest shore of Lake Michigan, with the minimum amount at the western shore of Lake Huron. The summer lake surface temperatures range from the coldest temperatures of deep Lake Superior (the deepest point 1,330 ft., or 405.38 m.) to the warmest temperatures of shallow Lake Erie (the deepest point 210 ft., or 64 m.), with very small inter-annual variability for the latter. In contrast, the lake-level pressures have very similar mean values and amplitudes for all lakes, which indicates the homogeneity of the circulation pattern over the Great Lakes Region.

Most of the Michigan territory is occupied by agriculture and forestry. Michigan is a significant producer of livestock, cherries, blueberries, cranberries, black beans, soybeans, corn, dairy, wheat, and beets. In the 20th century, the number of farms decreased from the 19th century number, but had stabilized by the beginning 21st century. Climatologically, the annual growing period is 180 days on in the southwest portion of the state. The number of growing days decreases moving north (to 80 growing days per year), due to the lower temperatures. Spruce, hemlock, and fir forests occupy the northern part of Michigan. The main Michigan trees are sugar and red maples. Forestry was the main industry at the end of 19th century, but, due to the introduction of Michigan conservation policies, has fallen in importance. Other important Michigan industries are manufacturing (automotive), mining (iron ore, magnesium compounds, gypsum, cement, sand and gravel, salt and calcium chloride, crushed stone, natural gas, and petroleum) and fishing (chub, whitefish, yellow perch, lake herring, yellow pike, carp, catfish, smelts, suckers, white bass, lake trout, and pacific salmon). The Michigan ports on Lake Michigan have access to the Mississippi River and thus to the Gulf of Mexico.

The Michigan economy depends on fresh water supply from the lakes, groundwater, and rainfall. A combination of rainfall, evaporation, and groundwater recharge rates define the freshwater balance in Michigan. There is a seasonal cycle in precipitation, temperature, and runoff, which affects the lake water levels. The highest lake levels are in the spring (because of high runoff from melting snow), and the lowest levels are in the autumn (because of high evaporation rates). The consumption of fresh water increases with population growth and economics needs. Historically, the lowest lake level was recorded in 1930, which corresponds to the fast development of the city of Detroit.

CONSEQUENCES OF ECONOMIC ACTIVITIES

Michigan's human economic activities increase pressure on Michigan's environment and the global environment. Air and water pollution from industry, traffic, and greenhouse gases increase because of industrial and domestic fossil fuel combustion; soil erosion from fertilizers and farm runoff are the main consequences of human economic activities, which can be reduced by investigating and implementing alternative energy sources (such as atomic, wind, solar power, bio-fuels, and land-field fuel), developing new technologies (for example, solar and electric cars), and discovering new efficiencies in human economic activities. If the climate shifts even slightly from its averages, Michigan will face changes in crop yield, changes in pests population, a shift in forest composition and health, a loss of bird diversity, a change in local mammal populations (such as raccoons, skunks, white-tailed deer, and moose), a change in the distribution of fishes; spread of invasive species, release of nutrients and contaminants, change in groundwater recharge, and a change in lake levels.

SEE ALSO: Alternative Energy, Overview; Pollution, Water; University of Michigan.

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Micronesia

THE FEDERATED STATES of Micronesia have contributed very little to global greenhouse gas emissions, but are likely to be severely affected by global warming. An excess of 600 small islands and atolls constitute Micronesia, which is divided into the states of Chuuk, Kosrae, Pohnpei, and Yap. Micronesia is situated in the tropics of the western Pacific Ocean, just north of the equator.

Between 1947–86, Micronesia was a part of the United Nations Trust Territory of the Pacific Islands, which was administered by the United States. Since 1986, Micronesia has been in a Compact of Free Association with the United States. Micronesia became a member of the UN in 1991, ratifying the UN Framework Convention on Climate Change (UNFCCC) on November 18, 1993. Micronesia signed the Kyoto Protocol on March 17, 1998, and ratified it on June 21, 1999. The UNFCCC came into force in 1994, and the Kyoto Protocol was effective as of 2005.

Micronesia is a member of the Alliance of Small Island States (AOSIS), which was formed to enable small island states to have a greater say in international relations, primarily with regard to climate change and sea-level rise. The country is particularly vulnerable to sea-level rise and to storm surges. Sea-level rise and loss of land are already occurring. Low lying islands are under threat. On islands that have higher ground, it is the low-lying coastal areas that are most heavily inhabited. Micronesia is affected by El Niño and La Niña weather events, and these may become more frequent and more intense as a result of global warming. El Niño causes drought conditions, while La Niña brings heavy rains, high waves, and storm surges. In the 1997–98 El Niño Southern Oscillation, Micronesia suffered drought conditions, reduced availability of drinking water, loss of agricultural crops, salt water intrusion of agricultural land, extreme sea-level variations, and erosion.

THREE STRATEGIES

The Micronesian government has identified three strategies through which to address the challenges faced because of the adverse effects of climate change. These are: to promote sustainable economic growth by reducing its economic, environmental, and social vulnerabilities; to balance resource conservation and management; and to ensure and improve quality of life for all its citizens and for future generations. Micronesia works with a number of bodies in its efforts to adapt to climate change, these include the Asian Development Bank, the South Pacific Regional Environmental Programme, and the Global Environment Facility-funded Pacific Island Climate Change Assistance Programme.

SEE ALSO: Alliance of Small Island States (AOSIS); El Niño and La Niña; Southern Oscillation.

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Midwestern Regional Climate Center

THE MIDWESTERN REGIONAL Climate Center (MRCC) is a cooperative program of the Illinois State Water Survey and the National Climatic Data Center, part of the National Oceanic and Atmospheric Administration, U.S. Department of Commerce. The MRCC is a partner in a national climate service program that includes the National Climatic Data Center, Regional Climate Centers, and State Climate Offices. The Center is based in Champaign, Illinois, and serves the nine-state Midwest region (Illinois, Indiana, Iowa, Kentucky, Michigan, Minnesota, Missouri, Ohio, and Wisconsin). The services and research provided by the MRCC help to gain a more in-depth understanding of climate change and its impacts on the Midwest. They also attempt to provide practical solutions to specific climate problems, and supply climate information for the Midwest on climate-sensitive issues, such as agriculture, energy, the environment, human health, risk management, transportation, and water resources.

The MRCC is committed to provide high-standard weather data for the midwestern area, to monitor and assess regional climate conditions and their consequences on the local environment, to compile historical datasets and to coordinate applied research on climate-related issues and problems. The MRCC has two research programs: the Climate Database Modernization Program and the West Nile Virus Project.

The Climate Database Modernization Program (CDMP) aims to preserve and make available online a wide range of observations about the climate from the last three centuries, including those carried out at U.S. Army forts starting in the early 1800s. Following these early observations, in the second half of the 19th century, the Smithsonian Institution and the U.S. Department of Agriculture directed volunteer observer networks, which eventually evolved into the Weather Bureau's Cooperative Observer Network. The Network remains in operation today for the National Weather Service. The creation of a digital database of the daily Forts/Volunteer Observer data from the 1800s will allow a more comprehensive analysis of daily climate variables and a more complete picture of climate change in the region. Thirty-nine distinct data types have been identified for digitization, including observations of temperature, pressure, precipitation, wind, clouds, state of the weather, river-gauge height, and surface water temperature. The Center carries out quality control tests on the digitized data to guarantee their accuracy in representing the observations recorded on the original documents. The MRCC is also developing a comprehensive set of metadata to complement the dataset. These metadata account for changes in instrumentation and observation practices, by classifying changes in the forms used by the observers. The metadata incorporates detailed information about each station as recorded on the forms, such as station name and location, and barometer correction and other instrument adjustments. This interest in extending weather data also applies to climate extremes, like heat waves, cold waves, and heavy precipitation events, to better understand their changes over time.

Within its interest in climate change, the MRCC is also investigating the topic of drought. The drought projects examine what causes alterations in drought frequency over decades, the impacts of recent droughts on the nature of winter in the Midwest, and the development of improved tools that can further the understanding of recent and ongoing drought.

The West Nile Virus Project aims to construct weather models to determine the period of the year when the northern house mosquito, the most common type of mosquito, becomes dominant in the Midwest, causing a higher risk of transmission to humans and other mammals. The white-spotted mosquito and the northern house mosquito are supposed to maintain the natural transmission cycle of West Nile Virus (WNV) between birds and mosquitoes in Illinois. During the spring and early summer, the white-spotted mosquito, which feeds on birds, is the dominant species, and is responsible for bird-to-bird transmission of WNV. As temperatures become warmer, the northern house mosquito, the most common night-flying mosquito, becomes more dominant. The female of this species is probably responsible for the rapid spreading of the arbovirus among birds, and may act as the major bridge vector to mammals, including humans, in the Midwest. Two types of climate models have been developed to provide an estimate of the likely date when the northern house mosquito begins to become the dominant species, and, thus, when the risk of WNV to horses, humans, and other wildlife is likely to increase.

The MRCC also has a comprehensive section on its website on weather resources, including material for teachers and schools related to climate change. Dr. Steven Hilberg has been the director of the MRCC since 1998. In that same year, Michael Paleki became the Regional Climatologist for the MRCC.

SEE ALSO: Climatic Data, Atmospheric Observations; Illinois; National Oceanic and Atmospheric Administration (NOAA); Western Regional Climate Center.

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Milankovitch, Milutin (1879–1958)

MILUTIN MILANKOVITCH, BORN in Dalj, Serbia on May 28, 1879, graduated from the Institute of Technology in Vienna, Austria in 1904. He worked as an engineer in Vienna before returning to Serbia, in 1905, to teach applied mathematics at the University of Belgrade. During the first Balkan War in 1912, he served in the military, assigned to the Danube division of the Serbian army. Milankovitch had begun a project to calculate temperatures at different latitudes and how temperature changed as a result of astronomical rhythms.

His goal was to explain the role played by astronomical cycles on ice ages by determining where various astronomical cycles coincided and combined to influence the amount of solar radiation leading to climate change.

After World War I, Serbia joined with other Balkan countries to become part of Yugoslavia. The political environment of the Balkan area remained in flux, including involvement in the Balkan War, World War I, and World War II. In spite of the unrest in the region, and an arrest and imprisonment as a prisoner of war, Milutin Milankovitch continued his work to determine, mathematically, the cycles of ice ages. He built on the theory that the ice ages were cyclical, and the work on astronomical rhythms by Scottish geologist James Croll.

Milankovitch completed a series of astronomical calculations using only his brain as the calculator, a writing implement, and paper. His calculations took into account the factors of the Earth's orbit, including tilt, axis of rotation, and axis of spin to determine the amount of insolation (sunlight, or the amount of solar radiation received by the Earth). He calculated detailed insolation curves for a few different northern latitudes, ranging back 650,000 years, and then calculated how ice sheets would respond to temperature changes. In addition, he performed similar insolation curve calculations for Mars and Venus.

His climate calculations took into account the distance from the Sun, the latitude and angle at which the Sun struck the surface of the planet. He focused on obliquity (the amount of axial tilt) and the precession of the equinoxes. He concluded the effect of eccentricity (the elliptical path of the orbit around the Sun) would be small, though later scientists have shown the importance of eccentricity. He postulated that insolation in the Northern Hemisphere drove the climate system because two-thirds of Earth's land mass lies in the Northern Hemisphere. He believed summer insolation levels at a boundary of 65 degrees N latitude, just south of the Arctic Circle, played a crucial role. If the ice caps survived the higher temperatures of summer below that specific latitude, the ice caps would have an increased chance of advancing, and by extrapolation, if the ice caps grew, the climate would cool.

His theory and calculations caused excitement among his contemporaries, but with no means of corroboration, his theory was shelved. Milutin Milankovitch died on December 12, 1958, before his research and theories had returned to prominence in the field. Since his death, in addition to using computers for improved accuracy, scientists have used carbon dating and the advanced ability to take remove cores from the ocean floor for comparison. Milankovitch's work returned to prominence. Despite flaws, and the fact that astronomical factors are not the only causes of climate change, scientists have shown a significant correlation between the climate record and Milankovitch's cyclical calculations. His work was established as a scientific model called the Milankovitch cycles in the 1970s.

SEE ALSO: Croll, James; Ice Ages; Milankovitch Cycles.

BIBLIOGRAPHY. Mark Bowen, *Thin Ice Unlocking the Secrets of Climate in the World's Highest Mountains* (Henry Holt and Co., 2005); John Gribbin, *The Scientists: A History of Science Told Through the Lives of its Greatest Inventors* (Random House, 2002); National Geophysical Data Center, "Milutin Milankovitch's Major Cycles," www.ngdc.noaa.gov (cited July 2003).

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Milankovitch Cycles

THE MILANKOVITCH CYCLES are recurring variations in the Earth-Sun orbital geometry. They collectively account for deviations in the amount and intensity of solar radiation received by the Earth. The cycles are named after Serbian astrophysicist Milutin Milankovitch (1879–1958), who developed the modern mathematical theory and formulas upon which these orbital perturbations are based. The central assertion of the Milankovitch theory is that the Earth's orbital relationship with the Sun is not stagnant, but dynamic, with three cyclic modes, which, when precisely combined, may significantly alter the Earth's insolation, resulting in a major global climate shift. While the Milankovitch theory was first proposed in the 1930s, the first supporting scientific evidence was not brought forth until the 1970s, when researchers of the CLIMAP project linked the timing of changes found in ocean sediment core data with associated orbital shifts of the Milankovitch cycles.

The three astronomical attributes constituting the Milankovitch cycles are: eccentricity or shape of the Earth's orbit about the Sun; obliquity or tilt of the Earth's axis from the perpendicular plane to the Earth's orbit; and precession or orientation of the Earth's rotational axis relative to the Sun. All three cycles fluctuate gradually at different rates with periodicities of thousands of years. These oscillations can operate jointly to control the strength and timing of seasons, including being a forcing mechanism for the frequency of glacial retreats and advancements.

Eccentricity is the change in the shape of the Earth's orbit around the Sun, fluctuating from a more circular (low eccentricity) to a more oval-shaped (high eccentricity) orbit. This cycle operates on several time periods depending on the Earth's juxtaposition to the gravitational pull of other planetary bodies (such as Jupiter), with a cycle of approximately 100,000 years most prominent. Currently, the Earth's orbit is in a low eccentricity phase, denoting a nearly circular orbit and a relatively small 3 percent difference in distance between the point of longest (aphelion) and shortest (perihelion) Earth-Sun distance. Because perihelion occurs on July 3 (Southern Hemisphere summer), this distance difference translates to approximately 7 percent more solar radiation received in the Southern than the Northern Hemisphere. At maximum eccentricity, the distance difference between aphelion and perihelion can be about 10 percent and account for over a 25 percent difference in solar radiation between the two hemispheres.

Obliquity is the deviation in the tilt of the Earth's axis away from the orbital plane. The current tilt of the Earth's rotational axis is 23.5 degrees, varying between 22.1 and 24.5 degrees over its 41,000-year cycle. Since the last peak obliquity occurred approximately 10,000 years ago, the current cycle is nearly at the midpoint of its range.

While the limits of the axial tilt cycle appear relatively small, the impact on seasons can be considerable, minimizing (exaggerating) seasonal differences with decreasing (increasing) obliquity, especially for the middle and high latitudes. During periods of less tilt, the severity of extratropical winters and summers is reduced, resulting in milder winters and cooler summers. This reduction in a seasonal contrast may promote the growth of ice sheets by decreasing the amount of summer melting and increasing high latitude winter snowfall accumulation, as higher winter temperatures increase the moisture capacity of the air. The present decreasing obliquity of the Earth has expanded the temperate latitudes and reduced the tropical and polar regions, effectively altering the position of the tropics and the polar circles at a rate of about a mi. (more than a km.) per century.

Precession is the change in the direction of the Earth's rotational axis, influencing the timing and intensity of the seasons. Often compared to the winding-down of a spinning top, the Earth wobbles on its axis, moving slightly forward as it travels in orbit around the Sun. During its average 26,000-year cycle, the Earth's axis of rotation pivots such, that the celestial poles are shifting, altering the current pole star of Polaris to other stars such as Vega in 14,000 C.E.

As a consequence of this wobble, the orbital locations at which the summer and winter solstices transpire periodically reverse; such as will be the case when Vega is the North Star. In 14,000 C.E., aphelion (perihelion) will coincide with the Northern Hemisphere winter (summer) solstice, resulting in the colder winters and warmer summers for the Northern Hemisphere and weaker seasonal temperature contrasts for the Southern Hemisphere. Precession is the only orbital parameter that is noticeable on a time scale of hundreds of years, influencing the timing of seasons by 1–2 days per century, on average. For the Northern Hemisphere, changes in precession during the past century have delayed the onset of winter and lengthened the summer.

SEE ALSO: CLIMAP Project; Milankovitch, Milutin; Orbital Parameters, Eccentricity; Orbital Parameters, Obliquity.

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Minnesota

CONSIDERED THE TRADE center of the Midwestern United States, Minnesota has a population of approximately 5 million people, ranking 21st in population among American states. Around 60 percent of the population resides in the Twin Cities of St. Paul, the state capital, and Minneapolis. The Twin Cities are home to the third largest trucking center in the United States. Minnesota is known as the Land of 10,000 Lakes, and Duluth, the fourth largest city in the state, is the largest inland trade center in America. Global warming and climate change impact Minnesota in a number of ways. Animal and plant habitats are threatened by shifting forests and grasslands. Floods and violent storms are threatening lives and property. Pests and diseases are expected to migrate into the state. Air and water quality is threatened, and smoggy summer days pose serious risks to health and the environment. The habitats of coldwater fish are jeopardized. Tourism and recreation are placed at risk from shorter winters. The focus of Minnesota's actions to reduce global warming and climate change is on educating the public, reducing pollution, ensuring clean air and water, instituting responsible land use, promoting conservation, and ensuring sustainable community development.

Between 1900 and 2001, the population of Minnesota increased by 13 percent. During that period, carbon dioxide (CO_2) emissions rose by 22 percent, reaching 95.9 million metric tons. Minnesota consumes some 2,600 million gallons of gasoline each year, and transportation accounts for 45 million tons of CO_2 emissions annually. The state has the 22nd highest level of CO_2 emissions in the country. Since the 1990s, Minnesota has placed restrictions on CO_2 emission levels. As a result of these concentrated efforts to reduce greenhouse gas emissions, Minnesota increased CO_2 efficiency by 20 percent 1990–2001. Ethanol is increasingly replacing gasoline in Minnesota. Ethanol plants provide farmers with an outlet for low-priced corn, and the 14 plants in the state produce more than 350 gallons of ethanol each year. Minnesota is one of more than 30 states that have agreed to develop a Greenhouse Gas Registry as part of a cooperative effort to reduce global warming and climate change.

In 2005, the Office of Environmental Assistance and the Pollution Control Agency were combined to create the new Minnesota Pollution Control Agency, which was given responsibility for promoting recycling, controlling pollution, educating the public, providing environmental assistance to local governments and the business community, advancing the concept of sustainable community development, generating policy, supporting environmental research, promoting green building practices, and providing grants and financial assistance for environmentally-motivated projects. The Department of Agriculture, the Department of Natural Resources, and the Board of Water and Soil Resources also have a role in protecting the state's environment.

In 2007, Minnesota began implementing the governor's Next Generation Energy Initiative. The legislature passed the 25x25 Renewable Electricity Requirements bill, which mandated that 25 percent of Minnesota's electricity be renewable by 2025. As part of the Next Generation BioEnergy and BioFuels provisions, the legislature appropriated $35 million for energy projects and research directed toward the development and use of alternative energy sources. The Next Generation Energy Act also calls for statewide greenhouse gas emission reductions of 15 percent of 2005 levels by 2015, 30 percent by 2025, and 80 percent by 2050. The bill also established the goal of having 1,000 environmentally friendly Energy Star Buildings in Minnesota by 2010. The governor further proposed an increase from 300 to 1,800 E85 gasoline pumps by 2010, promising that grants would be available for service station owners who install the new pumps, which dispense a fuel mixture of 85 percent ethanol and 15 percent gasoline.

PROGRAMS

In 2006, the governor of Minnesota proposed the Next Generation Energy Initiativem designed as a means of developing strategies for focusing public attention on renewable energy, energy conservation, and the need to lower carbon emissions. The following spring, the state created the Minnesota Climate Change Advisory Group (MCCAG), composed of 51 individuals representing business, utilities, environment, academics, religious organizations, the private

Although Minnesota is known as the Land of 10,000 Lakes, air and water quality is being threatened by climate change. Recreation and tourism are being placed at risk by shorter winters, and the habits of coldwater fish are being jeopardized.

sector, farming, local government, and Native Americans. MCCAG was charged with developing a statewide plan for reducing and sequestering greenhouse gas emissions and promoting the use of clean energy.

In 2006, Minnesota's proposed plan to reduce toxic power plant emissions won approval. The plan required Minnesota Power and Xcel Energy to cut mercury emissions at coal-fired power plants by 90 percent. As a result, Minnesota Power announced that it would spend $200 million purchasing pollution control equipment that would lower sulfur dioxide (SO_2) and nitrogen oxide (NO_x) emissions by 80 percent and mercury emissions by at least 90 percent.

Clean Air Minnesota was created under the auspices of the Minnesota Environmental Initiative. Composed of representatives from government, business, and the public, the organization promotes voluntary reductions in emissions from volatile organic compounds, nitrogen oxides, and fine particulate matter. In 2005, government agencies, business, and private organizations again came together to create Project Green Fleet, which focused on reducing pollution emitted by the state's 500 school buses. Recognizing that levels of pollution were five times higher inside school buses than outside, the group expressed concern about the health of Minnesota's children. Over a two-year period, school buses were retrofitted with pollution control equipment. Project Green Fleet also joined with local businesses to protest rising levels of heart and lung disease and asthma that were attributed in part to toxic emissions from motor vehicles.

In 1991, the Releaf Program was established for the purpose of reducing CO_2 levels by planting, maintaining, and improving trees. Funding for the program was derived from an environmental trust fund, the lottery, and private and corporate sources. In the first 10 years of operation, 361 trees were planted, and approximately 200 communities became involved in the project. The Releaf Program also serves in an advisory capacity, encouraging homeowners to reduce global warming and climate change in such simple ways as planting shade trees and wind breaks. Despite assurances that tree planting is essential to the sequestering of carbon, the future of the Releaf Program is in question because of a lack of funding.

SEE ALSO: Alternative Energy, Ethanol; Energy; Regulation; Transportation.

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Mississippi

LOCATED IN THE Deep South and bordering the Gulf Coast, Mississippi is one of the poorest states in the United States, and funding for environmental programs is not always considered high-priority. Parts of Mississippi are predominately agricultural, particularly in the fertile Black Delta of the northeast and in the Mississippi Delta of the south. More than half on the state's land area is forested. The Mississippi River, from which the state takes its name, is the state's major geographic feature, and the river has a significant influence on the economy and the environment. Mississippi is susceptible to hurricanes, and Hurricane Katrina devastated sections of the state in 2005. Each year, an average of 27 tornadoes touch down in Mississippi. All of these factors play a part in making the state vulnerable to global warming and climate change.

Scientists are predicting that, if global warming is not checked, sea levels around the world may rise from 7–23 inches by the beginning of the 22nd century. In Mississippi, this would drastically increase costal erosion and lead to loss of habitat, particularly along the Gulf Islands National Seashore. The number of destructive storms and hurricanes is likely to increase in Mississippi in response to climate change. Both economics and the environment of the state may be affected as a result of a decrease in agricultural productivity. Hotter temperatures may encourage the spread of tropical diseases and lead to major health problems, even death, in the hot summer months. Mississippi's responses to rising threats of global warming and climate change focus on improving air and water quality, protecting coastal areas, preventing pollution, educating the public, safely disposing of hazardous waste, and recycling.

Residents who blamed oil, chemical, and utility companies for global warming and damage to the states' wetlands that occurred in the wake of Hurricane Katrina filed a class-action lawsuit in Mississippi and Louisiana in 2005. Plaintiffs accused the companies, which included Columbia Gulf Transmission, Shell Pipeline, and Exxon Mobil Oil of precipitating global warming by destroying the natural protection that wetlands would have provided, had the companies not dredged pipeline canals in the area. An additional suit charged oil companies with responsibility for increasing the area's vulnerability to global warming and destroying property as a result of hazardous emissions released during the storm.

According to the nonpartisan Washington-based research organization, U.S. Public Interest Research Group, carbon dioxide (CO_2) emissions in Mississippi rose by 255 percent 1960–2001. PIRG believes that the increase was due to a combination of CO_2 emissions from motor vehicles and coal-fired power plants. Between 1990 and 2001, the population of Mississippi grew by 11 percent. During that time, CO_2 emissions rose by 44 percent to a total of 69 million metric tons, and CO_2 efficiency declined by minus 5 percent. Mississippi now ranks 34th in the nation in CO_2 emissions. Although most states have banned the use of conventional motor gasoline because of its influence on global warming and climate change, Mississippi authorizes its use statewide. Coal-fired power plants provide around a tenth of Mississippi's total energy. Eight states and the City of New York have filed suit against energy companies that are accused of generating most of the pollution in the United States. Two of the companies involved in the suit operate in Mississippi. The Southern Company is second on the list; and the Tennessee Valley Authority is third.

The Mississippi Department of Environmental Quality (MDEQ) has the chief environmental responsibility in Mississippi and is charged with ensuring clean air and water, preventing pollution, and safeguarding public health. The agency is supported by the seven-member Commission on Environmental Quality appointed by the governor. The Office of Pollution Control, the Office of Land and Water Resources, and the Office of Geology are subdivisions of MDEQ. Other state agencies involved in generating responses to global warming and climate change are the Department of Agriculture and Commerce; the Department of Marine Resources; the Department of Wildlife, Fisheries, and Parks; and the Forestry Commission.

PROGRAMS

Mississippi has a number of specific programs designed to deal with protecting the environment and reducing threats of global warming. As part of the Ambient Air Monitoring for Criteria Air Pollutants Program, MDEQ regularly tests levels of sulfur dioxide, ozone, carbon monoxide, nitrogen dioxide, and particulate matter in the air. The agency has the authority to enforce compliance with state and federal laws. MDEQ also oversees the Hazardous Air Pollutant Monitoring Program that examines levels of volatile organic compounds and carbonyl compounds in the air. The Mississippi Source Water Assessment Program was set up in 1996 to oversee Mississippi's compliance with the Federal Safe Drinking Water Act Amendments, which required all states to identify contaminants in drinking water and to take actions to improve water quality. The AGChem Program was established in 1987 to assess the impact of chemicals used in agriculture on the state's groundwater. The focus has historically been on areas in which pesticides are used extensively. Some of the other programs supervised by MDEQ include the Mississippi Waste Pesticide Disposal Program and the Household Hazardous Waste Program.

In the wake of Hurricane Katrina in summer 2005; Mississippi, Louisiana, and parts of Alabama were faced with massive cleanups along their coasts. The Mississippi Gulf Region Water and Wastewater Plan was created to deal with some of these environmental impacts of the storm, including spills of hazardous chemicals, fuels, and oils and with debris from oil pumps that had been destroyed. Katrina damaged a number of underground fuel tanks, leaking additional fuel into the atmosphere. In six coastal counties, Katrina rendered all city water treatment facilities inoperable. The Federal Emergency Management Agency (FEMA) estimated that Katrina generated approximately 45 million cubic yards of debris in Mississippi, with potentially devastating impacts on global warming and climate change. Massive amounts of solid waste had to be dealt with, and 300 debris management sites were set up in affected areas. Millions of fish, crayfish, freshwater mussels, and blue crabs were killed during the storm. Oyster reefs and habitats were destroyed and ecosystems threatened, posing threats for many decades.

SEE ALSO: Floods; Hurricanes and Typhoons; Mississippi State University; Oil, Production of.

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MISSISSIPPI STATE UNIVERSITY offers several educational options in the areas of meteorology and climatology. The Department of Geosciences offers on-campus undergraduate and graduate degrees in Geosciences, with optional emphases in broadcast meteorology, professional meteorology, climatology, geology, geography, and geographic information systems (GIS). The department also offers a distance-learning graduate degree specifically for Kindergarten–12 teachers and distance-learning certificate programs in broadcast meteorology, operational meteorology, and GIS. The university, located adjacent to the city of Starkville, is a land-grant university established in 1878. As of October 2006, the university enrolled 12,630 undergraduate students and 3,576 graduate students.

The Department of Geosciences began during the first year courses were offered by the university (1880–81), when meteorology and geology were both required courses for all students. The present department was started in 1916 as the Department of Geology and Geography; it was ultimately renamed the Department of Geosciences in 1993. In 1987, the department expanded its course offerings in meteorology and climatology, in order to support weather-related specializations for B.S. and M.S. on-campus students. Since that time, enrollment has steadily increased, and the department now enrolls approximately 120 meteorology majors each year. There are 20 courses currently taught on campus in the areas of meteorology and climatology.

The department is perhaps best known for its certificate in broadcast meteorology. Since 1987, the distance-learning Broadcast Meteorology Program has educated those that are already employed in the television industry. This program has continued to experience tremendous success, with more than 60 students earning certificates in broadcast meteorology each year, and more than 40 taking courses simply to continue their education. The department also offers a similar certificate program for military personnel through the Operational Meteorology Program.

Based on the success of the distance-learning certificate in broadcast meteorology, the department now offers a distance-learning graduate degree (M.S.) specifically for in-service teachers. The program, Teachers in Geosciences (TIG), which trains K–12 teachers in the areas of meteorology, climatology, geology, and environmental science, enrolled its first students in 1998. This program has been quite successful, as approximately 125 students complete it each year. As of August 2007, the Department of Geosciences employed 16 resident faculty (five with expertise in meteorology and/or climatology), three adjunct faculty (two with expertise in meteorology) and nine resident instructors (five with expertise in meteorology and/or climatology). Recent research topics by faculty, instructors, and students include: health, wildfire risk, tornado variability, continental snow-cover variability, and roles and perceptions of broadcast meteorologists.

The Department of Geosciences is home to the Office of the Mississippi State Climatologist and the Mississippi State University Climatology Laboratory. The department is also affiliated with Mississippi State University's GeoResources Institute and the Northern Gulf Institute. Mississippi State University's Department of Geosciences is producing qualified operational and research meteorologists, broadcast meteorologists, and geoscience teachers. The graduates of these degree and certificate programs contribute to the major components of weather research, forecasts, dissemination, and education. At least one-third of all U.S. television weathercasters have been educated by Mississippi State University, so a large portion of the public is likely to encounter graduates of the Department of Geosciences as they seek information regarding weather forecasts and/or climate change.

SEE ALSO: Education; Mississippi; Public Awareness; United States; Weather.

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Missouri

MISSOURI HAS A land area of 69,709 sq. mi. (180,693 sq. km.), a population of 5,817,211 (2000 est.), and a population density of 80.3 people per sq. mi. (31 people per sq. km.). Although it has historically been a southern state, it is located in the Midwest. As accurate statistics for the weather in Missouri exist from 1893, it has been possible to study changes during the early 20th century, and during the period from the 1970s when climate change was recognized. The climate in Missouri ranges from cold winters to hot and humid summers. As the state has neither large mountains nor coastline, it is heavily influenced in winter by cold Arctic air, and in summer by the hot and humid winds from the Gulf of Mexico.

The prospect of warmer weather, with the probable detrimental effects on agriculture, water supplies, and lifestyle, has caused many in Missouri to reconsider their existing lifestyle. One study in St. Louis projects that, by 2050, there could be as many as 200 people dying from heat-related deaths each summer, a 170 percent rise from the current rate of about 80 deaths per summer. There is also expected to be a decline in forested parts of Missouri by as much as 10–20 percent. Areas with poorer soil are expected to becoming rapidly unusable for agricultural purposes. Declines in the yield of corn and soybeans are probably, as is a fall of up to 30 percent in the amount of hay produced.

There are many industries located in Missouri, which has a heavy input into the aerospace and transportation industries. Many areas are also heavily reliant on agriculture, with half of the industry involving the raising of cattle for beef and dairy products. With large deposits of limestone, Missouri is heavily involved in the production of Portland cement, and is the state that produces the largest amount of lead. As a result of this, Missouri has much to offer, and potentially much to lose over plans to combat global warming and climate change. The emissions from aircraft are a major factor in greenhouse gas emissions, and the aerospace industry would be one of the first to suffer, should federal U.S. laws be introduced to combat climate change. Cattle emitting methane have also been identified as a major problem, and the production of cement is a major producer of carbon dioxide emissions.

To study the effects of the change in climate in the state, in 1989, the legislature of the State of Missouri ordered the formation of the Commission on Global Climate Change and Ozone Depletion, with its final report published in 1991. A Statewide Energy Study, published in the following year by Missouri's Environmental Improvement and Energy Resources Authority. To try to monitor changes to the climate in the state, which has helped coordinate the projects to reduce greenhouse gas emissions, the Missouri Climate Center was established in July 1995, as a section of the Atmospheric Science program of the Department of Soil and Atmospheric Sciences of the University of Missouri-Columbia's College of Agriculture, Food and Natural Resources.

The first focus of the plans to reduce greenhouse gas emissions was on electricity generation. With some 98 percent having come from coal-fired power plants, the government encouraged greater efficiency in generation, with increased use of renewable energy sources, with wind power, solar thermal energy, and photovoltaic cells and panels. There were also new regulations regarding the building of residential and commercial buildings to encourage changes in design to help with energy efficiency. This saw the introduction of Home Energy Rating Systems and Energy Star labeling. There were also moves to promote fuel-efficiency of automobiles, and to encourage public transport.

In July 2002, John Noller prepared the Missouri Action Options for Reducing Greenhouse Gas Emissions, highlighting further methods of helping reduce carbon dioxide emissions. He built on previous suggestions, including urging for the capture of methane gas from the state's landfills, and encouraging wider use of waste reduction schemes. He also supported making significant reductions in emissions from the transportation sector, with improved driving behavior, vehicle maintenance, and better public fleet management, as well as helping with the use of alternative fuel vehicles.

SEE ALSO: Automobiles; Methane Cycle; Regulation.

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Mixed Layer

A MIXED LAYER is a quasi-homogeneous turbulized layer in the world's ocean. Its upper boundary directly contacts with the atmosphere boundary layer, while the mixed layer bottom contacts with underlying thermocline. That is why mixed layer is also called the upper mixed layer. Vertical gradients of temperature and salinity within the mixed layer usually do not exceed 0.01 Kelvin degrees and 0.01 promille per meter. Mixed layer is formed as a result of turbulent mixing by thermohaline convection, vertical shear of oceanic currents, and surface waves (periodically breaking when their slope reaches some critical level).

The process of mixed layer deepening is accompanied by entrainment of more cold water of thermocline into the upper turbulized layer. This leads to negative mixed layer heat fluxes at its bottom. That is why mixed layer deepening is accompanied by its cooling. As a result of entrainment, the sharp interface between turbulized mixed layer and unturbulized thermocline is formed. If surface sources of turbulence are too weak to mix stably stratified thermocline, the mixed layer turbulence is decaying and the depth of mixed layer is decreasing. The mixed-layer shoaling causes its isolation from thermocline, because the new turbulized upper mixed layer is joined with the underlying old (relic) mixed layer with decaying turbulence. As a result, the heat fluxes at the bottom of new upper mixed layer is close to zero, and this does not prevent the upper mixed layer from the warming as, for example, from a generalized analysis of this processes discussed by Eric Kraus.

The mixed layer occupies almost the whole world's ocean. Its thickness is at a maximum in the sub-Arctic and sub-Antarctic regions in winter, when north Atlantic deep water and Antarctic bottom water are sinking up to 1.2–3.7 mi. (2–6 km.). In the tropics and subtropics, the typical mixed layer depth is of about 32–328 ft. (10–100 m.) throughout the entire year. It is controlled not only by intensity of surface turbulent mixing, but also by regular vertical motion, because of the divergence or convergence of oceanic currents. Therefore, in the vicinity of oceanic jets (such as the Gulf Stream or Equatorial Undercurrents/Countercurrents), the mixed layer thickness is changed significantly, and horizontal in-homogeneity should be taken into account for simulation of the mixed layer evolution.

In middle and high latitudes of the ocean interior, there is a strong seasonal cycle of mixed-layer parameters depending on heat fluxes at the surface. In winter, mixed layer is cooling and deepening as a result of net heat lost at the ocean surface and mixed-layer bottom. In that time, intense thermal convection is a principal cause of the mixed-layer deepening. A maximum mixed-layer thickness in the end of winter is, in fact, the depth of penetration of seasonal variations of temperature, salinity, and density. In spring and summer, the typical mixed-layer thickness is at a minimum as a result of surface heating. In that time, mixed-layer is turbulized by dynamic processes (that is, the vertical shear of oceanic currents and surface waves) and its thickness does not exceed a few to tens of meters.

Buoyancy forcing due to thermal convection is a principal cause of winter mixing of mixed layer elsewhere in subtropics, middle, and high latitudes of the world's oceans. However, haline convection also may be important, especially in the subtropical ocean bounded by large desert (such as the north subtropical Atlantic and Sahara), where very dry conditions lead to intense evaporation and sinking of salty waters to the depth. In these specific regions, buoyancy mixed-layer forcing by haline effects prevails. The same is true for the some close or semi-close seas situated in the arid zone (such as in the Red Sea and the Dead Sea).

SEE ALSO: Atmospheric Boundary Layer; Thermocline; Thermohaline Circulation.

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Modeling of Ice Ages

MODELING ICE AGES and their inception can reveal aspects of the climate system that are not able to be measured, and provide a key to the drivers of climate change. Ice age model results can also allow an analysis of the global and regional conditions at that time, and provide a comparison with proxy field evidence. Models range from simple conceptual models, to full global climate models that include vegetation growth and ocean dynamics. To simulate ice ages or their inception, modelers consider several forcing factors. Low greenhouse gas levels are critical. A continental configuration that limits the oceanic transfer of heat from the tropics to the poles is also important. Ice ages can be instigated by orbital conditions that lend themselves to cool summers in high latitude continents or by weathering processes that remove carbon dioxide from the atmosphere.

Once an area cools and an ice sheet begins to grow, there are many feedbacks that encourage its growth. These include local cooling caused by the ice itself—from the higher reflectivity (albedo) of the ice and the increasing altitude of the ice surface. There are also many feedbacks that alter the levels of atmospheric greenhouse gases. For example, marshes and other regions of vegetation can be a source of greenhouse gases; as these regions freeze or are covered in ice, that source of greenhouse gas is removed. As the globe cools and the oceans begin to cool, even more greenhouse gases are removed from the atmosphere, because a cool ocean has more capacity to absorb carbon dioxide. Feedbacks are instrumental in starting and maintaining an ice age or glacial period. In a warming world, these feedbacks occur in reverse, and evidence from ice cores indicate that warming feedbacks contribute to much more rapid changes in global climate than cooling feedbacks.

MODELING LAST GLACIAL MAXIMUM

One way to model ice ages is using a general circulation model (GCM) or Earth System Model of Intermediate Complexity (EMIC) to simulate the global climate representative of a particular time in history. Many early modeling studies attempted to simulate the most recent glacial, the Last Glacial Maximum (LGM). Since those early studies, a major project was established called the Paleoclimate Modelling Intercomparison Project (PMIP), providing a rich source of modeling studies of the LGM.

The PMIP is designed much like the Atmospheric Model Intercomparison Project (AMIP) or the Coupled Model Intercomparison Project (CMIP), with a range of modeling groups running their GCMs and EMICs with a set suite of forcing factors. Key epochs simulated as part of PMIP were the climatic optimum at 6,000 years ago and the Last Glacial Maximum (LGM), about 20,000 years ago. These times were chosen as end-members of the range of global climate in the recent geological past. They were compared with a present climate with pre-industrial greenhouse gas levels. The project has several aims. It aims to test the ability of models to simulate climates quite distinct from today, and the differences between models. Modeling extreme climates will help to understand the drivers of climate change and the climate's response to different forcing. Finally, the PMIP will provide many results to help fill in the gaps in knowledge of past climates and understand proxy evidence.

The first phase of PMIP included GCMs where full ocean dynamics were not considered, and which used low resolution EMICs. In most models, the ocean surface temperatures were prescribed from a map derived from proxy evidence. Some models also included interaction with the ocean surface. The main step to the second phase of PMIP was the inclusion of full ocean models. Some models also included interactive vegetation.

BOUNDARY CONDITIONS

Some consider changes in solar radiation pattern and timing associated with Milankovitch cycles an important factor in maintaining a glacial climate. These changes are routinely included in GCM simulations of the LGM, however, they have minimal impact, as they were actually very similar to today. The continental configuration was also very similar to today, and changes need not be considered. The conditions at the LGM were the culmination of 100,000 years of cooling, thus models of the LGM must include an estimate of certain features in the climate system that hold memory of that cooling. These features include massive continental ice sheets, cooler oceans, lower sea levels, and lowered levels of atmospheric greenhouse gases.

The massive ice sheets that spread across the polar reaches of the continents during the 100,000 years of cooling prior to the LGM were imposed when modeling the LGM. Antarctica was glaciated, as it is today. The other major ice sheets are called the Fennoscandian, which covered much of Europe, and the Laurentide, which covered much of North America. Both the change in surface type (to ice) and the increase in elevation are included. The bright white surface of the ice will reflect more sunlight, encouraging cool conditions. The height of the ice sheets (up to 2.5 mi., or 4 km.) also alters the track of weather systems, particularly in the Northern Hemisphere.

With so much water locked up in the extensive continental ice sheets, the sea level is estimated to have been 393 ft. (120 m.) lower at the LGM. This exposes more land and alters the pattern of land-sea contrast. This is particularly important in regions where landmasses are surrounded by shallow seas. One such place is to the north of Australia, where a land bridge connected Australia to Papua New Guinea and Indonesia to its north, limiting the oceanic warm pool, which is of great importance to the monsoon and rainfall in the region. The exposure of this land bridge also had consequences for human migration.

Oceans circulate on timescales much longer than the atmosphere. Conditions at the surface are slowly transferred to the deeper ocean, thus the ocean would have a memory of the cool conditions that were experienced for thousands of years prior to the LGM. The ocean could also be seen as forcing glacial conditions. As in the first phase of PMIP, sea-surface temperatures can be prescribed, which provides a strong constraint on the global climate. Models forced by prescribed sea-surface temperatures provide a test-ground for a range of experiments, including the consistency between proxy evidence from the land and ocean. They also require reasonably low levels of computing power. However, prescribing sea-surface temperatures neglects interactions between the atmosphere and the ocean, which are important to the climate and variability of both.

More recent efforts at modeling the extreme climate of the LGM include full models of the ocean. The LGM ocean has a temperature structure that has been exposed to thousands of years of cool atmospheric conditions during the preceding glacial cycle, and would be expected to be much cooler than the modern ocean, thus modeling the LGM ocean requires an appropriate initial state. There are a variety of methods used to achieve an appropriately cool ocean. Due to the high computational expense, approximations or accelerations are required. One method is to run the ocean model alone, intermittently inputting atmospheric information.

Variations in sea-ice extent alter the ocean-atmosphere interactions that can occur. If open ocean is exposed to the atmosphere, the relatively warm water has the opportunity to impart heat, moisture, and energy. However, a cover of sea-ice cuts off this interaction. There is evidence that sea-ice was more extensive at the LGM. Models with prescribed sea-surface temperatures also prescribe sea-ice, while models that include full oceans usually also include models that determine the extent of sea-ice from the oceanic conditions.

Levels of atmospheric greenhouse gases are very important to the climate, and these are generally imposed in models of the LGM. For well-mixed gases such as carbon dioxide, levels are reasonably well known from the LGM air bubbles trapped in polar ice. Some EMICs include a module of interactive atmospheric chemistry as part of the carbon cycle. For PMIP GCMs, the level of atmospheric carbon dioxide is set at 280 parts per million by volume (ppmv) for the present day (pre-industrial) and 185 ppmv for the LGM. This change is estimated to reduce the radiative forcing of the troposphere by 2.8 Wm-2.

Vegetation changes and atmospheric particulates are believed to have influenced the global and regional climate of the LGM. EMICs have generally included a crude estimate of vegetation; some of the most recent attempts to simulate the LGM include vegetation, its changes and feedbacks. At the LGM, the generally drier environment meant that there was more potential for dust from drier, less-vegetated surfaces to enter the atmosphere. The result of increased particulate levels in the atmosphere is to cool the surface—it is estimated that the increased dust at the LGM reduced the radiative forcing of the troposphere by about 1 Wm-2. Particulates and dust are not currently included in the GCMs in PMIP, but it has been flagged as an important component to be considered in the future.

RESULTS

The modeled LGM surface temperature is cooler compared to the modeled pre-industrial temperatures. The global cooling ranges from 5.9–8.4 degrees F (3.3–4.7 degrees C) when the temperature of the sea surface is prescribed. When the LGM ocean is also modeled the cooling is generally greater, ranging from 6.5–10.2 degrees F (3.6–5.7 degrees C) cooler. The Northern Hemisphere has greater cooling than the Southern Hemisphere due to the massive ice sheets, with temperatures up to 54 degrees F (30 degrees C cooler). The height of the ice-sheets also modifies weather systems, contributing to greater cooling right across Eurasia. In the tropics, the cooling is generally less pronounced, while over the ocean there is a large range, with cooling ranging from only 3.6–9 degrees F (2–5 degrees C).

The U.S. Geological Survey National Ice Core Lab in Denver, Colorado, stores and studies ice cores from all over the world.

A major shift in the LGM climate compared to the present was the reduction in atmospheric water vapor, leading to a much drier environment. This drying has implications for the energy of weather systems across the globe. The greatest drying is over the ice sheets and sea ice. Water vapor is also a strong greenhouse gas, and the reduction of water vapor, carbon dioxide, and methane in the atmosphere is the main driver of the cooling poleward of 54 degrees F (30 degrees C) in these modeled glacial climates. In the Northern Hemisphere, reflection off the massive continental ice-sheets and extensive sea ice were also important to the cooling at high latitudes. This effect was particularly important in summer, when the sun is higher in the sky, contributing to about half of the modeled cooling.

The westerly winds in the Southern Hemisphere impact the southern reaches of the three mid-latitude continents. The prescribed ocean-surface temperatures in the first phase of PMIP drove a southward shift of the westerlies at the LGM, particularly in the Australian region. The results from models that include full oceans are not in agreement. The models generally show no latitudinal shift in the westerlies, with most showing a reduction in the intensity of the winter winds, particularly in the Pacific Ocean sector. In the Northern Hemisphere, there was an equatorward shift in the winter jet-stream in most models.

The models involved in PMIP can clearly simulate a cooler climate for the LGM, although the prescribed ocean temperatures used in phase one have known errors that lead to erroneously warm conditions in some regions. Results are similar across models in those regions, where the models are strongly-constrained by boundary conditions such as ice sheets. However, away from these regions, such as in the Southern Ocean, there is great variability.

MODELING GLACIAL INCEPTION

Understanding the drivers and feedbacks of the climate system is important for a proper understanding of the world. Modeling the conditions required to drive the globe into an ice age is a great way to better understand the climate system. There are three major periods of glacial inception: the beginning of the current glacial cycle, about 115,000 years ago; the beginning of the current ice age, about 34 million years ago; and the Cryogenian period, when the Earth was believed to be nearly covered in ice.

The Milankovitch theory dictates that glacial conditions could be instigated when the Earth's orbit is more elliptical and the Earth is furthest from the sun in the Northern Hemisphere summer. These orbital conditions were in place 115,000 years ago, at the beginning of the glaciation that culminated in the LGM. Early modeling studies with simplified GCMs could not capture the appropriate initiation of glacier growth, however, there was more success with recent models that have more accurate representation of mountains. This suggests that it is on high peaks where snow will first persist year-round; then, as feedbacks come into play, the area of glaciation will expand. Experiments using differing levels of atmospheric carbon dioxide revealed that there were thresholds of carbon dioxide, below which shifts in orbital parameters became much more important.

It is believed that the growth of the Antarctic Ice Sheet about 34 million years ago, at the Eocene/Oligocene boundary, was instigated when the Drake Passage (the strait between Antarctica and South America) opened as South America moved north away from Antarctica. Modeling studies show that when the Drake Passage is closed, the southward ocean heat transport is increased by 15–20 percent over all southern latitudes. When the Drake Passage opened, it allowed the circumpolar current to develop, effectively thermally isolating the Antarctic continent. Thus, warm tropical waters could not make their way to the shores of Antarctica any more. Further modeling studies, using a dynamic ice-sheet model asynchronously coupled to a simplified GCM, indicate that carbon dioxide needed to fall below critical levels before ice-sheets would form, even if the Drake Passage was closed. Once ice growth began, feedbacks then aided ice-sheet growth and ice eventually covered most of the continent, as it does today.

Geological evidence of the continental configuration during the Cryogenian period suggests that the continents were centered on the equator, and ice covered much of the globe. Conceptual models of how this ice age came about suggest that the strong tropical rainfall weathered these continents, drawing carbon dioxide out of the atmosphere and reducing the greenhouse effect. Continents on the equator would also limit the oceanic transfer of solar input in the tropics to the poles, allowing the poles to cool. These conditions, combined with a weaker sun, are suggested as adequate climate drivers to lead to an Earth that was almost completely ice-covered.

SEE ALSO: Climate Forcing; Ice Ages; Milankovitch Cycles; Modeling of Paleoclimates; Quaternary Era.

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Modeling of Ocean Circulation

OCEAN WATERS MOVE in a global circulation system, transporting huge amounts of heat around the globe. The thermal capacity of the ocean is very large compared to that of the atmosphere, and through its circulation patterns, it can absorb heat in one region and return it to the atmosphere (often decades or centuries later) at an entirely different place. Ocean circulation is, thus, a key determinant of regional and global climate.

Ignoring tidal forces, the long-term mean oceanic circulation is driven by three external influences: wind stress, heating and cooling, and evaporation and precipitation; all of which, in turn, are ultimately driven by solar radiation. Ocean currents are either wind-driven (surface currents) or due to changes in the density of sea water (deep currents). The circulation of the atmosphere is, in turn, influenced by the distribution of oceanic properties, such as sea-surface temperature and the distribution of sea ice. In particular, the amount of evaporation from the ocean depends strongly on the sea-surface temperature; and when the evaporated water is returned as rain, it releases its latent heat into the surrounding air. This heating is probably the strongest driving force for atmospheric winds.

To understand the oceanic and atmospheric circulation fully, they are now treated as a single system of two interacting components, coupled at the air-sea interface through the fluxes of momentum, heat, and mass. However, early ideas on the nature of oceanic circulation pictured the motion in equilibrium or perpetual steady state. This view was formed from limited observations, often based on tracking floating objects released into the ocean. The classic picture of steady-state circulation was laid out in Harald Sverdrup's definitive textbook of 1942, *The Oceans: Their Physics, Chemistry and General Biology,* and although it included a description of the deep thermohaline circulation (now recognized as critical for climate), Sverdrup paid most attention to surface currents like the Gulf Stream. Through the 1950s, oceanographers concentrated on surface winds and currents, far easier to measure and far more important for mariners than the slow, deep circulation. How much of the overall general circulation was driven by the winds, and how much by density changes related to temperature and salinity, was still unknown.

Seminal efforts to numerically-model oceanic circulation began in the late 1960s, led by Kirk Bryan, a Woods Hole oceanographer, who with his collaborator Michael Cox built a model for a highly-simplified ocean basin with five depth levels. Their model produced a picture that looked roughly like the North Atlantic Ocean's Gulf Stream and equatorial flow. Despite deep skepticism from empirical oceanographers who were still mapping the basic patterns of motion in the ocean, Bryan extended his work, motivated by "the pressing need for a more quantitative understanding of climate." Recognizing that surface winds helped drive the ocean currents that transported heat from the tropics poleward, Bryan coupled his ocean basin model to Syukuro Manabe's model of atmospheric circulation. Published in 1969, this coupled ocean-atmosphere circulation model developed by Bryan and Manabe was a forerunner of modern general circulation models (GCMs).

Paralleling the increase in available computing power, the first global ocean model was developed by Cox in 1975, using nine depth levels and a horizontal grid resolution of 2 degrees latitude by 2 degrees longitude. Cox found he could simulate the ocean circulation for only a few years in its centuries-long progress, but overall the "in silico" ocean behaved somewhat like the real one. In 1988, S. Manabe and R. Stouffer developed a coupled atmosphere-ocean model that incorporated a realistic land and ocean topography. Starting from two different initial conditions, asynchronous time integrations of the coupled model, under identical boundary conditions, led to two stable equilibria. In one equilibrium, the North Atlantic has a vigorous thermohaline circulation and relatively saline and warm surface water. In the other equilibrium, there was no thermohaline circulation, with an intense halocline in the surface layer at high latitudes. These results suggested that the real ocean system might have at least two equilibria, echoing the result obtained by Henry Stommel 25 years previously, with a very simple pen-and-paper box model. The simulation raised the "intriguing possibility," as Manabe and Stouffer put it, that global warming might shut down the North Atlantic thermohaline circulation within the next century or so. Halting the steady flow of warm water into the North Atlantic would bring devastating climate changes in Europe and perhaps beyond.

With the advent of high-performance super-computers, coupled ocean-atmosphere models improved rapidly through the 1990s, and a number of studies confirmed the possibility that changes in ocean climate from global warming could eventually shut down the North Atlantic thermohaline circulation, however, the timescale of such a change is still far from certain. In the last decade, the availability of several polar orbiting satellites, that measure winds, waves, sea-surface temperatures, and ocean color, at high spatial and temporal resolution, means much more data are now available for the calibration and validation of numerical circulation models. Also recently launched is the Argo program—an international program to seed the global ocean with an armada of some 3,000 free-floating buoys that measure vertical profiles of ocean temperature and salinity, thus complimenting the surface data from satellites.

SEE ALSO: Bryan, Kirk; Climate Models; Current; Gulf Stream; Manabe, Syukuro; Stommel, Henry; Sverdrup, Harald; Thermohaline Circulation; Woods Hole Oceanographic Institution.

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Modeling of Paleoclimates

PALEOCLIMATE MODELING INCLUDES the development and application of numerical climate models to simulate climates through Earth's 4.6 billion-year history. Paleoclimate modeling is a theoretical branch of the natural science fields of paleoclimatology and paleoceanography, which seek to document and understand Earth's climate and ocean history. A fundamental goal of paleoclimate modeling is to determine the causes of past global climate change as a guide to modern and future climate change.

Numerical climate models are mathematical expressions of the theoretical laws and physical processes that govern the climate system, approximated and written in computer code for efficient computation. Climate models can vary tremendously in their complexity, capability, domain, and spatial resolution. Climate models used for paleo-applications range from relatively simple one-dimensional models that are based on the conservation of energy (energy balance models), to models that solve the primitive equations to predict the general circulation of the atmosphere and ocean in three dimensions (general circulation models). The capabilities of these models may be limited to one component of the Earth system, the atmosphere, for example; or may include interactions between several components, such as the atmosphere, biosphere, ocean, and cryosphere.

The model domain may be global in extent, or limited to a region, such as the western United States, and is discretized into grid cells. The horizontal (usually latitude by longitude) and vertical (usually altitude, depth, or thickness) resolution of the models can vary substantially between models. Regional models of limited domain may have a horizontal grid spacing of approximately 12 mi. (20 km.), while most global models have grid spacing on the order of hundreds of miles (kilometers). The decision to use a particular model at a specific resolution is based on the scientific problem to be addressed and consideration of the computational cost of running the model.

Paleoclimate models are nearly always initially developed and fine-tuned for the modern climate as a check on the performance of the model. If the model can successfully simulate important aspects of the modern climate, then the model may be modified for paleoclimate applications. It is often assumed that modern climate dynamics and physics are representative of past climates, and thus these aspects do not change for paleoclimate applications. The modifications for paleo-applications are frequently limited to the model's boundary conditions. In mathematics, boundary conditions define the limits of a set of partial differential equations. Similarly, in paleoclimate modeling, the boundary conditions define the limits of the numerical model. Modifications to the boundary conditions are made to represent processes that occur on geological timescales, such as continental drift and seafloor spreading, mountain building and erosion, sea-level change, evolution, and geochemical cycling.

Common boundary conditions required for global paleoclimate modeling include continental positions and topography, ocean bathymetry, vegetation distribution, soil type, solar luminosity, river drainage, atmospheric trace gases (such as carbon dioxide, methane, nitrous oxide, and ozone), and Earth's orbital characteristics (such as obliquity, precession, and eccentricity). The accurate reconstruction of these boundary conditions is a critical aspect, and one of the largest uncertainties, of paleoclimate modeling. For very ancient time periods, geological evidence of past boundary conditions may not exist or may be known only crudely. Numerous paleoclimate-modeling studies have demonstrated that differences within the uncertainty of a boundary condition can have regional or global climatic consequences, as shown by Poulsen, et al.

Paleoclimate studies often simulate a specific interval or time slice. In this case, the boundary conditions remain constant throughout the experiment, and the model is run until a steady-state climate is achieved. The length of the integration varies, depending on the residence time of the system that is modeled. An atmosphere-only model may be run for as little as 30 years, while models that include ocean and ice-sheet components require thousands of years of model integration. The simulation of time slices is prevalent in studies that predict climate on geological timescales, since it is impractical with modern computational capabilities to run most numerical models for millions of years. Transient runs, in which the time-varying response to a forcing is of interest, have been used in studies of Quaternary climate change where the time interval of interest may be hundreds to thousands of years, as shown by Ganopolski and Rahmstorf.

Two approaches are frequently used in the application of paleoclimate models. Many paleoclimate modeling studies fall within the category of sensitivity experiments: modeling experiments in which one parameter is varied at a time and compared to a control case. Sensitivity experiments quantify the model's climate response to a single factor, such as carbon dioxide. This methodology can be used to evaluate how uncertainties in boundary conditions influence the climate prediction. Alternatively, some researchers have attempted to simulate a particular time interval by specifying the best boundary conditions, and then comparing the simulation to climate proxy reconstructions. In practice, many studies mix these two approaches.

The validation of paleoclimate models is made through comparison with climate proxies, paleo-oceanographic and geologic evidence used to infer past climate. Climate proxies differ tremendously in type, spatial and temporal distribution, and accuracy. In general, climate proxy uncertainties increase with age, while the sampling density decreases with age. Types of paleoclimate proxies include: lithologic indicators (such as tillites, evaporites, and coals), geochemical indicators (such as foraminiferal and ice $\delta^{18}O$, foraminiferal Mg/Ca ratios), and paleo-floral indicators (such as tree-ring dendrochronology, distribution of plant types, and leaf-margin analysis). The comparison of paleoclimate models and proxies is often not direct because climate models are not usually capable of simulating geologic processes, for example, the deposition of evaporites or the incorporation of O^{18} in the tests of marine invertebrates. Rather, climate models produce output, such as surface temperature, rates of precipitation and evaporation, winds and currents, snow and sea ice, which are indirectly compared with climate proxies.

APPLICATIONS OF PALEOCLIMATE MODELING

The applications of paleoclimate modeling include: identifying mechanisms of climate change, quantifying the climate response to specific forcing factors, recognizing climatic feedbacks and processes that amplify/damp climatic forcings, identifying limitations of climate proxies from the geological record, and demonstrating strengths/shortcomings in numerical climate models. Paleoclimate modeling studies have contributed to many of the outstanding problems in paleoclimatology.

A few of the most significant advances have been made in: evaluating the plausibility of global glaciation and deglaciation in the Neoproterozoic; demonstrating the effect of super-continentality on Paleozoic climate; delineating the conditions required for glaciation in the Ordovician and Late Paleozoic; understanding the role of greenhouse gases during the Cretaceous, Eocene, and Pliocene periods of global warmth; demonstrating the influences of Cenozoic mountain uplift and ocean gateways on regional and global climate; simulating the conditions of the Last Glacial Maximum and Holocene; quantifying the influence of Earth's orbital variations on climate variability and ice volume in the Pleistocene and Holocene; and simulating the ocean's thermohaline variability and its influence on global climate. These paleoclimate modeling studies have provided insights into the causes and dynamics of past climate change, revealed the major climate forcings through Earth history, and identified shortcomings in our understanding of climate.

With regard to modern and future climate change, paleoclimate modeling has made several notable contributions. By investigating extreme climates outside of the range of modern climate variability, paleoclimate modeling has provided a critical test of climate models, and has shown that they adequately simulate many, but not all, aspects of past climate on a global scale. Importantly, outstanding issues remain including the simulation of abrupt climate change and past warm climates. Paleoclimate modeling has also established greenhouse gases as one of the most important factors in past climates, and demonstrated that other factors (solar variability and volcanic outgassing) could not account for the global warming since the pre-Industrial Revolution, as discussed by Crowley.

SEE ALSO: Climate Models; Computer Models; Modeling of Ice Ages; Modeling of Ocean Circulation.

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Moldova

LOCATED IN EASTERN Europe, the Republic of Moldova, formerly a constituent republic of the Soviet Union, has a land area of 13,067 sq. mi. (33,843 sq. km.), with a population of 3,794,000 (2006 est.), and a population density of 339 people per sq. mi. (111 people per sq. km.). Approximately 46.7 percent of the population lives in urban areas. Fifty-three percent of the land is arable, a further 13 percent is used as meadows and pasture, and 8 percent is forested.

In 1990, Moldova had a per capita carbon dioxide rate of emission of 4.8 metric tons, which fell steadily to 1.7 metric tons in 2003. Because of the cold winter climate in Moldova and its heavy industry, electricity and heat production accounts for 44 percent of carbon dioxide emissions, other energy industries account for 12 percent, another 12 percent is from manufacturing, and 8 percent from transportation. In terms of the source of emissions, 68 percent come from gaseous fuels, 10 percent from solid fuels, and 22 percent from liquid fuels—the latter from heavy use of automobiles.

Moldova has seen a rise in temperatures that has resulted in some water shortages, and heat waves such as those in the summers of 2006 and 2007 that badly affected Moldova and its southern neighbor Romania. This has added to the demand on water supplies, and a gradual reduction of available, arable land. Further complications are caused by the formation of Transdniestra, a breakaway part of Moldova, where there are even more problems enforcing environmental controls.

The Moldovan government took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, and ratified the Vienna Convention in 1996. The government has not signed the Kyoto Protocol to the UN Framework Convention on Climate Change.

SEE ALSO: Agriculture; Global Warming; Romania.

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Monaco

LOCATED AROUND THE city of Monte Carlo, the Principality of Monaco has a land area of 0.75 sq. mi. (1.9 sq. km.). With a population of 33,000 (2006 est.), and a population density of 47,358 people per sq. mi. (18,285 people per sq. km.), it is the most densely populated country in the world.

With a very high standard of living, carbon dioxide emissions from the principality are high, although its statistics are usually included in those of France, which encompasses the land borders of the country. This is because France supplies all electricity used in Monaco, and the country is serviced by Nice Airport, also in France. Monaco has an effective urban bus transport system operated by the Compagnie des Autobus de Monaco, going some way to alleviate the use of cars, although the Grand Prix there each year helps encourage the fascination with Formula 1 cars, adding to carbon dioxide and carbon monoxide emissions.

The Monégasque government took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, and signed the Kyoto Protocol to the UN Framework Convention on Climate Change on April 29, 1998, ratifying it on February 27, 2006, with it taking effect on May 28, 2006.

SEE ALSO: Automobiles; France; Transportation.

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Mongolia

THE LANDLOCKED COUNTRY of Mongolia, bordered by China and Russia, has a land area of 603,909 sq. mi. (1,565,000 sq. km.). With a population of 2,629,000 (2006 est.), and a population density of 4.4 people per sq. mi. (1.7 people per sq. km.), the country has the lowest population density in the world. Six percent of the land is arable, 10 percent is forested, and 81 percent of the country is officially registered as meadows and pasture, mostly for low-intensity grazing for cattle, sheep, and goats.

The country's electricity production comes entirely from fossil fuels; the country had a per capita emission rate of carbon dioxide in 1990 of 4.5 metric tons, rising to 5.4 metric tons in the following year, and then slowly falling to 3.1 metric tons per person in 2003. With a relatively low level of private automobile ownership, 83 percent of carbon dioxide emissions come from solid fuels, with many people using wood or coal for heating in the cold winters, and 16 percent from liquid fuels, reflecting the use of buses and automobiles to cover the large distances when traveling in the country.

Evidence of global warming in Mongolia was discovered in 2000 with the examination of some trees in the remote alpine forests located in the Tarvagatay Mountains, which are on the north side of the Hungai Mountains, in west-central Mongolia. A study of the tree-rings showed that 1980–99 had the highest temperatures of any 20-year period on record, and eight of the 10 highest growth years were since 1950.

The Mongolian government took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, ratified it in the following year, and in 1996 the government ratified the Vienna Convention. On December 15, 1999, the government accepted the Kyoto Protocol to the UN Framework Convention on Climate Change, which took effect on February 16, 2005.

SEE ALSO: China; Climatic Data, Tree Ring Records; Russia.

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Monsoons

A MONSOON IS any wind that reverses direction seasonally. These occur in many parts of the globe, but the most famous is the Indian monsoon wind. The name monsoon is an adoption of the Arabic word *mausim,* which means season. For centuries, Arab sailors took the seasonal *mausim* as a wind that would carry them to India and beyond. The term was originally applied to the Indian monsoon. However, as the phenomenon came to be studied more thoroughly, the term *monsoon* has been applied to other annual weather cycles in both tropical and subtropical regions. It has also been applied to evidence of weather patterns in the geologic past, such as a monsoon system over the prehistoric super-continent of Pangaea, and to some extreme continental climate patterns.

Monsoons can occur in summer months or in winter months. Those that occur in summer months usually blow as a prevailing wind from a westerly direction. The westerly monsoons usually bring great amounts of rain as the rising air comes from the ocean and brings moisture that falls as rain. In the winter months, monsoon winds usually blow in an easterly direction. Because easterly winds usually blow from the land, they generally bring dry weather. They may also bring drought as the easterlies diverge or shift about. The intensity of monsoons varies annually. Some years they are stronger than in others. The strength of the annual monsoons is affected by the Earth's total climate system. As the amount of energy available varies, the system has different outputs, such as the strength of the monsoons, which results in variable amounts of annual rainfall.

INDIAN MONSOON

The Indian monsoon is a wind that blows seasonally over India and the land areas surrounding India. The winds blow in different directions at different times of the year. The monsoon winds blow from the southeast from April to October. From November to March they blow from the northeast. The monsoon brings rains when it blows from the southwest across the warm waters of the Indian Ocean. Hundreds of millions of people depend upon the rains it brings. When it blows from the northeast, dry air prevails to create the dry season. Monsoons also occur in northern Australia, the northern and eastern coasts of Asia, some of the Pacific Coast of North America, South America, and Sub-Saharan Africa. In addition, the Indian Ocean has monsoon areas that include parts of the east coast of the African continent.

Differences in the temperatures on land and sea cause the monsoon winds. The temperature differences occur because the heat transfers in the ocean happen in a different manner than the heat transfers on land. In the ocean, sunlight heats the water to a depth of about 64 ft. (50 m.). Winds and wave action churns the ocean waters and as it heats and cools with annual seasonal changes energize or slow wind action. The heating and cooling of the land and waters of the Indian Ocean cause the temperature differences. Sunlight striking the surface of the Earth heats it to much higher temperatures than it does ocean water. As the heated air rises, a large area of low pressure caused by the rising air is formed. The relatively cooler and denser air that blows across the Indian Ocean flows in to fill the low-pressure areas with its heavier air. At the same time, the relatively cooler air is laden with moisture, but is heated over the land so that the moisture rises is cooled at high elevations, condenses, and falls as rain over the land. During the winter, the land is cooler than the Indian Ocean, so as the air over it rises to form low-pressure areas the denser land airflow from the land into the low pressure over the waters of the Indian Ocean.

SOUTHWEST MONSOON

The southwesterly monsoon is a prevailing wind that blows during the wet seasons of April to October. Very heavy rains are brought to India and to countries surrounding the Indian Ocean. These include Pakistan, Bangladesh, Burma, Thailand, the Arabian Peninsula (Oman, Saudi Arabia, the United Arab Republic, and Yemen) and neighboring African countries that border the Indian Ocean and the Arabian Sea. The rains are very heavy and bring the majority of the rainfall to the region each year. There are places in India that receive over 200 in. of rain per year (over 500 cm.). The warm moisture in the southwesterly monsoon falls as rain over the foothills of the Himalaya Mountains. The southwest Indian monsoon is the source of water for most agriculture in the region. If the monsoon fails, or is not strong, there will be drought with the starvation of millions.

The Tibetan Plateau affects the Indian monsoon. The vast Himalayan Mountain system has reached great heights because the India plate is elevating it. Theorists argue that the land's formation and the development of the Indian monsoon began about 8 million years ago. However, other scientists have hypothesized that an older monsoon existed that also was tied to the Tibetan plateau.

From June through September, the southwestern monsoon wind prevails in India. In the Great Indian

Monsoons that occur in summer months usually blow as a prevailing wind from a westerly direction. These westerly monsoons usually bring great amounts of rain, as the rising air comes from the ocean and brings moisture that falls as rain.

Thar Desert, and the areas to the north and south of it, the Indian subcontinent develops very hot temperatures during the long days of the summer months. The hot air causes lower pressure to prevail in the area. Moisture laden air flows into the Indian subcontinent from the Indian Ocean. When the warm moist air reaches the Himalayas, storm clouds form, because the great height of the Tibetan plateau blocks the moist air. The warm air rises to heights where it cools enough that rain falls in varying amounts. When the oceanic southwest monsoon reaches the Indian subcontinent, it splits into two parts. The eastern part becomes the Bay of Bengal branch; the western part becomes the Arabian Sea Branch of the Southwest Monsoon.

The Bay of Bengal branch of the Southwest Monsoon flows over the Bay of Bengal and northward toward Calcutta and then meets the eastern area of the Himalayan Mountains, where it drops huge quantities of rain over Northeast India, northern Burma, and Bangladesh. Cherrapunji, located on the slopes of the Himalayas in Shillong, is one of the wettest spots on Earth. The remaining portion of the Bengal Branch of the Southwest Monsoon then flows westward over the Grand Trunk Road in the Indo-Gangetic Plain. Great quantities of rain pour down during the height of the seasonal monsoon. The Arabian Sea Branch of the Southwest Monsoon bounces off of the Western Ghats of the Indian subcontinent. The monsoon then moves northward, producing rain along the west coast of the Indian subcontinent. The Ghats are steps, or hills that are shorter steps to the Decca plateau. The eastern Ghats are located on the Bay of Bengal side of the Indian subcontinent. They receive considerably less rain than do the western Ghats, which are on the Arabian Sea side of the Indian subcontinent.

Without the monsoon, India would be much more arid. About 80 percent of the rainfall in India is associated with the monsoon. The huge agricultural population in India is totally dependent upon the monsoon rains for growing rice and other crops. In the 1990s, a few days delay affected the future crops. On the other hand, the Bengal Bay Branch of the

Indian monsoon has regularly brought floods. The monsoon is also a great benefit to Indian city-dwellers because it brings relief from the heat and rains that wash away debris from the cities. The first day of June is considered the normal date for the beginning of the Southwest Monsoon. However, in September, the northern part of the Indian subcontinent begins to cool rapidly. The denser air now blocks the flow of the Southwest Monsoon and, instead, reverses in the direction of the retreating monsoon (Northeast Monsoon) that flows from the Indian subcontinent into the Indian Ocean.

NORTHEAST MONSOON

This retreating monsoon also brings rain to areas that received less during the time of the advancing monsoon. The cooler and drier air flowing from the high Himalayas across the Bay of Bengal bring rain to areas of the eastern part of the Indian peninsula. The Northeast Monsoon brings less rain than falls during the Southwest Monsoon, but it bring vital moisture to areas that were missed earlier in the summer.

In southern Asia, the northeastern monsoon appears in December and lasts until early March. In Central Asia, wintertime temperatures are cold so that a dome of high-pressure air develops. As the jet stream passes over the area, it splits into the polar jet and the subtropical jet stream. The subtropical flow passes over southern Asia, creating clear skies over India. At the same time, warm water from the Philippines eastward develops into a low pressure system. The system spreads over Southeast Asia, Indonesia, and northern Australia. The winds then flow in a monsoon trough into the swamp wet areas of northern Australia and into the interior of the continent, bringing much-needed summertime rains.

SUB-SAHARAN MONSOON

The African monsoon in sub-Saharan Africa is different from the monsoon rains that water the vast Serengeti Plains or the areas of East Africa that adjoin the Indian Ocean. The sub-Saharan monsoon is caused by seasonal shifts in the Intertropical Convergence Zone. The Sahara Desert reaches great temperatures in the summertime and creates hot air low-pressure centers. As they move off of the African continent from June to December, they cross the Atlantic Ocean and have the potential to develop into hurricanes. However, in the winter, the dry northeastern trade winds and the extreme harmattan winds shift and bring dry weather to the regions to the south. In the summer, they act to bring moisture to the savannah regions and to the Sahel as far east as the Sudan.

AMERICAN MONSOONS

The South American Monsoon is a key factor in Brazil's weather patterns. Seasonal winds from the Atlantic bring summertime rains that feed the Amazon basin. They also frequently bring flooding to Rio de Janeiro.

The North American monsoon begins in late June and ends in September. It blows from the Pacific Ocean onto Mexico is a relatively weaker version of the Indian monsoon. It is an invasion of humid air that brings thunderstorms. The North American monsoon is sometime called the Summer Monsoon, Mexican Monsoon, Southwest Monsoon, Desert Monsoon, or the Arizona Monsoon. It begins in the south off of the coast of Mexico. It soon affects areas such as the region of Guadalajara. As the Mexican Monsoon spreads, it affects the Sierra Madre Occidental, Arizona, New Mexico, Utah, Colorado, West Texas, and California. In California, it brings moisture-laden winds to the Peninsular Ranges and the Transverse Ranges in Southern California.

As the Desert Monsoon, it brings up to 70 percent of the rain that falls in the Mohave and Sonoran Deserts. Compared to the Sahara, these deserts appear wet. In the upper elevations, the rains also bring moisture that mitigates the summer temperatures with its natural drying effects. Oddly, while reducing drought conditions, the monsoon rains can increase wintertime plant growth, which, in turn, provides fuel for wildfires. The thunderstorms over the Grand Canyon or in the high mountains can create hazards from flash floods. Or, lightening can strike to begin fires or to injure or kill the unwary.

SEE ALSO: Hurricanes and Typhoons; India; Rain; Rainfall Patterns; Thunderstorms.

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Montana

MONTANA'S AVERAGE ELEVATION is 3,400 ft. (1,036 m.) above sea level. The border of western Montana is formed by the Rocky Mountains and includes a section of the Continental Divide, the separation mark of the Pacific and Atlantic watersheds begins in Glacier National Park and runs south at one point, forming part of the southern boundary between Montana and Idaho. While western Montana is mountainous with highlands and the location of most of Montana's natural lakes, eastern Montana is Great Plains with grassland prairie and scattered small mountains. Fort Peck Dam on the Missouri River in northeastern Montana creates Fort Peck Lake, the world's third largest reservoir. According to the 1972 state constitution, all water in the state, even water on private land, is under state control.

The average annual precipitation is 15 in. (38 cm.), with the higher mountain areas receiving more than 50 in. (127 cm.) with winter snow. To the west of the Rocky Mountains, mild air currents from the Pacific give cooler summers and warmer winters than the area east of the Rocky Mountains, which receives Canadian and Arctic air currents in winter, and warm moist air flows from the Gulf of Mexico, in summer. Average July temperatures vary from 72 degrees F (22 degrees C) in the southern plains, to 60 degrees F (16 degrees C) in the mountains, and average January temperatures are below freezing. The highest temperature recorded in the state was 117 degrees F (47 degrees C) on July 5, 1937, and the lowest temperature recorded in the state was minus 70 degrees F (minus 57 degrees C) on January 20, 1954.

The state supports a population of approximately one million people. Coal, petroleum, and natural gas are mined in Montana. Forests cover 22 million acres, providing opportunities for commercial logging. The eastern part of Montana is perfect for agriculture, including beef, wheat, barley, and sheep. Western Montana's milder climate is suitable for fruits (berries, cherries, and apples). Electricity is generated by coal-burning plants and by hydroelectric plants.

IMPACT OF CLIMATE CHANGE

Climate models vary on the amount of temperature increase possible; however, potential risks include having decreased water supplies; increased risk for wildfires; population displacement; changes in food production with agriculture improving in cooler climates and decreasing in warmer climates; and change in rain pattern to downpours with the potential for flash flooding and health risks from certain infectious diseases from water contamination or disease-carrying vectors such as mosquitoes, ticks, and rodents; and heat-related illnesses.

Park officials at Glacier National Park show glaciers are melting with warmer temperatures. Snow pack in Montana holds about 75 percent of the state's water supply and acts as a reservoir that keeps streams flowing in the summer months. Warmer temperatures resulting in decreased snow pack could mean less water in Montana's lake and streams during the summer months. Montana may benefit from changing climate. Shorter, milder winters could mean longer growing seasons and increasing crop yields, though higher temperatures may mean changing crops produced for those more adapted to a warmer climate and more drought-resistant. The milder climate could attract more tourists. Taking advantage of sun and wind to produce electricity could provide economic benefits.

ADDRESSING HUMAN-INDUCED CONTRIBUTIONS

Based on energy consumption data from the Energy Information Administration, Montana's total CO_2 emissions from fossil fuel combustion in million metric tons for 2004 was 35.10, made up of contributions by source from: commercial, 1.08; industrial, 5.87; residential, 1.58; transportation, 7.73; and electric power, 18.84.

The Montana Climate Change Advisory Council (MCCAC) formed in 2005, with members appointed in Aril 2006, by the Department of Environmental Quality, includes representatives from industry, environment, local and tribal governments, transportation, and agriculture. It was given the task of inventorying and developing policy options for reducing greenhouse gas emissions. One of their recommendations is to design a mandatory reporting program, as carbon emission-reporting is not yet required.

Montana holds observer status with the Western Regional Climate Action Initiative, in which the partners will set an overall regional goal for reducing greenhouse gas emissions and will design a market-based mechanism to help achieve that reduction goal. Montana joined the Climate Registry, a voluntary national initiative to track, verify, and report greenhouse gas emissions, with acceptance of data from state agencies, corporations, and educational institutions, beginning in January of 2008.

During the 2007 Legislative session, lawmakers debated several greenhouse gas and climate change-related bills. Those approved include legislation to provide permanent property tax rate reductions for new investments in transmission lines for renewable-source electricity, liquid, and carbon sequestration pipelines, in addition to those available for new investments in biodiesel, biomass, and other defined technologies; prohibiting approval of new electric generating units primarily fueled by coal unless a minimum of 50 percent of the CO_2 produced by the facility is captured and sequestered. Natural gas plants also must include cost-effective carbon offsets. The bill applies only to electric generating units constructed after January 1, 2007.

In addition to activities at the state level, the mayors of Billings, Bozeman, and Missoula have signed the U.S. Mayors Climate Protection Agreement, in which mayors commit to reduce emissions in their cities to 7 percent below 1990 levels by 2012. Missoula, Montana is the base for GlobalWarmingSolution.Org, a network of 35 member organizations representing 320 groups in the United States and individual supporters. Founded in 2003, the group's mission is to advocate global greenhouse gas emissions reduction. Other conservation organizations active in Montana include the Montana Environmental Information Center, Montanans for a Healthy Climate, and Montana Trout Unlimited.

SEE ALSO: Glaciers, Retreating; Glaciology.

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Montreal Protocol

THE MONTREAL PROTOCOL is an international treaty designed to protect the ozone layer by phasing out the production of a number substance (such as CFCs—Chlorofluoro compounds) believed to be responsible for ozone depletion. In the late 1920s, chemicals called chloroflourocarbons (cloro-floro-carbons) or CFCs, were invented. These chemicals were not poisonous and did not harm fabrics, plants, or people. Companies thought they were great products and used them in refrigerators, air conditioners, styrofoam packaging, and spray cans. From the 1920s to the 1970s, billions of CFC molecules were released into the air.

In the 1970s, scientists began to wonder what happened to all the CFCs after they had been in the air for a while. Scientists eventually learned that CFCs could float past the troposphere (troposphere is a layer of atmosphere that is closest to the Earth. It extends to about 3.7–10.5 mi. (6–17 km.) above the Earth's surface and is thickest at the equator. Temperatures in the troposphere decrease as altitude increases. They are warmer nearest the Earth, in part because gases in the troposphere are warmed by heat radiated from the earth.) up into the stratosphere (stratosphere is the second layer of atmosphere, and extends out beyond the troposphere, to about 31 mi. (50 km.) above the earth. Gases in the stratosphere are heated mainly by incoming radiation from the Sun; temperature in the stratosphere gradually increases as altitude increases. As a consequence of temperature differences between the troposphere and stratosphere, and the resulting circulation patterns, exchange of air between the two layers is slow. The stratosphere is also known as the ozone layer. The distribution of ozone is closely linked to the vertical structure of the atmosphere. Approximately 90 percent of all ozone molecules are found in a broad band within the stratosphere. This layer of ozone-rich air acts as an invisible filter to protect all life forms from over-exposure to the Sun's harmful ultraviolet (UV) rays. Long-term ozone depletion is result of human-activity.) where UV rays would break them down. The chemicals that make up CFCs, mainly chlorine and fluorine, float around the stratosphere, breaking up ozone molecules.

Although CFCs were invented in 1920s, and research in the impact of CFCs on the ozone layer began as early as the 1930s, it received attention mainly in 1970s. During the 1970s, concerns arose that stratospheric transport aircraft might damage the ozone layer. This concern started in 1973, when the American Chemists (Frank Sherwood and Mario Molina) decide to study the impact of CFCs on the Earth's atmosphere. They discovered that CFC molecules were stable enough to remain in the atmosphere until they got into the stratosphere where they would finally be broken down by ultraviolet radiation releasing a chlorine atom, after an average of 50–100 years for the two common CFCs.

In 1974, Sherwood Rowland and Mario Molina discovered a dramatic change in the chemical composition of our atmosphere, an enormous increase in concentration of chlorine throughout the world. This increase in chlorine is attributed to widespread use of CFCs. It was at this time that the theory was proposed that CFCs were depleting the ozone layer. At the time, CFCs were used in refrigeration, aerosol cans, and some industrial processes. Initially greeted with a great deal of skepticism, further research and monitoring began to convince the scientific community that the CFC hypothesis might be valid. In the late 1970s and early 1980s, some national governments imposed bans on CFCs as aerosol and other propellants in non-essential uses for antiperspirants, hairsprays, and deodorants. In 1977, the United Nations Environment Program (UNEP) established the Coordinating Committee on the Ozone Layer.

In 1981, UNEP acted on a proposal submitted by a meeting of legal experts and decided to develop a global convention. In 1985, the Vienna Convention on the Protection of the Ozone Layer was signed. The period between the Vienna Convention (March 1985), and the Montreal Protocol (September 1987), was characterized by incredible progress in negotiations. In 1987 a hole in the ozone layer was found over Antarctica, the size of the United States. This discovery transformed politics and international negotiations. In 1987, over 60 countries met in Montreal (more than half of them were developing countries) to discuss the treaty. The global scientific community reached consensus, while meetings were held in Rome to clarify and quantify the current global emissions of ozone-depleting substances and future trends, and new mechanisms for control were discussed. By September 1987, the disagreements and lack of understanding on CFCs and its role on ozone depletion had given way to trust. In turn, the trust offered the prospect of consensus on control measures. Thus, on September 16, 1987, the Montreal Protocol on Substances that Deplete the Ozone Layer was signed by 24 countries. The treaty was opened for signature on September 16, 1987, and took effect on January 1, 1989. It has undergone five different revisions since: in 1990 (London), 1992 (Copenhagen), 1995 (Vienna), 1997 (Montreal), and 1999 (Beijing).

All Parties agreed to meet near-term targets of freezing consumption of key CFCs and halons at 1986 levels, and reducing consumption by 50 percent within next 10 years. While the Protocol is complex, its most important feature was the dynamic process for controlling ozone-depleting substances, in addition to those initially identified in the Protocol. One of the major steps was the amendment to the Montreal Protocol in Copenhagen, in 1992, which resulted in a further acceleration of the phase-out of several

The status of ratification as of October 10, 2007.

	Ratification of:					
	Vienna Convention	Montreal Protocol	London Amendment	Copenhagen Amendment	Montreal Amendment	Beijing Amendment
Total number of countries	**191**	**191**	**186**	**178**	**158**	**133**

ozone-depleting substances. In addition to CFCs, hydrochlorofluorocarbons, and methyl bromide were added to the list of substances subject to control.

The Montreal Protocol was the first treaty to protect the atmosphere from human impacts on the ozone layer. The agreement and the way it was developed are unique. For instance, research findings were a vital part of the decision-making process, and scientific assessments are stipulated in the Protocol every four years as a basis for further decisions on ozone-depleting substances.

In 1979, many countries, including the United States, banned CFCs from manufacture or use. This was a big step toward fixing the problem. Today, no spray cans contain CFCs. Other chemicals are gradually replacing the CFCs in air conditioners. Scientists originally predicted that the ozone layer would be the thinnest around 2008, but then start recovering. But new research shows that other air pollution problems are not only worsening the general situation, but also slowing down the ozone layer's ability to rebound. There are products that still contain CFCs and need to be treated with care. One example of this is car air-conditioners. When the air-conditioner breaks, or the car is taken to a junkyard, the CFCs need to be carefully taken out and recycled or stored so that they do not leak into the air. This can be best achieved by educating people that they should have their car air conditioners fixed by mechanics who are certified to work with CFCs; it is essential in protecting human health (skin and eyes) from the harmful effects of UV rays.

The Montreal Protocol has been a success story and it owes a great deal of this success to the actions of the U.S. government, which played a very aggressive role in producing the protocol. American companies also played a large role in the protocol's success, because they stood at the forefront of technological innovation in creating substitutes for the chemicals that were causing ozone-depletion. All of these countries are complying with their obligations for it has been shown that the ozone-depleting chemicals' global emissions have decreased by over 95 percent since the Protocol was put into action. Atmospheric concentrations of all of these chemicals have also been declining since 1994. By 2050, it is expected that the ozone layer will return to its natural level. Since the Montreal Protocol, 15 of the worst CFCs were phased-out worldwide, with the United States, Europe, and Canada completely phasing-out all use of CFCs. As a result of all of these restrictions, new damage to the ozone layer has greatly decreased and the hole in shrinking.

Due to widespread adaptation and implementation, the Montreal Protocol is hailed as an example of exceptional international cooperation, which prompted Kofi Annan, the former Secretary General of the United Nations, to state that the Protocol is "Perhaps the single most successful international agreement to date.…"

SEE ALSO: Carbon Dioxide; Mesosphere; Stratosphere; Technology; Thermosphere; Weather.

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Morocco

LOCATED IN NORTHWEST Africa, the Kingdom of Morocco covers an area of 172,414 sq. mi. (446,550 sq. km.), with a population of 31,224,000, 49 percent of which lives in urban areas. The country has a population density of 181 people per sq. mi. (69.8 people per sq. km.), although few people live in the Western Sahara region.

Twenty-one percent of the land in Morocco is arable, with another 47 percent used for meadows and pasture. The agricultural sector, including fishing, accounts for nearly a third of all export earnings; main crops include wheat and fruit, especially oranges. With 91.3 percent of Morocco's electricity production coming from fossil fuels, and only 8.7 percent from hydropower, and increased industrialization in the country, the per capita rate of emissions of carbon dioxide still remains relatively low at one metric ton in 1990, rising to 1.2 metric tons per person in 2004. Sixty percent of the country's total carbon dioxide emissions come from liquid fuels, 29 percent from fossil fuels, and 11 percent from the manufacture of cement. The high use of liquid fuels comes from the heavy use of oil, a quarter of which comes from Saudi Arabia, and a fifth from the United Arab Emirates, supplemented by some local production of oil and gas, with Morocco having to import electricity from Algeria. In addition to use in automobiles, liquid fuels is used to run generators on isolated properties and farms, and as a reliable source of electricity in many urban areas.

Since the 1980s, the government has tried to develop a program for the generation of hydroelectric power, but hydroelectric plants have failed to generate anywhere near the planned output. One of the problems has been that the hydroelectric facility at Ammogguez in the Atlas Mountains has experienced cave-ins in the hydro tunnels because of gypsum. The possibility of oil in the Western Sahara is expected to generate new wealth for the country, along with a probabile rise in greenhouse gas emissions. In terms of the carbon dioxide emissions by sector, 35 percent comes from electricity and heat production, 18 percent from manufacturing and construction, and 11 percent from residential use, with only 6 percent from transportation, a figure kept low by the extensive public transport network, with a bus service covering much of the country.

Global warming and climate change will affect the agricultural base of Morocco, leading to less land available for farming and declining crop production. This will come about through longer droughts that have been affecting Morocco for many centuries, but which have rarely lasted longer than two years. The Moroccan government took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, and ratified the Vienna Convention in 1995. They accepted the Kyoto Protocol to the UN Framework Convention on Climate Change on January 25, 2002, which took effect on February 16, 2005. The Moroccan government has also signaled its support for the Clean Development Mechanism as part of its National Sustainable Development Strategy.

SEE ALSO: Agriculture; Drought; Oil, Production of.

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Movements, Environmental

ENVIRONMENTAL MOVEMENTS ARE groups collectively trying to improve the conditions of the environment for human health, biodiversity, and ecosystem integrity. Environmental movements can have a diverse set of political perspectives and ethical orientations and engage in tactics that vary from social protest and direct action to litigation and policy reform. Environmental movements promote one or more dimensions of environmentalism, which seek social change based on a commitment to resource sustainability and ecosystem preservation.

Some of the earliest environmental movements were organized around concerns about hunting and conservation of wildlife. By the 20th century, urban environmental issues with sanitation, clean water, clean air, and public health became another key focus for environmental movements. Environmental movements emerged at the same time as the women's liberation, the anti-Vietnam War, and other leftist counterculture movements. The counterculture of the 1960s connected environmentalism to the critique of capitalist consumer society. Some note the image of a fragile Earth from the early space missions as a key moment for environmental movements. Widespread support for environmental movements emerged with attention to the story of Love Canal, where children were exposed to toxins in the soil below a school on a site that previously was a toxic dump. Environmental movements began to emphasize local and household issues, where families took up concerns about children's exposure to toxins.

The ethical orientations of environmental movements range from the conservation-oriented utilitarians who look to preserve resources for human use, to those with preservation-oriented perspectives who attribute intrinsic value to ecological systems, biodiversity, and charismatic species. Utilitarian perspectives are often characterized as anthropocentric because they ascribe rights only to present and future generations of humans. The eco-centric and bio-centric perspectives extend the domain of ethical consideration to living species and assemblages of species. The eco-centric and bio-centric perspectives have their origins in the Romanticism of Thoreau and other 19th century nature writing. These ethical views come into conflict in questions about the human use of natural resource and wilderness.

Given the diversity of environmental problems, environmental movements are quite diverse in their foci, although the political power of these groups often varies with the political power of the opponents they encounter. Environmental movements shape environmental outcomes in various ways, some using the political system, some focusing on the promotion of green consumerism and stewardship, and ecological modernization, while others use more violent tactics, like ecotage. As of 1995, there were over 10,000 environmental organizations in the United States, with 44 million members, income of $2.7 billion, and assets of over $5.8 billion. Environmental organizations come from a variety of perspectives, raising a diverse set of concerns ranging from those that focus on local, not-in-my-back-yard issues; mainstream Washington-based lobby and policy-oriented nongovernmental organizations, such as the Union Concerned Scientists and the World Watch Institute; political parties like the U.S. and German Green Parties; legal-action groups, like Friends of the Earth, the Center for Foods Safety, and the Defenders of Wildlife; donor and member-driven groups such as the Sierra Club, The Nature Conservancy, GreenPeace, the Wilderness Society, and World Wildlife Fund; and radical direct-action groups ranging from Greenpeace to Earth First!

RADICAL MOVEMENTS AND GREEN POLITICS

The Earth Liberation Front (ELF) is probably the most controversial group that could be characterized as a green movement, as the Unabomber's lone actions probably do not qualify as a movement. ELF is a radical environmental group that approves of destructive tactics to achieve their aims. Listed as a terrorist organization by the Federal Bureau of Investigation, the decentralized organization has claimed responsibility for a handful of actions, including arsons committed in new suburban housing developments in Long Island, and the destruction of new Hummers at a dealership in southern California, which gained widespread media attention. Those acts of ecotage are inspired by the Edward Abbey classic, the *Monkey Wrench Gang*, where a group of friends who gain inspiration from the wild, clandestinely sabotage equipment used to extract natural resources.

Radical environmentalists are often depicted as adherents to deep ecology, an environmental worldview that advocates a duty to preserve nature. Deep ecology was coined by Arne Naess, a Norwegian philosopher and mountaineer who has written extensively on the moral philosophy of environmentalism. Deep ecologists have been criticized for holding onto pristine myths about nature and for pressing for U.S.-style national parks and wilderness areas in developing countries.

Green movement popularity has also lent itself to the mainstream programs of political parties. Political parties from all persuasions now seek to claim the environment for themselves. Political parties, such as the German Greens, *Die Grünen*, have gained a populist following. The German Greens have led a strong critique of industrial society and colonialism, and have brought questions about the environment, public health, and military spending into their platform. Ralph Nader's appearance as a Green Party candidate in the U.S. presidential elections of 2000 is often cited as the reason Al Gore lost to George W. Bush. Former Vice President Al Gore is often described as an environmental movement leader, a claim buttressed by his film *An Inconvenient Truth*.

AGRICULTURE

The question about what to eat is perhaps one of the most controversial topics among environmental movement activists. Animal-rights activists and sustainable food system activists have many clashing opinions, but also many overlapping agreements. While they differ on the question of local animals in food systems for example, they agree that modern industrial animal production is cruel and wasteful.

The sustainable agriculture movement is also considered an environmental movement. It shares issues in common with the appropriate technology movement, which advocates a new economy based on a reflection on the social consequences of technological change. They share similar concerns with the "back to the land" movement. The influence of books such as E.F. Schumaker's *Small is Beautiful*; Wendell Berry's *Unsettling of America*; Rachel Carson's *Silent Spring*, an attack on DDT that was serialized in the *New Yorker* in the early 1960s; and Murray Bookchin's *Our Synthetic Environment* demonstrate a significant overlap between environmental and agricultural concerns. Today, the sustainable agriculture movement overlaps with anti-genetic engineering activists who critique technological change in agriculture, drawing on the environmental implications of the Green Revolution and agricultural development.

Some environmental movements see the roots of environmental problems as stemming from globalization. These groups focus efforts on remaking communities based on the ideals of more local production-consumption linkages. The promotion of green or ethical consumption is directed at getting consumers to shorten commodity chains through more direct purchasing, such as farmer's markets, to establish connections between producers and consumers of locally-grown food as opposed to industrial and fast food. Perhaps the most widely-recognizable form of ethical consumerism is vegetarianism, which is motivated by the ethical consequences of eating meat. Epitomizing ethical consumerism and the role of environmental movements is the international coffee situation, where a transition to large plantation, full-sun coffee has led to declines in migratory birds that over-winter in the tropics where coffee has been traditionally grown in shade coffee systems. Environmental groups have promoted the consumption of bird-friendly coffee because small-scale, shade-grown coffee plantations have demonstrated higher levels of biodiversity in birds, trees, and many other species. Ethical labeling has become a popular tactic for environmental movements from organic agriculture to fisheries conservation to timber certifications.

The sustainable agriculture movement shares similar concerns with the appropriate technology movement.

THE GREEN STATE

Environmental movements have played a significant role discursively, as well as materially, in transforming the state to a green one. The heyday of the environmental movement is often described as the time period that saw formation of the Environmental Protection Agency (EPA) and the passage of the Water Pollution Control Act, the Clean Air Act, the National Environmental Policy Act, and the Endangered Species Act during the early 1970s. However, the codification of environmental problems through the state took the environmental movement's momentum away from the left, and took up environmentalism as a cause for the right.

The Richard M. Nixon Administration sought a consensus approach to environmental problems, and his creation of a policy apparatus for environmental problems served to take away the political momentum of the left. While the EPA regulated the harms from production practices, the failure to include the Department of Agriculture, Department of Energy, and Department of Transportation in the planning and regulatory sphere left their interventions more at the whims of market forces and political cronyism. The critique entitled the *Death of Environmentalism* blamed the failure of the environmental movement on a narrowly-defined policy reform that failed to maintain political coalitions and win-win scenarios that could promote jobs and environmental concern.

Some have questioned whether or not the institutionalization of mainstream environmental movement organizations qualifies them as a social movement, which, to some, is a contradiction: you cannot have a movement that is institutionalized. The institutionalization of environmental movements through nongovernmental organizations has seen an increase in passive members who simply write checks in the name of some environmental organization, many of which must maintain large overheads to stay fiscally afloat. Another concern is mainstream environmental organizations' move away from protest tactics and critiques of multinational corporations to a more collaborative approach. Yet, it is unclear if collaborative environmental movements makes them more or less effective in dealing with environmental problems. There is also a concern that the institutionalization of environmental movements has led to the scientization of environmental problems. This has narrowed the focus to the science of environmental problems, often neglecting their social origins.

Environmental movement concerns merge with concerns about development in the developing world. Successful environmental movements—so called red/green movements—in developing countries include the Chipko Andolan Movement, a group that protected trees in Northern India through acts of civil disobedience against transnational logging companies. Often, these campaigns link concerns about livelihoods with concerns about the environment. Chico Mendez led a group of rubber tappers in Brazil on a crusade to link their practices to the preservation of biodiversity in the Amazon. However, not all developing-country environmental campaigns have been successful. The Three Gorges Dam project in China is one glaring example of mass relocation and devastating environmental impact that environmental movements have found difficulty in challenging.

More recently, environmental justice movements have refocused attention to environmental concerns in urban areas and cities. An executive order by President William J. Clinton, in the 1990s, required federal agencies in the United States to evaluate the consequences of agency actions on the distribution of environmental burdens. Many urban environmental movements draw attention to the problem of environmental racism, where communities are disproportionately exposed to negative environmental consequences. With the rapid rise of urban populations around the world, the promotion of sustainable cities has been cited as a high priority for environmentalists.

SEE ALSO: Food Miles; Green Cities; Policy, International; Policy, U.S.; Public Awareness.

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Mozambique

THE REPUBLIC OF Mozambique, formerly a Portuguese colony, located in southeast Africa, has a land area of 309,496 sq. mi. (799,400 sq. km.), with a population of 21,397,000 (2006 est.), and a population density of 65 people per sq. mi. (25 people per sq. km.). With less than a quarter of the population employed in agriculture, 4 percent of the land is arable, and 56 percent officially classed as meadows or pasture, and 20 percent of the country remains forested, although there is a large timber industry in the country.

As for Mozambique's electricity production, 96.4 percent of it comes from hydropower, and only 3.6 percent comes from fossil fuels. The Portuguese built some of the hydroelectric power plants, the major one at Cabora Bassa. During the war between the Portuguese and FRELIMO (Mozambican Liberation Front) in the 1960s and early 1970s, the Portuguese guarded the dam heavily, but FRELIMO did not attack, realizing its importance to power generation after independence in 1975. After independence, some other hydroelectric plants were built, with the Chinese helping to fund a new plant for Maputo.

As a result of the extensive use of hydropower, Mozambique's per capita carbon dioxide emissions were previously 0.1 metric tons, and fell to 0.08 metric tons by 2003. Another effect from the heavy use of hydropower is that electricity is responsible for only 1 percent of the country's total carbon dioxide emissions, with the use of solid fuels making up only 7 percent of carbon dioxide emissions. About 82 percent of carbon dioxide emissions come from liquid fuels, with transportation making up 67 percent of all emissions by source. Another important factor is the manufacture of cement, which is responsible for 11 percent of carbon dioxide emissions.

Mozambique experienced flooding in many parts of the country in February and March 2000, causing the death of about 800 people, the loss of 20,000 cattle, and the inundation of 540 sq. mi. (1,400 sq. km.) of arable land. There was another flood in December 2006, when the water overflowed the Cahora Bassa Dam, leading to the deaths of 29 people and the displacement of 121,000 more.

The Mozambique government took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, which it ratified in 1995. It also ratified the Vienna Convention in 1994, and accepted the Kyoto Protocol to the UN Framework Convention on Climate Change on January 18, 2005, which took effect on April 18, 2005.

SEE ALSO: Agriculture; Floods; Transportation.

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Munk, Walter (1917–)

INFLUENTIAL PHYSICAL oceanographer and geophysicist, Professor Emeritus of Geophysics and Secretary of the Navy/Chief of Naval Operations Oceanography Chair at Scripps Institution of Oceanography in La Jolla, California. He made fundamental discoveries in different fields such as the effect of the moon on tides and the circulation of the deep sea. Munk also had a leading role in devising a method for calculating the course of long-term climatic changes related to global warming. In 1999, he became the first in his field to be awarded the Kyoto Prize by the Inamori Foundation.

Born in Vienna, Austria, on October 19, 1917, Munk was sent to preparatory school in New York in 1932. He applied for American citizenship in 1939, after the annexation of Austria by Nazi Germany. His family chose New York as they wanted Walter to follow his relatives' vocation for business and finance. Yet, Munk disliked banking and, after three years, left Columbia University to study physics at the California Institute of Technology, from where he graduated in 1939. Munk then applied for a summer job at the Scripps Institution of Oceanography. The next year, the director of Scripps, the distinguished Norwegian oceanographer Harald Ulrik Sverdrup, accepted him as a doctoral student, although he warned Munk that there might not be many jobs in oceanography. During the war, Munk was excused from active service in exchange of defense-related research at Scripps. Together with several of his colleagues from Scripps, he developed methods related to amphibious warfare, which were used successfully to predict surf conditions for Allied landings in North Africa, the Pacific theater of war, and, on D-Day during the Normandy invasion. During the testing of nuclear weapons at

Bikini Atoll in the southern Pacific Ocean in 1946, Munk contributed to the analysis of the currents and diffusion in the lagoon and the water exchange with the open seas.

Munk graduated with a Ph.D. in oceanography in 1947. Since then he has spent his whole career at Scripps Institution. In 1947, he became an assistant professor. In 1953 he married Judith Horton and the following year he became a professor of geophysics and also was named a member of the UC's Institute of Geophysics. In 1960, he established a branch of the institute on the Scripps campus in La Jolla. Until 1982, he served as director of the Scripps branch and as an associate director of the Institute of Geophysics and Planetary Physics (IGPP). Munk also served as a member of JASON, a prestigious panel of scientists who advised the U.S. government on military strategies.

In the 1960s, Munk focused his research on the attenuation in ocean swells generated in Antarctica. The project measured variations with pressure-sensing devices lowered to the ocean floor. Measurements were also taken at six different Pacific Ocean locations and from FLIP, the Floating Instrument Platform, developed at Scripps. During this decade, Munk began measuring tides in the deep sea, using extremely sophisticated pressure-sensing devices that were dropped to the ocean floor and retrieved by acoustic release.

A NEW MODEL

Munk's relevance for the field of global warming lies in his work on the acoustic tomography of the ocean that he developed from the 1970s through to the 1990s. Munk had a leading role in the development of a new method for tracing long-term changes in climate linked with global warming. Munk came to the conclusion that important information about the ocean's large-scale structure could be gathered by studying the sound propagation patterns and the time it takes for sound to travel through the oceans. He conceived the Heard Island Experiment, where acoustic signals were sent out by instruments lowered 492 ft. (150 m.) underwater near the remote island in the southern Indian Ocean. During four days in January 1991, "the sound heard around the world" experiment took place. Signals were sent from Heard Island, on the east and west coasts of the United States, as well as at many other stations around the world. These researches led to the Acoustic Thermometry of Ocean Climate (ATOC) project. ATOC was based on the idea to send sound signals from underwater speakers and determine how long it takes them to reach receivers anchored to the floor of the Pacific thousands of miles away. Since sound travels faster in warmer than in cooler water, a long-term series of tests that showed increasingly faster travel periods would be the evidence that the ocean is warming.

AWARDS AND ACCOLADES

Throughout his long career, Munk has received numerous awards. He was elected to the National Academy of Sciences in 1956, and to the Royal Society of London in 1976. He has been the recipient of a Guggenheim Fellowship three times. In 1965 he received the Arthur L. Day Medal from the Geological Society of America, and, in 1966, he was awarded the Sverdrup Gold Medal of the American Meteorological Society. The Royal Astronomical Society of London gave him the Gold Medal in 1968. In 1976, he obtained the first Maurice Ewing Medal sponsored by the American Geophysical Union and the U.S. Navy. In 1977, he was given the Alexander Agassiz Gold Medal of the National Academy of Sciences. Munk was honored with the 1999 Kyoto Prize in Basic Sciences for his fundamental contributions to the field of oceanography. The Navy League of the United States honored Munk with the 2001 Albert A. Michelson Award for research that has significantly improved the nation's maritime forces or the U.S. industrial technology base. In the same year, the scientist was awarded the inaugural Prince Albert I Medal from the International Association for the Physical Sciences of the Oceans (IAPSO).

SEE ALSO: Climatic Data, Oceanic Observations; Climatic Data, Sea Floor Records; Modeling of Ocean Circulation; Ocean Component of Models; Oceanic Changes; Oceanography; Scripps Institute of Oceanography.

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Myanmar

LOCATED IN SOUTHEAST Asia, the Union of Myanmar has a land area of 261,227 sq. mi. (676,577 sq. km.), a population of 48,798,000 (2006 est.), and a population density of 193 people per sq. mi. (75 people per sq. km.). Yangon (formerly Rangoon), the largest city and the former capital, has a population of 4,668,775, making it the 29th largest city in the world. The new capital, Naypyidaw, dates from 2005, and, internationally, little is known about it. About 15 percent of the country is arable, an additional 1 percent used for pasture, and 34 percent of Myanmar remains forested, although there has been an increase in logging in recent years, with teak now the major export of the country.

Relatively underdeveloped, and with large parts of the country having only irregular use of electricity, if at all, Myanmar has a very low rate of carbon dioxide emissions per capita, at 0.1 metric tons per person in 1990, and rising gradually to 0.21 metric tons per person in 2004. This is in spite of the tropical climate, and the heavy use of air conditioners in the cities. Myanmar has its own oil industry, with petrol and gas used to generate electricity. Approximately 83.3 percent of the country's electricity comes from fossil fuels, with the remainder from hydropower. As a result, liquid fuels make up 57 percent of carbon dioxide emissions, and gaseous fuels make up another 39 percent. The remainder comes from solid fuels and from the manufacture of cement. About 36 percent of the carbon dioxide emissions in the country come from transportation, 30 percent from the generation of electricity, and 15 percent from manufacturing and construction.

The main effect of global warming and climate change on Myanmar has been the increased risk of flooding, especially at the mouth of the Irrawaddy. The Boxing Day Tsunami in 2004 led to serious flooding of this region. Although the Myanmar government officially stated that the death toll was only 61, with 200 missing, most commentators felt that many more human casualties occurred. The flooding washed away topsoil and destroyed arable land, and will also cause a rise in insect-borne diseases, such as malaria and dengue fever.

The Myanmar government took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992. They accepted the Kyoto Protocol to the UN Framework Convention on Climate Change on August 13, 2003, and it took effect on February 16, 2005.

SEE ALSO: Floods; Deforestation; Diseases; Hurricanes and Typhoons.

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Namibia

THE REPUBLIC OF Namibia has a land area of 318,696 sq. mi. (824,290 square km.), a population of 2,074,000 (2006 est.), and a population density of 6.5 people per sq. mi. (2.5 people per square km.). Namibia has the lowest population density of any African country. Much of Namibia is arid, with only 1 percent of the land arable and 46 percent used for pasture, mainly low intensity grazing of cattle, sheep, and goats. The country has an extremely low rate of carbon dioxide emissions, at 1 metric ton per person in 1995, rising to 1.24 metric tons by 2004. This is largely because there is relatively low electricity use in the country; of the 603 million kWh used in 2001, some 578 million kWh was imported from South Africa, and 98 percent of local production came from hydropower.

Since independence in 1990, there have been a number of attempts to increase hydropower production. There was a projected water shortage in the late 1990s, which stopped plans to build a hydroelectric plant on the Kumene River, in the Kaokoveld region, which, as well as power, would also be able to provide water to Windhoek, the capital. However, in 2000 and 2001, there were heavy rains, resulting in extensive flooding, which provided far more water than was needed. The distances in Namibia are vast, with transportation accounting for 85 percent of the carbon dioxide emissions in the country. Thirteen percent of emissions come from manufacturing and construction.

Although it contributes very little to greenhouse gas emissions, the effects of global warming and climate change on Namibia have been significant. The rising temperatures have reduced the already limited amount of arable land in the country. The coastline of Namibia, nicknamed the Skeleton Coast because of the remains of whales from the whaling industry of the 19th century, and the shipwrecks of the 19th and 20th centuries, has also been badly affected by the Benguela El Niño. This has come about from the temperature of the Benguela Current, off the coast of Namibia, reducing fish stocks and impacting the coastline.

The Namibian government took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992. The government accepted the Kyoto Protocol to the UN Framework Convention on Climate Change on September 4, 2003, and took effect on February 16, 2005.

SEE ALSO: Benguela Current; Deserts; El Niño and La Niña.

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THE NATIONAL ACADEMY of Sciences (NAS) is an honorific society incorporated by the U.S. Congress and signed into law on March 3, 1863, with the mandate to "investigate, examine, experiment, and report upon any subject of science or art" when requested to do so by the government. The NAS advises policymakers and its private sponsors on technical matters, and promotes the advancement of science and its use for the public welfare. The NAS is one of four organizations that comprise the National Academies, which also include the National Academy of Engineering (NAE), the Institute of Medicine, and the National Research Council. The NAS organized the National Research Council in 1916, as its operational arm. The National Research Council is now the primary operating agency of the National Academy of Engineering and is administered by the NAS, the NAE, and the Institute of Medicine. Committee activities by the National Academy of Science in 2007 covered more than 20 focus areas, including Agriculture, Behavioral & Social Sciences, Chemistry, Computer & Technology, Earth Science, Energy & Energy Conservation, Environmental Issues, Health & Medicine, International Issues, Policy & Research, and Space.

MEMBERS

Current members elect new members of the NAS, like those of the NAE and the Institute of Medicine. Membership in the NAS is regarded as one of the highest tributes conferred in American science. More than 200 members have won the Nobel Prize. Annually, up to 72 members and 18 foreign associates may be elected to membership. With the election in 2007, the number of active members, each of whom is associated with one of 31 disciplines, stood at 2,025. The NAS also has approximately 350 foreign associates. In 2007, the NAS garnered attention for electing the lowest number of women elected to membership since 2001. Only nine women were inducted as new members, raising the total number of members who are women to approximately 10 percent.

The NAS espouses an ongoing commitment to the inclusion of women in leadership and decision-making and in access to grant-funding opportunities and fellowships. In 1994, NAS and the Royal Society of London issued a joint resolution in support of this commitment. According to the leadership of the NAS, the pace at which women are joining the institute may be attributed to the time needed for scientists to build credentials noteworthy enough for consideration for membership. In an effort to inspire an interest in science in middle-school-aged girls, the NAS actively supports the publication of Women's Adventures in Science, a biography series about contemporary women working in diverse scientific fields, and the series' companion website.

AWARDS

In addition to recognizing distinguished accomplishments by electing members to its own ranks, the NAS recognizes the work of other accomplished scientists by bestowing annual awards, currently 30 in number, in nine fields: Astronomy/Astrophysics, Behavioral/Social Sciences, Biology and Medicine, Chemistry, Earth and Environmental Sciences, Engineering and Applied Sciences, Mathematics and Computer Sciences, Physics, and a General category. Awards include the John J. Carty Award for the Advancement of Science, with an emphasis in ecology; the Arthur L. Day Prize and Lectureship, focusing on the physics of the Earth; the Public Welfare Medal, and the NAS Award for Scientific Reviewing, in the fields of social and political sciences; and the Public Welfare Medal. The Public Welfare Medal is awarded in honor of distinguished service in the application of science to the public good. Noted recipients include Gilbert White, in 2000, for educating members of the academic community and government institutions on water resource management, hazard mitigation, and environmental assessment; Carl Sagan, in 1994 for his ability to describe complex scientific theories in graspable language; and Herbert Hoover, in 1920 for the utilization of science in food conservation and distribution.

PUBLICATIONS

The NAS also publishes *Proceedings of the National Academies of Sciences*, founded in 1914, which is published weekly and includes research reports, reviews, and papers, and *Issues in Science and Technology*, which is published quarterly and available in print by subscription. Articles from back issues of both of these publications are available online at no charge. *Biographical Memoirs,* published since 1877, highlights the life histories and accomplishments of deceased members of the NAS. Monographs printed from 1995 to date can be accessed online free of charge. The National Academies Press also publishes books and reports for the NAS, many of which are available in their entirety, or by chapter, online.

PROGRAMS AND ACTIVITIES

Among the many activities of the National Academies and its member organizations is the Keck Futures Initiative, a 15-year undertaking to stimulate interdisciplinary research, particularly cutting-edge research, and to increase interaction among researchers, universities, funding institutions, and the general public. The National Academies Keck Futures Initiative incorporates the following annual activities: Futures Conferences, Futures Grants, and National Academies Communication Awards. As of 2003, the National Academies annually bestow three $20,000 Communication Awards recognizing writers, journalists, and producers who have demonstrated excellence in communicating about science, engineering, and/or medicine to the general public through different media formats. In 2006, Elizabeth Kolbert, staff writer for the *New Yorker*, won the Newspaper/Magazine/Internet award for her three-part series "The Climate of Man." Additional 2006 finalists in the category, writing about climate change, included writer Michelle Nijhuis, "Hot Times: Global Warming in the West," *High Country News*, and Clayton Sandell, producer, and Bill Blakemore and Jay Lamonica, co-producers, for "Global Warming & Extinction," *ABC News*.

Since 1991, the NAS has addressed a broad range of contemporary scientific issues across disciplinary boundaries through the annual Arthur M. Sackler Colloquia, named in honor of the well-known scientist, philanthropist, editor of *Journal of Clinical and Experimental Psychobiology*, and founder of the *Medical Tribune*. An average of four to six such colloquia are held, each generally two days long, global in scope, and featuring presentations by leading scientists and discussions with at least 100 researchers interested in the field. The colloquium, "Early Cities: New Perspectives on Pre-Industrial Urbanism," was held in Washington, D.C., in 2005; "Auditory Neuroscience: Development, Transduction, and Integration," in 2000 in Irvine, California; and "Carbon Dioxide and Climate Change," organized by Charles Keeling, of the Scripps Institution of Oceanography, in Irvine in 1995.

The NAS also supports the Marian Koshland Science Museum, which features interactive displays about the role of science in people's daily lives and in national policymaking. The exhibit, "Global Warming Facts & Our Future," delved into issues related to global warming and its global impact on the quality of life. Questions addressed by the exhibit include: Is the Climate Warming, Are Humans Causing Climate Warming, What Effects Might Climate Warming Have, and What Should Be Done About Climate Warming. In 2004, the museum received the Bronze Galaxy Award for the exhibit, one of more than 400 entries from 14 countries to the 15th annual competition. In addition to exhibits, many of which are not permanent, the museum offers public and educational programs to stimulate discussion about science.

GLOBAL WARMING AND POLITICIZING SCIENCE

The NAS's reputation in research and the dissemination of information about global warming and climate change precedes its accolades for its museum exhibits about climate change. In 1991, the NAS released a report, *Policy Implications of Greenhouse Warming,* calling for a decrease in the dependence on fossil fuel, the advancement of nuclear and solar energy technologies, and the promotion of energy conservation, all aimed at a reduction in greenhouse gas emissions. The NAS asserted that the United States could reduce emissions by up to 40 percent cost-effectively and that a potential ecological disaster because of global warming was reason enough to implement changes immediately.

The NAS's report was met with general approval by environmental groups, most of which supported the recommendation for increased funding to develop renewable technologies, but opposed the NAS's call for the development of nuclear power. Although the White House maintained that the administration's National Energy Strategy was consistent with the recommendations by the NAS, then-Senator Albert Gore, Jr., a Democrat from Tennessee and future U.S. Vice President and author of *An Inconvenient Truth: The Planetary Emergency of Global Warming and What We Can Do About It* (2006), charged that many of the administration's policies actually conflicted with the recommendations of the NAS. Gore also predicted that history would judge President George H.W. Bush harshly if global warming continued.

In 1998, the NAS distanced itself from a confusing mass mailing that urged scientists to apply pressure to sway public policy and opinion against the Kyoto Protocol to the United Nations Framework Convention on Climate Change to assign mandatory carbon dioxide emissions limitations. The mailing, which appeared in a format similar to that of a NAS journal reprint, challenged the prevailing climate change research and included a cover letter from former NAS President Frederick Seitz urging scientists to lobby against the Kyoto treaty to reduce carbon dioxide emissions. The NAS did not take a position on the Kyoto treaty, although it had long-since recommended a prompt response to global warming, but opposed only the mailing, which generated more than 15,000 signatures because of its misleading design.

Although the NAS conducts research at the request of the government and advises policymakers on technical matters, the academy itself is not a political body. Nonetheless, the alleged distortions of the academy's research by members of presidential administrations to meet political agendas have been the subject of debate, during the William J. Clinton White House and increasingly during the George W. Bush administration. The head of the NAS stated in an interview, however, that he does not think that a deliberate scheme of misrepresentation exists, but that the extent of the problem in the George W. Bush White House is greater and that scientists agreed with policies of the Clinton administration more than those of the Bush administration, under which their independence may be more constrained.

The NAS found itself in the center of discussions about global warming in 2001, following a report commissioned by President George W. Bush, who had rejected the Kyoto Protocol and had hoped the report's findings would alleviate the pressure to find another option to the Kyoto treaty and limits on carbon emissions. The report, however, reached the conclusion that human activity had most likely brought about the increase in global temperature in the 20th century. Accounts issued by a Democratic Congressman in 2003 and 2004 claimed that the Bush administration had, in fact, misused scientific findings to support its own policy agenda. More than 5,000 scientists, including over 100 members of the NAS, signed a letter accompanying the reports that concurred with criticism of the White House.

Among the claims of impropriety were those by an associate director from 1998 to 2003 within a part of the National Institutes of Health, who charged that the Clinton administration was quick to approve suggested appointees to his scientific advisory committees, but the Bush administration rejected over 70 percent of his appointees, in some cases taking months to do so, and apparently in opposition to scientific independence. The Union of Concerned Scientists claimed that the EPA eliminated a chapter about global warming from a 2003 report about the nation's environment after the Bush administration's revisions might have led readers to believe that doubts persisted about global warming when, in fact, none did. Republicans maintained that reports and claims critical of the White House were simply politically-motivated. Democratic staff issued a memorandum that documents obtained from the White House Council on Environmental Quality (CEQ) indicated that additional changes were made in a fiscal year 2003 report to Congress from the administration on the status of the U.S. Climate Change Program. In 2007, the chief of staff for the White House Council on Environmental Quality, however, defended alterations to scientific climate change findings as an acceptable practice to synchronize reports of the executive branch with policies of the administration.

The NAS issued a report by the Nuclear Regulatory Commission (NRC) to the U.S. Climate Change Program in early 2007 that identified for the U.S. Climate Change Science Program, 11 critical components of global change assessments. This is the process through which experts reach agreement about issues related to the environment, including the loss of biodiversity and climate change. Among the essential elements identified were strategic framing of the assessment process, sufficient funding to support an effective assessment process, strong leadership, and the commitment and involvement of stakeholders with clear, unambiguous interactions and exchanges among policymakers and scientists. The NAS, in spite of the charged political environment that surrounds it, continues to support research and programs to effectively inform policymakers.

SEE ALSO: Bush (George H.W.) Administration; Bush (George W.) Administration; Climate; Clinton Administration; Nuclear Power; Scripps Institute of Oceanography.

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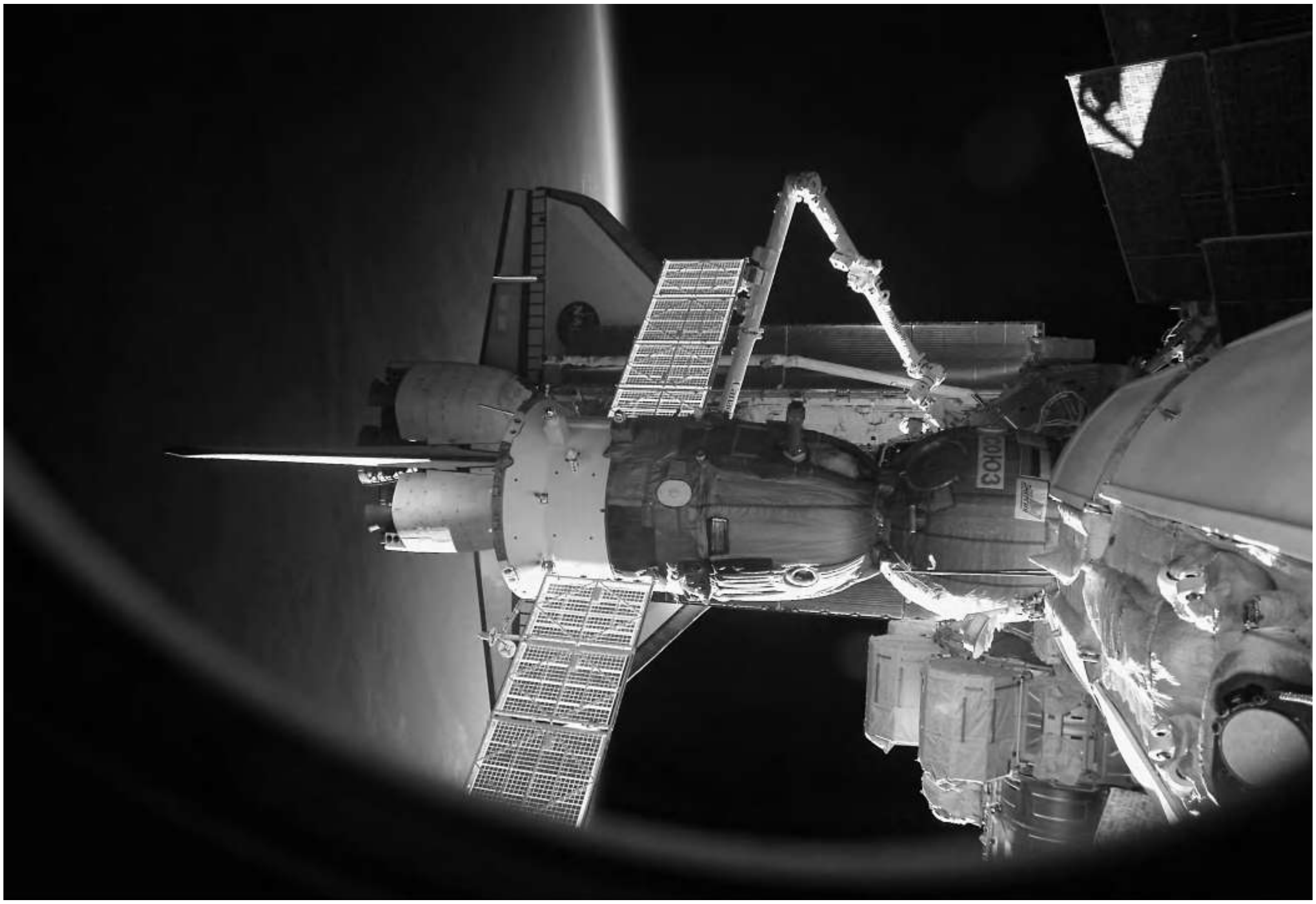
National Aeronautics and Space Administration (NASA)

THE NATIONAL AERONAUTICS and Space Administration (NASA) is an independent U.S. governmental agency, established in 1958, for the research and development of vehicles and activities for the exploration of space within and outside of Earth's atmosphere. Within NASA, the Goddard Institute for Space Studies (GISS) at Columbia University in New York carries out research related to climate change and global warming. NASA is structured around five program offices. Aeronautics and Space Technology is responsible for the development of equipment. Space Science and Applications deals with programs for understanding the origin, structure, and evolution of the universe, the solar system, and the Earth. Space Flight is concerned with manned and unmanned space transportation and all matters related to the space shuttle. Space Tracking and Data involves tracking and data acquisition. Space Station has the long-term goal of establishing a manned space station. A number of additional research centers are affiliated, including the Goddard Space Flight Center in Greenbelt, Maryland, within which the Goddard Institute for Space Studies operates; the Jet Propulsion Laboratory in Pasadena, California; the Lyndon B. Johnson Space Center in Houston, Texas; and the Langley Research Center in Hampton, Virginia. NASA headquarters are in Washington, D.C.

NASA was created largely in response to the Soviet launching of Sputnik in 1957. It was organized around the National Advisory Committee for Aeronautics (NACA), which had been created by Congress in 1915. NASA's organization was already underway by the early years of President John F. Kennedy's administration, when the President proposed that the United States sent a man to the Moon by the end of the 1960s. To that end, the Apollo program was designed, and, in 1969, the U.S. astronaut Neil Armstrong became the first man on the Moon. Later unmanned programs, such as Viking, Mariner, Voyager, and Galileo, explored other bodies of the solar system. When NASA began its operation on October 1, 1958, the agency consisted of only about 8,000 employees and had an annual budget of $100 million. In addition to a small headquarters staff in Washington, D.C., that conducted operations, NASA had three major research laboratories inherited from the National Advisory Committee for Aeronautics: the Langley Aeronautical Laboratory established in 1918, the Ames Aeronautical Laboratory activated near San Francisco in 1940, and the Lewis Flight Propulsion Laboratory built at Cleveland, Ohio, in 1941. It also had two small test facilities, one for high-speed flight research at Muroc Dry Lake in the high desert of California, and one for sounding rockets at Wallops Island, Virginia. It soon added several other government research organizations.

The Apollo program was designed to land humans on the Moon and bring them safely back to Earth. *Apollo 8* and *Apollo 10* tested various components while orbiting the Moon, and returned photographs of the lunar surface. On July 20, 1969, *Apollo 11* landed the first man on the moon, Neil Armstrong.



The International Space Station, with the docked Soyuz spacecraft (foreground) and the Space Shuttle Discovery *(background), orbiting the earth. The onboard lab is ideal for earth observation and all manner of experiments.*

The Apollo program included six missions that landed on the Moon and returned a wealth of scientific data and almost 882 lbs. (400 kg) of lunar samples. Experiments addressed topics such as soil mechanics, meteoroids, seismic, heat flow, lunar ranging, magnetic fields, and solar wind experiments. NASA was also in charge of the development and launch of a number of satellites with Earth applications, such as Landsat, a series of satellites designed to collect information on natural resources and other Earth features; communications satellites; and weather satellites. It also planned and developed the space shuttle, a reusable vehicle capable of carrying out missions that cannot be conducted with conventional spacecraft. The spectacular successes of the agency is tempered by the controversies and tragic disasters that marked its space shuttle program. The flights of the shuttle turned out to be much more expensive than initially expected. On January 28, 1986, the Space Shuttle *Challenger* was destroyed during its launch from the Kennedy Space Center. The explosion occurred 73 seconds into the flight as a result of a leak in one of two Solid Rocket Boosters that ignited the main liquid fuel tank. On February 1, 2003, the Space Shuttle *Columbia* broke up about 15 minutes before the scheduled landing. In both cases, all the astronauts on board lost their lives. The Space Shuttle *Columbia* disaster, in 2003, caused a 29-month interruption in space shuttle flights and led to a serious re-examination of NASA's priorities. The U.S. government, various scientists, and the public all reconsidered the future of the space program.

The shuttle, however, was also used to launch milestone projects like the Hubble Space Telescope (HST) in 1990, which has proved popular with both scientists and the public. Some of the images it has returned have attained an almost legendary status, such as the groundbreaking Hubble Deep Field images. The shuttle was also instrumental in the creation of the International Space Station (ISS), a cooperative project that mainly involves the United States and Russia for the construction of the biggest space station ever built. Costing over $100 billion, it has been difficult at times for NASA to justify the ISS. During much of the 1990s, NASA also faced shrinking annual budgets because of Congressional belt-tightening. This caused NASA administrators to adopt the "faster, better, cheaper" approach that enabled the agency to cut costs, while still delivering a wide variety of aerospace programs. Yet, that method was criticized and re-evaluated following the twin losses of the Mars Climate Orbiter and the Mars Polar Lander in 1999.

NASA's ongoing investigations include in-depth surveys of Mars and Saturn and studies of the Earth and Sun. Other NASA spacecraft are presently en route to Mercury and Pluto. With its spacecraft and satellites, the agency covers over half the solar system. In 2004, President George W. Bush launched the Vision for Space Exploration, which contemplates another human landing on the Moon by 2020, and the establishment of outposts in preparation for human exploration of Mars and other destinations.

From 2002 to 2006, the mission statement of the agency included understanding and protecting "our home planet." Since February 2006, however, the statement has been reworded and the portion pertaining to understanding and protecting our home planet has been deleted. This has been read by some as a result of the controversy concerning some NASA scientists such as James Hansen and the U.S. governments over the issue of global warming. Hansen, the director of the GISS, bitterly criticized the Bush Administration for what he thought were its ineffective environmental policies. In 2005 and 2006, Hansen also claimed that NASA officials were closely monitoring his participation in public events where he was invited to speak about global warming. This was part of an attempt to influence his statements on global warming. NASA officials have denied that the mission statement has been altered because of the controversy on global warming, but simply reflects the priority of space exploration for the agency in the coming years. They have also denied trying to manipulate Hansen and monitoring his scientific activities. Yet, Hansen has restated his accusations in the Al Gore-hosted documentary *An Inconvenient Truth* (2006).

The NASA sector that deals with research on climate change and global warming is the GISS, located at Columbia University's Armstrong Hall, in New York City. GISS is a component laboratory of Goddard Space Flight Center's Earth Sciences Division, which is part of GSFC's Sciences and Exploration Directorate. The institute was originally established, in May 1961, by Dr. Robert Jastrow to do basic research in space sciences in support of Goddard programs. The initial research at the Institute focused on planetary atmospheres using data collected by telescopes and space probes; in time that led to GISS becoming a leading center of atmospheric modeling and of climate change. The Institute currently encompasses a broad study of Global Change, treating it as an interdisciplinary initiative addressing natural and anthropogenic changes in our environment. These can occur on various timescales (from one-time forcings, such as volcanic explosions, to seasonal/annual effects, such as El Niño, and on up to the millennia of ice ages) and have a different impact on the habitability of the planet. Program areas at GISS may be roughly divided into the categories of climate forcings, climate impacts, model development, Earth observations, planetary atmospheres, paleoclimate, radiation, atmospheric chemistry, astrophysics and other disciplines. However, due to the interconnections among these topics and the interdisciplinary approach, most GISS personnel are engaged in research in several of these areas.

The main aim of GISS researchers is the prediction of atmospheric and climate changes in the 21st century. Their research combines analysis of comprehensive global datasets, derived mainly from spacecraft observations, with global models of atmospheric, land surface, and oceanic processes. GISS studies past climate change on Earth, and of other planetary atmospheres, as a useful tool in assessing our general understanding of the atmosphere and its evolution. The perspective provided by space observations is crucial for monitoring global change and for providing data needed to develop an understanding of the Earth system. As the principal NASA center for Earth observations, Goddard Space Flight Center plays a leading role in global change research. Global change studies at GISS are coordinated with research of other groups within the Earth Sciences Division, including the Laboratory for Atmospheres, Laboratory for Hydrospheric and Biospheric Sciences, and Earth Observing System science office.

The Climate Modeling Program at GISS attempts to develop three-dimensional general circulation models (GCMs) and coupled atmosphere-ocean models for simulating the Earth's climate system. Some research efforts may also include the use and development of two-dimensional energy balance models (EBMs), and one-dimensional radiative-convective models (RCMs). Primary emphasis in the use of the GCMs is placed on investigation of climate sensitivity, including the climate system's response to such forcings as solar variability, and anthropogenic and natural emissions of greenhouse gases and aerosols. GISS GCM simulations study the potential for humans to impact the climate, as well as the impact of a changing climate on society and the environment. GCM research focuses on sensitivity to parameterizations of clouds and moist convection, ground hydrology, and ocean-atmosphere-ice interactions, as well as explorations of more accurate numerical methods. The program also involves the advance of techniques to understand global cloud properties from satellite radiance measurements of the International Satellite Cloud Climatology Project. Ongoing field and laboratory programs in palynology, paleoclimate reconstruction, and other geophysical sciences offer fundamental climate data for evaluating and validating model predictions.

Research in the area of Earth Observation builds on the assumption that satellites provide the potential for observing changes of the Earth system on a global scale. GISS attempts to define which satellite observations are needed for the advancement of research, and to study how satellite data relates to and supports data acquired using more conventional techniques. Satellite observations are analyzed to obtain information on the Earth's surface, atmosphere, and, especially, global cloud systems. GISS is particularly interested in clouds, because they represent a great source of uncertainty in predicting future climate. Clouds are potentially the most powerful feedback mechanism in the climate system. Thus, further research is needed to decide if they are a positive feedback, which will enhance future greenhouse warming, or a negative feedback.

As far as climate impacts are concerned, GISS aims to develop a complex framework of analysis for interactions among biophysical and socioeconomic processes. GISS research in this area investigates the sequence of causes and effects linking climate and its impacts, utilizing the GISS global climate model (GCM), physically based impact models, chemical tracer models, and interdisciplinary teams. Distinctive features of research methods in this field include regional disaggregation, high spatial and temporal resolution, and theoretical improvement in the treatment of uncertainty. GISS climate impacts study addresses the impacts of current climate variability, such as El Niño Southern Oscillation (ENSO) events, and potential impacts of climate change resulting from greenhouse gas emissions. Observed climate data and climate model outputs (temperature, precipitation, solar radiation) are used as inputs for impact models to produce regional changes in variables such as crop yields, water availability, and forests. These changes are then measured in terms of economic and social costs, including the number of people threatened by hunger, drought, or coastal storm surges.

Studies in Planetary Atmosphere, a long-standing tenet of NASA, enables testing of basic understanding of atmospheric processes, including the greenhouse effect, aerosol and cloud physics, and atmospheric chemistry and dynamics. Aware of the difficulty interpreting observational data without comparing them to the results of an atmospheric model, GISS researchers use a variety of models, from relatively simple simulations of radiative transfer to full-fledged general circulation models (GCMs). The more complex models, developed through the conversion of Earth GCMs, allow the study of dynamical atmospheric processes, including the role of eddy, diabatic, and dissipative processes in the context of comparative planetary meteorology.

GISS Paleoclimate research is based upon the use of global climate models (GCMs) to generate simulations of past climates. GCMs are employed, in combination with geophysical, geochemical and sedimentological data analyses, to reconstruct various time periods and events in the Earth's climate history. Paleoclimate simulations are also used to test the ability of GISS digital representations of climates that differ significantly from the present. The ability to simulate climate changes that occurred in the past strengthens confidence in the conclusions drawn from simulations of future climate.

Several warm time periods are also of particular interest, because they provide insights regarding processes and impacts related to global warming scenarios.

Radiation studies at GISS cover three main areas: the construction of accurate radiative transfer models, which allow the interpretation of remote sensing data of Earth and other planets obtained from ground-based and satellite sensors; the accurate and efficient calculations of radiative transfer to determine heating and cooling rates in computer models of climate; and the theoretical modeling required to improve the methods and approximations used in radiative models. Theoretical modeling can also provide fundamental understanding of the physical processes involved in the absorption, scattering, and emission of electromagnetic energy. The study of radiation at GISS follows an interdisciplinary pattern, interacting with other fields, such as atmospheric chemistry, climate modeling, Earth observations, and planetary atmospheres. Projects in radiation studies include understanding the water vapor continuum absorption, modeling the effect of aerosols, as well as trying to retrieve their microphysical properties, analysis of aircraft and ground-based data, and understanding the difference between broadband and narrowband flux retrievals.

Research in atmospheric chemistry at GISS includes both near-term issues, such as air quality and ozone depletion, and the longer-term linkages between atmospheric chemistry and global climate.

GISS works cooperatively with area universities and research organizations, most especially with Columbia University. Almost half of GISS personnel are members of Columbia's Center for Climate Systems Research (CCSR) and also work with researchers at Columbia's Earth Institute and Lamont-Doherty Earth Observatory. Systems and programming support for GISS is provided by Sigma Space Partners, a joint venture of Sigma Space Corp. and SGT, Inc.

SEE ALSO: Bush (George W.) Administration; Climate.

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National Association of Energy Service Companies (NAESCO)

ESTABLISHED OVER 20 years ago, the National Association of Energy Service Companies (NAESCO) is a trade organization that encourages the widespread use of energy efficiency. On behalf of its members, NAESCO, based in Washington, D.C., attempts to open new markets for energy services. To reach this aim, the association promotes the importance of demand reduction to customers through seminars, workshops, training programs, and publication of case studies and guidebooks. As its chairm Buddy Hahs put it, "NAESCO's mission [is] to build market opportunities by encouraging customers and policy makers to rely on energy efficiency as the first energy priority. NAESCO has taken a leading role in establishing industry best practices and supporting its membership in the creation of tangible economic value." As an association interested in promoting energy efficiency, NAESCO is committed to fight against global warming and strongly supports the implementation of legislation limiting greenhouse gas emissions. Its representatives have been heard as witnesses in Senate committees dealing with the impact of global warming on the U.S. economy.

NAESCO wants to play a major role in devising innovative policies for a changing marketplace. It represents the various parts of the energy services industry and advocates for the cost-effective supply of inclusive energy services to all types of customers. In order to promote industry quality, NAESCO has organized a meticulous endorsement program for ESCOs (Energy Service Providers and Energy Efficiency Contractors) to identify capabilities and experience. The Association has the ambition to gather the broadest spectrum of market participants in the energy industry. Its membership includes about 75 companies that deliver over $4 billion of energy efficiency, renewable energy, and distributed generation projects across the United States every year. NAESCO also tries to go beyond American national boundaries, acting as a forum for energy service-providers from around the world on how to facilitate market opportunities. The association has members in Israel, China, and Mexico.

Far from believing that legislation on energy efficiency and greenhouse gas limitation will cause the U.S.

economy to slow down, NAESCO holds that energy efficiency can contribute to industrial competitiveness and employment growth. It believes that investments in energy-efficiency schemes will result in the creation of new job opportunities. In addition, institutions, such as schools, will be able to hire new staff thanks to the energetic savings. NAESCO also counters the line of reasoning claiming that the new jobs in energy efficiency will simply be replacements for jobs lost in energy production and distribution. According to the testimony of Donald D. Gilligan, NAESCO's President, before the Senate Committee on Environment and Public Works, in September 2007, the marginal job losses caused by energy-efficiency programs are largely going to be overseas. Gilligan argued that the United States is dependent on foreign sources for oil supply and for Liquefied Natural Gas for fuel used for heating and electrical generation.

He identified this dependency as a drain on American economy and a threat to national security. So reducing this dependency would benefit the whole country. Citing the National Action Plan for Energy Efficiency, Gilligan found that a national effort by utilities to invest about $7 billion a year in energy efficiency would leverage an additional $20-30 million of nonutility investment, which, in turn, would yield annual savings to consumers of about $22 billion in 2017, or a net present value of about $344 billion. Based on three different studies of job creation effects, Gilligan made a mid-point estimate, identifying the jobs created under the investment levels envisioned by the National Action Plan at about 298,000. The adoption of a large-scale energy-efficiency program would not entail a drastic reduction of energy-producing plants. In addition, the adoption of such scheme does not mean the discharge of skilled trade workers who are employed to build and maintain electric power plants and transmission and distribution systems. Finally, new job opportunities can be created by the research needs of the new energy production and generation technologies (widespread renewables, clean coal, nuclear fuel, oil from shale or tar sands). In conclusion, NAESCO believes that a major national commitment to energy efficiency and to greenhouse gas limitation, the cornerstones of all green initiatives, will create hundreds of thousands of high-skill, high-wage jobs, providing a substantial boost to the American national economy.

SEE ALSO: Energy; Energy, Renewable; Nuclear Power.

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National Center for Atmospheric Research (NCAR)

BASED IN BOULDER, Colorado, the National Center for Atmospheric Research (NCAR) provides the university community with the tools, facilities, and support required to perform innovate research. Through NCAR, scientists have access to high-performance computational and observational facilities, such as supercomputers, aircraft, and radar. These resources can be used to improve human understanding of atmospheric and Earth system processes. NCAR and university scientists collaborate on issues such as atmospheric chemistry, climate, cloud physics and storms, weather hazards to aviation, and interactions between the Sun and Earth. In all of these areas, scientists are looking closely at the role of humans in both creating climate change and responding to severe weather occurrences.

The core research of NCAR is based on the assumption that human activities are causing large-scale changes in the Earth system. The advances in scientific understanding, Earth system modeling, and computational and observational technology can shed new light on how the Earth system works. NCAR's activities contribute to the development of a predictive Earth system science that can help sustain Earth's habitability, improve environmental quality, safeguard human health, reduce the impacts of natural disasters, and increase economic productivity. This predictive Earth system becomes of particular importance in the face of global warming. The Climate and Global Dynamics Division of the Earth and Sun Systems Laboratory conducts broad-ranging research on all aspects of climate. The center explicitly connects global climate change, "whether it involves more heat or more cold, more precipitation or more drought," with "planetary warming." NCAR estimates that, since 1900, the Earth has warmed about 1 degrees F (about 0.6 degrees C). This warming of temperatures has various effects regionally. The center points out that scientists contributing to the 2007 International Panel on Climate Change predict changing precipitation patterns and retreating glaciers in Latin America, higher crop productivity in high-latitude regions, and sea-level rise along coastal regions. To lessen the insecurities about future climates, NCAR employs various tools and techniques, including climate models, radar and weather-balloon observations, satellite data, and so on, to understand the impacts of global and regional climate change.

NCAR has taken a clear stance on global warming, arguing that the data collected for more than 100 years on the Earth's surface temperature through a global network of land-based weather stations, supplemented by readings taken across the oceans, have shown a global rise in temperatures since the late 1800s. The center identifies human activities that amplify the natural greenhouse effect as "a major culprit." The NACR report on the topic states that "this warming of the average temperature around the globe has been especially sharp since the 1970s." The global models at NCAR have simulated 20th century climate and found three main factors at work. Solar activity contributed to a warming tendency in global average temperature in the first three decades of the last century. However, climate simulations at NCAR have shown that solar changes are accountable for less than a third of the warm-up during the last century. As industrial activity increased after World War II, Sun-blocking sulfates and other aerosol emissions helped lead to a slight global cooling up until the 1970s. Since 1980, the rise in greenhouse gas emissions from human activity has overwhelmed the aerosol effect to produce overall global warming. Thus, the most straightforward explanation for a warming Earth, NCAR states, is the greenhouse gases emitted when fossil fuels are burned in homes, gas and coal-fired power plants, vehicles, and factories. One of the objections of global warming skeptics is that some urban areas warm up due to the heat-island effect, because buildings and pavement retain more heat than undeveloped areas. NCAR scientists and researchers have made their estimates on global warming with particular attention to this heat-island effect. They have worked to remove and other potential biases from the global record. Even after these adjustments, they claim that the rise in global temperature remains clear.

NCAR lists other signs of a warming planet, such as retreating glaciers. Modeling by NCAR scientists has shown that, in the Arctic, the thickness and extent of summer sea-ice have decreased at a fast pace over the last 50 years. In addition, NCAR modeling has predicted that the Arctic's summer ice may virtually disappear by 2040. The increasing snowfall over Antarctica is, to NCAR scientists, a paradoxical sign of warming temperatures in this frozen land. The annual cycle of plants and migrating animals points to a expansion of the warm season over much of the Northern Hemisphere.

Reporting on the temperature in the troposphere several miles above Earth, NCAR states that satellites initially showed a smaller temperature rise at these heights than at ground level. Yet, it now seems that most of the disagreement was due to errors in the satellite data and how they was interpreted. There are still differences between tropospheric and surface warming in some regions, but NCAR researchers point out that a 2006 U.S. Climate Change Program report has cancelled the discrepancy on a global scale. NCAR is committed to the improvement of data-gathering, computer modeling, and analysis for studies of past, present, and future climate. For example, research at NCAR has focused on a re-examination of the role of decades-long cycles of solar variation in explaining the observed warming in the first half of the 20th century. NCAR researchers have identified another impact of humanity's increasing consumption of fossil fuels: the alterations in seawater chemistry as the oceans absorb more carbon dioxide. These alterations create a real danger to marine organisms, including those that build coral reefs around the world.

Many NCAR scientists are part of a global team studying global warming and its meaning for the Earth's future. In 2001, NCAR scientists estimated that increasing levels of greenhouse gases will warm the globe by a significant amount. They came up with a 90 percent likelihood that the range will fall between 3 and 9 degrees F (1.7–4.9 degrees C) over 1990 levels by the year 2100. NCAR researchers have concluded that the effects will be far more varied than a simple, uniform warming over the entire planet, because heating also alters the water cycle, among other changes. As a result, some regions will become considerably hotter or cooler, or wetter or drier, than others. NCAR scientists are working to improve understanding of potential regional changes in climate, such as the change in U.S. rainfall and snowfall patterns. Researchers are also working to translate temperature changes from a model into consequences that affect people's everyday lives. A 2004 NCAR study estimated that, by the period 2080–99, American and European heat waves will be more severe, frequent, and will last longer. A related study found that days in which temperatures dip to 32 degrees F (0 degrees C) will decrease in many parts of the globe by 2080–99. The biggest reductions are foreseen for the northwest parts of Europe and North America.

New research, in 2006, by NCAR scientists considered more specifically the possibility of an increase in weather extremes in a warmed climate. Employing simulations from nine different climate models, the researchers demonstrated the risk of dangerous heat waves, intense rains, and other kinds of extreme weather in the next century. NCAR studies have been used in preparing the 2007 Intergovernmental Panel on Climate Change assessment.

SEE ALSO: Bush (George W.) Administration; Climate.

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National Oceanic and Atmospheric Administration (NOAA)

THE NATIONAL OCEANIC and Atmospheric Administration (NOAA) is a scientific agency of the U.S. Department of Commerce, which studies the conditions of the oceans and the atmosphere. NOAA issues warnings of dangerous weather, charts seas and skies, guides the use and protection of ocean and coastal resources, and conducts research to improve understanding and preservation of the environment. NOAA is particularly active in the fields of climate change and global warming. In addition to its civilian employees, the NOAA Corps, staffed by 300 uniformed service members, support NOAA research and operations. The Undersecretary of Commerce for Oceans and Atmosphere at the Department of Commerce, retired Navy Vice Admiral Conrad C. Lautenbacher, serves as the director for NOAA.

NOAA's main aim is to contribute to the creation of "an informed society that uses a comprehensive understanding of the role of the oceans, coasts, and atmosphere in the global ecosystem to make the best social and economic decisions." The agency's mission is "to understand and predict changes in the Earth's environment and conserve and manage coastal and marine resources to meet our nation's economic, social, and environmental needs." NOAA supports its mission through the pursuit of four targets that form the

A tornado photographed in Oklahoma by the National Severe Storms Laboratory, part of the scientific agency NOAA.

guiding principles of its operations. Each of them corresponds to activities focusing on ecosystems, climate, weather and water, and commerce and transportation. NOAA encourages the sustainable use of resources and the balance among competing uses of coastal and marine ecosystems, which recognize both their human and natural components. NOAA works to understand changes in climate, including global climate change and the El Niño phenomenon, to ensure that societies can respond and adapt properly to climate change. It provides data and forecasts for weather and water-cycle events, including storms, droughts, and floods. Finally, NOAA gives weather, climate, and ecosystem information to make sure individual and commercial transportation is safe, efficient, and environmentally sound.

NOAA was created in February 1970, within the Department of Commerce, combining the Bureau of Commercial Fisheries, Weather Bureau, Coast and Geodetic Survey, Environmental Data Service, National Oceanographic Data Center, National Satellite Center, Research Libraries, and other components. Although NOAA was officially created in 1970, the different bureaus that merged into it were among the oldest in the Federal Government: the Coast and Geodetic Survey was formed in 1807, the Weather Bureau in 1870, and the Bureau of Commercial Fisheries in 1871. President Richard Nixon proposed creating a new department to serve a national need "for better protection of life and property from natural hazards … for a better understanding of the total environment … [and] for exploration and development leading to the intelligent use of our marine resources…."

NOAA's offices and divisions play an important part in various aspects of American national life. The National Ocean Service (NOS) has been a leading institution in the introduction of electronic nautical charts that, together with GPS, have enhanced the safety and efficiency of navigation. NOS has also played a leading role in advocating coastal and ocean stewardship. As the trustee for 12 marine protected areas, NOAA protects National Marine Sanctuaries, which are akin to national underwater parks. Each sanctuary has a unique goal, from protecting the breeding ground of humpback whales, to preserving the remains of historical shipwrecks, or coral reef colonies. Through the sanctuary program, a growing number of partners and volunteers embrace NOAA's ocean mission to preserve, protect, and respect our nation's marine environment.

Thanks to NOAA's cooperative weather observers, including a network of more than 10,000 National Weather Service (NWS) volunteers across the country, the agency can continue to take daily weather measurements that become part of U.S. climate records. This is a tradition that goes back to Thomas Jefferson and the times before the American revolution. These records, along with other records from the NWS, U.S. Navy, U.S. Air Force, the Federal Aviation Administration, and meteorological services around the world, are housed at the National Climatic Data Center in Asheville, North Carolina. The center is the largest active archive of climate data in the world, and is part of NOAA's National Environmental Satellite, Data, and Information Service (NESDIS). In addition to the climate center, NESDIS also manages the National Geophysical Data Center in Boulder, Colorado, and the National Oceanographic Data Center in Silver Spring, Maryland. National and international users access these data to study how climate and environment are changing.

NOAA's satellite operations grew out of the space program and the desire to study our earth from a vantage point. NOAA's satellites have evolved from weather satellites to environmental satellites. Data are used for applications related to the oceans, coastal regions, agriculture, detection of forest fires, detection of volcanic ash, monitoring the ozone hole over the South Pole, and the space environment.

The NWS uses complex technologies such as Doppler radar, automated surface-observing systems, sophisticated computer models, high-speed communications systems, flying meteorological platforms, and a highly-trained and skilled workforce to issue more than 734,000 weather, and 850,000 river and flood forecasts, and between 45,000 and 50,000 potentially life-saving severe weather warnings annually. The Weather Service has also developed the Advanced Weather Interactive Processing System, the final piece of technology in a $4.5 billion modernization program to improve climate, water, and weather products and services that help protect life and property, and increase economic growth. It was estimated that the NWS's accurate, long-range predictions for the 1997–98 El Niño episode, helped California prevent about $1 billion in losses.

NOAA's National Marine Fisheries Service takes a rational, scientific approach to the difficult, contentious issues of living marine resource management. NOAA

Fisheries Service advocates the sustainable use of living marine resources, seeking to balance competing public needs and interests in the use of those resources, while protecting their biological integrity. Two recent examples are represented by international and domestic actions to rebuild swordfish stocks, working with both industry and conservationists; and developing an innovative, long-term strategy for restoring threatened and endangered salmon in the Pacific Northwest.

NOAA's Office of Oceanic and Atmospheric Research (OAR) establishes cooperative projects between its scientists and their university partners to better understand the Earth. OAR is the theoretical base that allows better weather forecasts, longer warning lead-times for natural disasters, new products from the sea, and a greater understanding of our climate, atmosphere, and oceans. NOAA research is done both in traditional laboratories, and also aboard ships, on planes, and beneath the sea. NOAA research tools can be as high-tech as supercomputers or as basic as rain gauges. Officers of the NOAA Corps, the smallest of the seven uniformed services of the United States, operate NOAA's fleet of research vessels and aircraft.

As the ultimate goal of all NOAA's activities is to predict environmental changes on a wide range of time and space-scales, to protect life and property, and provide industry and government decision-makers with a reliable base of scientific information, most of the agency's researches and programs are increasingly focusing on global warming and climate change. NESDIS data centers are extremely important in answering some of the most pressing global change questions that remain unresolved. The National Climatic Data Center contains the instrumental records that can measures the nature of climatic fluctuations at timescales of a up to a century. The National Oceanographic Data Center provides the subsurface data, which portray the ways heat is distributed and redistributed over the planet. Knowing how these systems are changing, and how they have changed in the past, is crucial to allow predictions of how they will change in the future. And, for climate information that extends from hundreds to thousands of years, the paleoclimatology program, also at the National Climatic Data Center, helps to provide longer-term perspectives.

The most significant effort in the research on global warming and climate change is NOAA's international Tropical Ocean-Global Atmosphere (TOGA) program, which officially began in 1984. This program aims to understand the role that the tropical Pacific Ocean plays in producing climate changes over North America. The principal focus of the program is the El Nino-Southern Oscillation, two phenomena that when coupled can cause dramatic changes in climate pattern amd result in major damage. NOAA has established a monitoring network and computer-modeling capability, which will allow scientists to recognize the early signals of the phenomenon so they can be predicted. This predictive capability is a priority for the agency as it will avert economic damages and will also be one of the most significant contemporary scientific achievements.

NOAA's research, since the 1980s, has also played a key role in the area of longer-term climate changes and air quality. Building on a strong tradition of research in atmospheric chemistry, in 1985, NOAA started the Radiatively Important Trace Species (RITS) research program. NOAA had already been researching the causes and potential effects of carbon dioxide on the Earth's climate, the so-called "greenhouse warming. In the early 1980s, however, NOAA provided the scientific community with a fuller picture by identifying other so-called "greenhouse gases," such as methane and the chlorofluorocarbons which are becoming increasingly central in debates over stratospheric ozone depletion. NOAA scientists have calculated that the global greenhouse warming from these gases could be as great as that expected from carbon dioxide. NOAA was among the first institutions to investigate the reasons for the increasing levels of these gases and predict the potential climatic and chemical consequences of such changes. The RITS program remains the principal coordinated agency response to this scientific challenge and environmental problem.

In 1986, NOAA led an Antarctic Ozone Expedition to McMurdo Base to investigate the Antarctic ozone hole. The results showed highly-elevated abundances of reactive chlorine compounds, reduced levels of nitrogen oxides, and 40 percent depletion of ozone at 7–12 mi. (12-20 km.) altitude. Because the cause of the ozone hole had not been defined with certainty, NOAA also led a second expedition in 1987, and a NOAA scientist was also selected as mission scientist for an interagency aircraft observation program to fly through the ozone hole in 1987. More recently, the Paleoclimatology Program has provided the paleoclimate data and information needed to contruct interannual to centennial-scale environmental change. This research proved the importance of understanding past climates to understand global warming, and, through paleoclimate data, provided a long baseline of past change. This long baseline revealed the natural variability of Earth climate, and illustrated how climate and greenhouse gases have changed in the past. The Paleoclimatology Program also began to shed some light on several disputed global warming issues, such as the extent of anthropogenic responsibility for greenhouse gases emissions, the future levels of warming, and the other changes that will occur with future warming. The Program's estimate is that about 50 percent of the observed global warming is due to greenhouse gas increases. The paleoclimatic record shows how much temperature change occurred in the past when carbon dioxide levels were different. Studies explain that the 100 parts per million (ppm) reduction in carbon dioxide during the last glacial era was followed by a 5.4 degree F (3 degrees C) cooling in the western tropical oceans. This amount of temperature change is consistent with the change predicted by numerical climate model simulations. Changes at higher latitudes were much larger, and included the formation of large ice sheets. Studies of the glacial world demonstrate that many aspects of climate were different when carbon dioxide was reduced, including lower sea level, lower snowlines, and altered patterns of circulation. Starting from these studies, NOAA scientists predict that other aspects of the climate, in addition to temperature, will change with future warming.

NOAA plays a crucial role as the Federal Government's principal operational climate observing, prediction and information management center. These activities characterize NOAA's unique role and contribution to an evolving national and international scientific program to understand and predict natural and anthropogenic changes in the global environment. Together with the other principal U.S. participants in these efforts, the National Aeronautics and Space Administration and National Scientific Foundation, NOAA has recognized the importance of focusing on the global climate system, because changing climate has far-reaching economic, health and safety, and national security consequences. NOAA programs in oceanic and atmospheric observations, monitoring, data processing, research, predictive modeling, and information management contribute to advancing our understanding of phenomena related to global warming and climate change.

SEE ALSO: Climatic Data, Atmospheric Observations; Climatic Data, Oceanic Observations.

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National Science Foundation

THE NATIONAL SCIENCE Foundation (NSF) is a U.S. government agency that supports research and education in science and engineering. The agency was created by Congress in 1950 "to promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense." With an annual budget of about $5.91 billion, the NSF funds approximately 20 percent of all federally-supported research conducted by U. S. colleges and universities. In some fields, such as mathematics, computer science, economics, and other social sciences, NSF is the major source of federal funding. NSF has funded several important studies in the area of global warming.

The President of the United States appoints the NSF's director, its deputy director, and the 24 members of the National Science Board (NSB), who are then confirmed by the Senate. The director and deputy director are responsible for administration, planning, budgeting and day-to-day operations of the foundation, while the NSB holds six meetings per year to establish its overall policies. The NSF is unlike other U.S. government agencies, in that it does not operate its own laboratories, but seeks to fulfill its mission mainly through competitive, limited-term grants, in response to specific proposals from the research community. NSF receives about 40,000 proposals each year, and funds about 10,000 of them. The projects that receive funding are selected in a merit review process carried out by panels of independent scientists, engineers, and educators who are experts in the relevant fields of study. These are selected by NSF with particular attention to avoid conflicts of interest;

for example, no-one of the reviewers can work for the institutions whose project is under examination.

NSF grants typically go to individuals or small groups of investigators who carry out research at their academic institutions. Other grants provide funding for mid-scale research centers, as well as instruments and facilities that are useful to researchers from different bodies. Finally, there are grants that fund national-scale facilities shared by the research community as a whole. Examples of national facilities include NSF's national observatories, with their giant optical and radio telescopes; its Antarctic research sites; its computer facilities and ultra-high-speed network connections; the ships and submersibles used for ocean research; and its gravitational wave observatories. In addition to research and research facilities, the NSF supports sciences through education grants from pre-Kindergarten through to post-graduate work.

NSF's workforce is made up of about 1,700 employees, nearly all working at its Arlington, Virginia, headquarters. That includes about 1,200 career employees, 150 scientists from research institutions on temporary duty, 200 contract workers, and the staff of the National Science Board office and the Office of the Inspector General, which examines the foundation's work and reports to the NSB and Congress. NSF is divided into seven directorates that fund science and engineering research and education: Biological Sciences; Computer and Information Science and Engineering; Engineering; Geosciences; Mathematics and Physical Sciences; Social, Behavioral and Economic Sciences; and Education and Human Resources. An assistant director heads each section which is further divided into smaller units such as materials research, ocean sciences and behavioral and cognitive sciences. Some of the divisions within the NSF's Office of the Director are also involved in supporting research and researchers. These include the Office of Polar Programs, the Office of Integrative Activities (covering a wide-range of activities), the Office of International Science and Engineering, and the Office of Cyberinfrastructure. The NSF also has offices charged with financial management, award processing and monitoring, legal affairs, outreach and other functions.

According to David M. Hart, the NSF was the result of an unsatisfactory compromise among too many contrasting visions of the purpose and scope of the federal government. In the years following its foundation, the agency was superseded in importance by the more-specialized agencies established because of the postwar anxieties in the fields of medical research (National Institutes of Health), nuclear energy (U.S. Atomic Energy Commission), space science (National Aeronautics and Space Administration) and defense-related research (Defense Advanced Research Projects Agency). With the end of the Cold War, however, NSF gained importance and acquired new fields of research that were not included in its original mission. Now the Foundation is the federal agency with the largest mandate, acting as a support for all scientific fields, except for medical research. The technological boom of the 1980s was another important factor in increasing the NSF's prestige. The awareness that scientific and technological research was necessary to keep the United States a safe and competitive nation ensured strong bipartisan support in Congress for the NSF. Its growing prestige is mirrored in its budget, which has increased from $1 billion in 1983, to the current $5.91 billion.

The grants and projects provided by the NSF have contributed significantly to technological advancement. For example, NSF-funded research helped to develop the internet as well as Mosaic, the first freely-available internet browser that allowed users to view World Wide Web pages with both texts and images. It has also launched the Digital Library Project to extend and develop digital library methods and technologies.

Several important projects funded by the NSF have dealt with issues related to global warming. It's interest in ozone depletion dates back to the mid-1980s when it supplied researchers at the South Pole with ozone sensors, along with balloons and helium, to measure stratospheric ozone loss. The action was taken due to data forecasts of a steep drop in ozone over a period of several years. In 1996, NSF-funded research led to the conclusion that the chemistry of the atmosphere above Antarctica is apparently abnormal, and that levels of key chlorine compounds are extremely high. NSF researchers contributed to further understanding and awareness about the ozone hole. In 2004, researches focused on the potential impact of global warming on high-altitude plants and animals. NSF researchers concluded that large-scale climate change (warming temperatures, receding glaciers, and the loss of permanent snowfields) could lead to a loss of many species of birds and plants. In the same year, researchers also assessed the potential of dissolved carbon in the Arctic ocean for the process of global warming. The international team of scientists concluded that most of that carbon was fairly young and not likely to affect the balance of global climate. Yet, they still cautioned that a well-documented Arctic warming trend could result in ancient carbon, a reservoir of the gas currently locked into peat bogs, being released and added to the mix contributing to the warming trend. Researchers stressed that, under the current warming trends in the Arctic, more of the old carbon would enter the carbon cycle as carbon dioxide. This would increase the greenhouse effect and accelerate global warming. This was the first time that gases trapped in the bogs were accounted for in climate change models.

In 2006, a joint research of NSF and Scripps Institution of Oceanography found out that global climate change may have quickly disrupted ocean processes and led to drastic shifts in environments around the world. Although the researchers were concerned mainly with a warming trend that took place over 55 million years ago, known as the Paleocene/Eocene Thermal Maximum (PETM), their data were relevant to the contemporary warming trend. The results of the research indicated that deep-ocean circulation in the Southern Hemisphere abruptly stopped the conveyor belt-like process known as overturning, in which cold and salty water in the depths exchanges with warm water on the surface. This process became active in the Northern Hemisphere, causing a shift of unusually warm water to the deep sea, likely releasing stores of methane gas that led to further global warming and a massive die-off of deep-sea marine life. The researchers further stated that modern carbon dioxide input from fossil fuel sources to the Earth's surface was approaching the same levels estimated for the PETM period, and they claimed that this should raise concerns about future climate and changes in ocean circulation. Thus, the Paleocene/Eocene example suggests that human-produced changes may have lasting effects not only on global climate, but on deep ocean circulation. Richard Norris, one of the leading researchers on the team, went as far as stating that "the case described here may be one of the best examples of global warming triggered by the massive release of greenhouse gases. It gives us a perspective on what the long-term impact is likely to be of today's human-caused warming."

One of the most recent NSF-sponsored research studies carried out by climate modelers at the National Center for Atmospheric Research found out that, despite efforts to reduce greenhouse gas emissions, global warming and a greater increase in sea level are inevitable during the 21st century.

SEE ALSO: Climate; Sea Level, Rising.

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Natsource

NATSOURCE-TULLET (NATSOURCE) IS an international company based in Alberta, Canada. It is one of many international companies that respond to the needs of governments and corporations for assistance in meeting the demands of global greenhouse gas (GHG) emissions reduction policies. There are three major branches of Natsource business: Advisory Services, Transaction Services, and Asset Management Services. Advisory Services assist in developing policies whereby markets are created for GHGs and air pollutants. Additionally, the company advises clients on the impact of potential policies. Transaction Services assist interested parties in establishing a route for transactions for trading environmental goods and renewable energy. Finally, Natsource Asset Management (NAM) services manages the Greenhouse Gas Credit and Aggregation Pool (GG-CAP), which closed in 2007, holding commitments from 26 parties valued at greater than $550 million. Additionally, NAM oversees Aeolus, which is a series of on-shore and offshore funds.

NAM's GG-CAP is the first private sector plan to assist global nations in meeting GHG emissions standards. The European Union Emissions Trading Scheme and the Kyoto Protocol have set the major emissions-reduction standards. While meeting these reductions will ultimately protect the environment and industry for a longer period of time than current standards would. Meeting them requires great financial commitment, which may be a burden to some developing countries. Therefore, the GG-CAP established a pool of capital that will be used to buy and trade emissions-reductions credits. Thus, a company with emissions under the standards can sell its extra credits to another company that is struggling to meet standards. These extra credits would be at a lower cost to the purchasing company than the restructuring needed to meet the standards. The principle behind this trade is that the selling company is rewarded for exceeding standards, and the purchasing company is given extra time to meet those standards, without penalty. Overall, the same net amount of emissions is effectively released, as if the two companies had both met standard allowances.

The Natsource Asset Management Services (NAM) is based in the Calgary office; other offices around the globe are located in La Paz, Bolivia; London; New York; Ottowa; Tokyo; and Washington, D.C. Each office is situated to address specific regional concerns in an international context. For example, the La Paz office manages Latin American interests and monitors carbon dioxide emissions reductions in this region, while the London office manages the interests of the United Kingdom and in Europe.

The New York office focuses on international efforts; the Washington, D.C., office works to engage all levels, such as corporations, governments, and other institutions, in policymaking. The Ottowa office houses Natsource's Global Change Strategies International (GCSI). The purpose of GCSI is to provide consultation regarding climate change and other broad environmental issues. Finally, the Tokyo office serves Japanese corporations.

SEE ALSO: Cantor Fitzgerald EBS; Economics, Cost of Affecting Climate Change; Economics, Impact From Climate Change; Greenhouse Gases; Policy, International.

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Natural Gas

NATURAL GAS IS a fossil fuel existing in deposits in the Earth over wide regions of the globe. It is composed of hydrocarbons, which are molecules of hydrogen and carbon of up to five different combustible gases, and traces of other gases such as nitrogen, hydrogen sulfide, carbon dioxide, and helium. The type of hydrocarbon gas depends on the number of carbon atoms in the molecule. Methane is the primary gas of natural gas, having just one carbon atom per molecule. As a result, it is the cleanest burning fossil fuel, with less carbon than the equivalent amount of oil or coal. The greenhouse gases of natural gas are methane, carbon dioxide (CO_2), and minor amounts of nitrous oxide.

The combustion of natural gas releases CO_2 and nitrous oxide. Combustion is a rapid form of oxidation in which carbon will bond with oxygen as carbon dioxide or carbon monoxide. Gasoline is not natural gas, but is instead refined from oil. By contrast, gasoline has 8–11 carbon atoms, so produces more CO_2 per unit of energy. Therefore, using natural gas as a fuel, from a greenhouse gas point of view, is better than other fossil fuels. However, this does not take into account cost and practicality. CO_2 by volume is not considered as significant a greenhouse gas as methane. Methane is reported as 21 times stronger in its entrapment of heat in the atmosphere. Methane in the atmosphere has other sources besides natural gas. Living organisms, such as livestock, are considered major sources of methane in the atmosphere.

Natural gas exists in large portions of the globe. In many regions, it is trapped as large deposits in rocks deep beneath the Earth's surface. It is also found in deposits of crude oil and coal, and in ice crystals in permafrost regions. Natural gas is found at shallow depths, less than 100 ft. (30 m.), to depths of over 20,000 ft. (6,096 m.) Shallow depth gas is typically biogenic gas, meaning generated by the bacterial decay of organic matter. It is generated over a relatively short period of time. Methane from landfills and swamps are examples of biogenic gas. Another type of shallow depth natural gas is hydrates—gas trapped in ice crystals in permafrost.

THE INCREASING VALUE OF NATURAL GAS

Most of the natural gas produced is trapped in rock formations that are millions of years old and at depths much deeper than the shallow-biogenic type. The market for natural gas has developed recently, relative to the history of the oil industry. For many years, it was regarded as a nuisance because necessary pipelines did not exist and could not be justified financially. Therefore, discoveries of gas in the search for oil were abandoned, and when gas was produced as a co-product from oil wells, it was ignited and flared for safety reasons. Natural gas is now regarded as a valuable commodity and only minor amounts are flared or lost to the atmosphere. Markets have developed and demand is strong and growing. The primary transportation of natural gas is by pipeline, and because of higher prices, smaller deposits of gas can justify drilling and laying a pipeline. In addition, a rapidly-developing transportation mode for natural gas is by tanker in liquefied form. Large volumes can be pressurized and moved on the high seas to coastal terminals where pipelines then move the gas to consumers. Natural gas is now a global commodity.

The increased value also spurs exploration for new deposits at depths of 4 mi. (6.4 km.), and the development of nontraditional sources, such as from landfills and coal seams. The production of natural gas from coal beds, known as coal bed methane, is through wells drilled into the coal. This same gas has been the source of coalmine explosions when not properly ventilated. The production of coal bed methane can reduce the eventual release of methane to the atmosphere through mining operations. The production of natural gas from hydrates is not a reality yet, for technical and economic reasons. Ironically, the methane in gas hydrates of tundra regions may be released by global warming. The permafrost is thawing in some areas. This will release the gas trapped in ice crystals to the atmosphere. In this instance, global warming becomes the culprit in creating greenhouse gas.

Most of the methane in the atmosphere is the result of living organisms such as livestock, and not natural gas. Natural gas is sequestered in the Earth until released through production into a pipeline or other vessel. It enters the atmosphere in raw form or as CO_2 and nitrous oxide from combustion. While the greenhouse gases released are in lesser amounts than from burning other hydrocarbons, the concern is for the enormous volumes of natural gas being produced and, therefore, the enormous amount of CO_2emitted. Natural gas has been forming for millions of years; the first organisms on Earth are thought to be more than 600 million years old. These organisms, if buried before decay, can generate natural gas through a maturation process in the absence of oxygen. If not buried, they oxidize in the atmosphere and release gases at that time. The natural gas produced today literally represents a deposit of greenhouse gas that was not spent at the time the organism died. So, millions of years of saved deposits of greenhouse gas are now being released at a rapid and accelerating rate with the popularity of natural gas as a clean, efficient burning fuel.

Based on trapped gases in ice cores in Antarctica, there has been a dramatic increase in greenhouse gases in the global atmosphere since the beginning of the Industrial Revolution. Samples indicate that in the last 200 years, CO_2 has increased by 35 percent, methane by 600 percent, and nitrous oxide by 18 percent. Data for CO_2 suggest that about 100 years ago there was an increase in the growth rate of atmospheric concentration, followed by another rate increase beginning about 50 years ago, when the world consumption of hydrocarbons, combined oil and gas, surpassed coal in energy content.

SEE ALSO: Carbon Dioxide; Carbon Emissions; Coal; Greenhouse Gases; Oil, Production of.

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Natural Resources Defense Council (NRDC)

THE NATURAL RESOURCES Defense Council (NRDC) describes itself as "the nation's most effective environmental action organization," and indicates that the world's foremost environmental problem is global warming. In 2007, the NRDC was a founder and organizer of the U.S. Climate Action Partnership, a coalition of environmental organizations and corporations advocating legislative action to address global warming. Incorporated in New York in 1970, the NRDC also has offices in Los Angeles, San Francisco, Washington, D.C., Chicago, and Beijing. Frances Beinecke was named president in January 2007.

According to its mission statement, the NRDC strives "to protect nature in ways that advance the long-term welfare of present and future generations." In addition to affirming the "integral place of human beings in the environment," and decrying the "pattern of disproportionate environmental burdens borne by people of color and others who face social or economic inequities," it emphasizes a way of life "that can be sustained indefinitely without fouling or depleting the resources that support all life on Earth." The group began as a public interest lobbying organization funded by the Ford Foundation, and now focuses on litigation and legislation involving protection of the environment. Its program foci include Health, Nuclear, Land and Forests, Urban, Climate, Air and Energy, Water and Oceans, International, Market Transformation, Advocacy Campaigns, and Legislation and Litigation.

NRDC has frequently appeared before the U.S. Supreme Court, and has been involved in federal, state, and local litigation. NRDC was partially responsible for passage of the Clean Water Act, which allowed citizens to sue water polluters directly. Removal of lead from gasoline and the increase of energy efficiency in home appliances have also resulted from NRDC's actions. A 1976 court battle resulted in limitations on water pollution for 24 major industries, and, in 1978, a successful lawsuit cut sulfur dioxide emissions by a million tons annually. Legal action, in 1984, forced the U.S. Department of Energy's nuclear weapons facilities to comply with environmental laws. Two other lawsuits forced major corporations, Bethlehem Steel in 1987, and ARCO and Texaco in 1993, to pay stiff fines for water pollution.

In October 2007, 11 of its 160 program staff members worked in its Climate Center. Invited by the U.S. House to testify on global warming legislation, the NRDC responded with substantial scientific data and an offer to work with the government on solutions "to prevent the worst global warming impacts, meet other objectives such as reducing our oil dependence, and promote continued strong economic growth." The NRDC helped craft and pass California's landmark Global Warming Solutions Act that requires substantial reduction of greenhouse gas (GHG) emissions. It also was a party to the *Massachusetts vs. EPA* case, in which the Supreme Court, in 2007, affirmed the EPA's ability to regulate GHG emissions. The group also gives attention to the social effects of global warming.

The NRDC funded a 2006 study, by the Institute for Lifecycle Environmental Assessment, which determined that producing and burning ethanol is better for the environment than producing and burning gasoline, and that celluosic ethanol has a substantial advantage over corn ethanol. The NRDC's suggested program for cutting GHG emissions by more than half (with approximate percentages of total reductions) involves boosting energy efficiency (41 percent), building better cars (24 percent), increased use of renewable and biofuels (19 percent), and scrubbing carbon from fossil fuels (16 percent).

The NRDC spends 80.3 percent of its budget on its programs and services, and uses 8.1 percent of its functional expenses on administrative costs. The group uses 11.5 percent of its expenses to raise funds, and spends 9 cents to raise each $1 it receives. NRDC has five top administrators, and over 300 employees. In 2005, its then-president, John Adams, received $297,140 in compensation, which was .51 percent of the group's total expenses. According to the Better Business Bureau, the NRDC meets the Standards for Charity Accountability.

SEE ALSO: Environmental Defense; Nongovernmental Organizations (NGOs); World Resources Institute.

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Nauru

THE REPUBLIC OF Nauru, located in the Pacific, has a land area of 8.1 sq. mi. (21.2 sq. km.), a population of 10,000 (2006 est.), and a population density of 1,608 people per sq. mi. (621 people per sq. km.). With very little arable land, Nauru is completely dependent on imported food and water. Nauru makes its money from the sale of phosphate, which has led to the destruction of much of the country, and during the 1970s and 1980s, incredible wealth. Electricity production in Nauru comes from fossil fuels, with Nauru contributing heavily, relative to its size, to global warming and climate change. In 1990, its carbon dioxide emissions were 13.9 metric tons per capita, falling to 10.8 metric tons per capita by 1992, and rising to 14.2 metric tons per capita in the following year.

The effect of global warming and climate change will be dramatic for Nauru. With much of the island physically removed by the phosphate industry, the likelihood of massive water inundation is high. Many of the coral reefs off the coast of Nauru have experienced coral bleaching, and with the money from phosphate significantly reduced during the 1990s and 2000s, the country has faced major environmental problems.

The Nauru government of Bernard Dowiyogo took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992. The government of René Harris ratified the Kyoto Protocol to the UN Framework Convention on Climate Change on August 16, 2002, and it took effect on February 16, 2005. However, Nauru added an extensive addendum to its signing of the Kyoto Protocol stating that "in the light of the best available scientific information and assessment of climate change and impacts, it [the government of Nauru] considers the emissions and reduction obligations in Article 3 of the Kyoto Protocol to be inadequate to prevent the dangerous anthropogenic interference with the climate system."

SEE ALSO: Alliance of Small Island States (AOSIS); Floods; Kyoto Protocol.

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THE U.S. NAVY was established on October 13, 1775, with the Department of the Navy founded on April 30, 1798. While the mission of the U.S. Navy is to "maintain, train and equip combat-ready naval forces capable of winning wars, deterring aggression and maintaining freedom of the seas," it also serves to provide important astronomical information to scientists and analysts. Given its handling of vast quantities of hazardous chemicals and environmentally-dangerous substances, the Navy recognizes its responsibility to the local and greater environments and makes efforts to remain environmentally conscious.

One example of Naval efforts to study the effects of environmentally-hazardous materials took place in 2007. The U.S. Navy participated in a joint research effort to investigate the effect and impact of aerosols on global warming and climate change. The mission was called UAE2 (United Arab Emirates Unified Aerosol Experiment), took place in the Arabian Desert, and joined scientists from the Naval Research Laboratory (NRL), the National Aeronautics and

In addition to the Navy's own research, it delivers supplies annually to research scientists at McMurdo Station, Antarctica.

Space Administration (NASA), and the Scripps Institution of Oceanography. Aerosols are tiny airborne particles, which naturally contribute to cloud formation and, therefore, rainfall. They can be classified as light or dark. Lighter aerosols reflect sunlight and heat; therefore, they have a cooling effect on the atmosphere. Darker aerosols, however, trap sunlight and heat within the atmosphere, causing the temperature to rise.

Additionally, the U.S. Navy maintains equipment that can be used by scientists to study extreme weather conditions. This equipment, while intended for other purposes, has characteristics that can be taken advantage of by researchers. For example, the Navy has two major types of submarines: the TRIDENT ballistic missile submarine, and the Attack submarine that is less encumbered by large, bulky weapons and can travel into most waters, including those of the Arctic Ocean. The Attack submarines have been used for years by researchers, taking scientists to the Arctic waters to collect data regarding global warming. Such data include ice sheet thickness, water temperature at increasing depths, and other variables.

The Navy also has an undersea surveillance that can be used to collect data regarding global warming. This system is called SOSUS, the Sound Surveillance System. It is part of IUSS, the Integrated Underwater Surveillance System, and passively senses acoustic data that can be analyzed to monitor underwater activity of ships, as well as animals and other environmental components.

The U.S. Navy uses many pieces of equipment; each piece requires a significant amount of energy. As a major consumer of energy and fuels, the Navy makes efforts to reduce its fuel and energy consumption and to use cleaner fuel and energy options. For example, in Crane, Indiana, Team Crane consists of the Naval Facilities Engineering Command Midwest and the Public Works Department at the Naval Surface Warfare Center Crane Division. Team Crane uses a fuel that is 80 percent biodiesel and 20 percent soybean oil; the fuel is called B-20 and comes from the Indiana Soybean Board. Plans are under way to convert all the diesel-burning equipment at Crane to B-20 utilizing equipment. The base at Crane is not the only naval station that practices environmental responsibility.

AWARDS

To foster environmental stewardship, the Navy gives annual awards to those who exhibit exemplary environmental responsibility and awareness. For example, the Secretary of the Navy honors ships annually with the Secretary of the Navy Environment Quality Award. This award recognizes a ship's responsibility and leadership in environmental stewardship. The principal factor in this stewardship is the ship's storage, handling, and disposal of environmentally-hazardous material. Examples of systems on ships to handle hazardous material include those for dealing with trash, sewage, and incinerations of these materials. Additionally, a ship may actively avoid interfering with any visible marine life.

The Chief of Naval Operations Environmental Quality Award recognizes naval stations that follow environmental requirements to protect both the local environment and people. In 2003, then Public Works Environmental Division Director Tim Riordan outlined the environmental concerns at naval stations: "... a range of programs, including air emissions, drinking water, hazardous materials, hazardous waste, historic and cultural resources, and natural resources and endangered species, to name a few."

ORGANIZATION OF THE NAVY

The Navy has three main branches: the Navy Department, the operating forces, and the shore establishment. The Navy Department is mostly located in Washington, D.C.. The operating forces include the Coast Guard (in times of war), the Marine Corps, and the naval reserve (during peace, the U.S. Coast Guard is managed by the Department of Homeland Security). The Secretary of the Navy oversees the Chief of Naval Operations and the Commandant of the Marine Corps. The Chief of Naval Operations oversees the shore establishment and the naval operating forces, while the Commandant of the Marine Corps oversees the Marine operating forces. Finally, the two operating forces can work together and provide support to one another. The shore establishment includes all land-based personnel who support the system of naval ships, termed the fleet. These offices include the Naval Facilities Engineering Command, the Naval Meteorology and Oceanography Command, and the U.S. Naval Observatory.

The U.S. Naval Observatory is among the longest-standing scientific institutions in the United States. It has been in operation since 1830, when it was called the Depot of Charts and Instruments. It operates from its Washington, D.C., headquarters, as well as an observatory in Flagstaff, Arizona, and a Master Clock facility for the United States, based in Colorado Springs, Colorado. The Naval Observatory also manages the Lieutenant James Melville Gilliss Library, which houses an impressive astronomical literature selection. The Naval Observatory serves to collect and transmit invaluable astronomical information, such as the orientation of the Earth.

SEE ALSO: Air Force, U.S.; Department of Defense, U.S.; National Aeronautics and Space Administration (NASA); Scripps Institute of Oceanography.

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Nebraska

NEBRASKA IS MADE up of a combination of mountain rages and high plains. The state has an area of 77,354 sq. mi. (200,346 sq. km.), with inland water making up 481 sq. mi. Elevations range from 840 ft. (1,246 sq. km.) above sea level on the Missouri River, to 4,424 ft. (1,348 m.) at Kimball County in Western Nebraska (the southwest corner of the panhandle). Nebraska can be divided into three geographic zones. Eastern Nebraska has many rivers, salt marshes, and grassland. Central Nebraska is flat in the south with the Platte River and the sand hills in the north with shallow lakes. A dam holds back the North Platte River, forming Lake McConaughy, the largest lake in the state. Western Nebraska, the Panhandle, has the highest in elevation of all of Nebraska, and is windy. Nebraska is drained by the Missouri River system.

Nebraska's climate experiences light snow, low humidity, hot summers, and cold winters. Warm, moist air flows from the Gulf of Mexico, while hot, dry air travels from the southwest, and cool, dry air currents flow from the northern Pacific Ocean and northwest Canada. The Rocky Mountains limit moisture from the west. Annual precipitation in the eastern third of the state averages 27 in. (69 cm.), in the central third 22 in. (56 cm.), and in the western third 18 in (46 cm.). An excessive rate of rainfall is frequent during summer thunderstorms. Floods occur in the eastern third of the state, as do tornadoes. Average snowfall normally ranges from about 20–40 in. (51–102 cm.), with the heaviest snows in late winter. Severe weather is common, from blizzards, to damaging winds, hail, and torrential rain.

Underneath central and western Nebraska is the largest aquifer in the world. Ogallala Aquifer lies underground beneath eight states, including Nebraska. The aquifer was named for the town of Ogallala in 1899. The level of water in the aquifer has been dropping steadily for decades and farmers are now trying to conserve this water by practicing conservation in irrigation. The rate of depletion has not stopped the dropping level of water, but it has slowed. Agriculture is a major economic concern, especially corn, livestock, soybeans, and sugar beets.

IMPACT OF CLIMATE CHANGE

During the Great Flood of 1993, natural disaster rain and snow runoff raised the Missouri river to flood stage and devastated southeastern Nebraska. While climate models vary on the amount of temperature increase possible, potential risks include decreased water supplies; increased risk of wildfires; changes in food production, with agriculture improving in cooler climates and decreasing in warmer climates; change in rain pattern to downpours with the potential for flash flooding; health risks of certain infectious diseases from water contamination or disease-carrying vectors such as mosquitoes, ticks, and rodents; and heat-related illnesses.

Nebraska's substantial agricultural resources are sensitive to changes in climate. Increased heat could push temperatures above the tolerance level for crops like corn, causing a decline in yields. Strained water systems could pose a significant problem for state agriculture. Most runoff in Nebraska comes from snowmelts in Colorado and Wyoming that could decline with higher temperatures. The state's substantial groundwater resources could also be impacted by reduced spring and summer recharge. Weather variability would also likely increase with in increase in crop-damaging droughts. Positive impacts could include increasing carbon sequestration for emissions credits. Also, Nebraska farmers could see an increase in demand for corn-based ethanol.

ADDRESSING HUMAN-INDUCED CONTRIBUTIONS TO CLIMATE CHANGE

Based on energy consumption data from the Energy Information Administration, released in 2007, Nebraska's total CO_2 emissions from fossil fuel combustion in million metric tons for 2004 were 42.85, made up of contributions by source: commercial, 1.83; industrial, 6.01; residential, 2.44; transportation, 12.18; and electric power, 20.39.

Nebraska remains innovative in conservation practices. On April 10, 2000, the state became the first to enact legislation linking agricultural policy with greenhouse gas reduction. While agriculture is not a high contributor to greenhouse gas emissions, it has the potential to mitigate climate change. By forming a Carbon Sequestration Advisory Committee, made up of advisors from public and private sources in agriculture, industry, energy, and government and authorizing funding from the Nebraska Environmental Trust Fund, legislators ensured a quality, detailed assessment and recommendations. The benefits to Nebraska would be promoting the continuation and improvement of soil conservation programs, as well as an economics policy on the national or global carbon markets. The major problems with implementing pilot programs are initial and ongoing funding as well as the need for single-source oversight from CSAC or a similar lead organization.

The University of Nebraska is home to the Applied Climate Sciences (ACS) program for researching climate impacts in the Great Plains region. Because the area is sustained by agriculture, the university began an agricultural meteorology program in the 1960s. The program continues today within the university's School of Natural Resources. In addition, Julius Sterling Morton, a Nebraska newspaper editor, began the Arbor Day Foundation, located in Nebraska City, in the 1870s. His vision was to help beautify the state, provide shade, and prevent soil erosion. The nonprofit foundation continues today with a mission to create a world where trees and forests are abundant, healthy, and sustainable. To meet this goal, the Arbor Day Foundation helps protect the global environment by promoting rain forest preservation, urban and community forestry, and tree planting throughout the world. Trees absorb carbon dioxide, thus, the more trees are planted, the more carbon dioxide can be absorbed. Planting shade trees near a home can also reduce annual heating and cooling costs.

SEE ALSO: Agriculture; Floods; University of Nebraska.

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Needs and Wants

THE CONCEPT OF needs and wants and the ability to distinguish one from the other plays an important role in society. The issue is explored in philosophy, psychology, ethics, and modern social thought. To assert that something is a need is to argue that it is an essential element that is required for the body or society to exist. Some philosophers call needs real goods, and wants apparent goods. In Western political thought, the goods of having, doing, and being are seen as needs. The good of having refers to physical things like food, water, clothing, and shelter. The good of doing refers to a state of freedom, the ability to determine one's own life. The good of being refers to the ability to choose one's own thoughts and spiritual sensibilities.

In American political philosophy, these three goods are seen as required needs, the required foundation for any good republic. These real goods, or needs, may be seen in the phraseology of "life, liberty and the pursuit of happiness." Basic needs are also defined by humanitarian aid agencies and may include human rights, medicine, freedom from torture, control of reproductive rights, and access to nourishment. Needs are argued to be objective goods, universal and compelling. Sometimes, needs are argued to be self-evident.

Whereas needs are seen as universal and objective, wants are argued to be products of taste, culture, and personal preference. Wants are seen as acquired, pluralistic, contingent, and subjective. Wants are stylish, preferential, dispensable, and luxuries beyond what are needed. Wants may also be insatiable, such as the desire for experience, luxury, and social competition.

Both needs and wants stem from human desire. Needs are in relation to natural desires, and wants come from acquired desires. While human beings may all have the same needs, individuals are different from each other in their wants. The Greeks thought an educated man was one who was trained to desire the right things and distinguish needs from wants, real goods from apparent goods. Their end goal was creating leaders of good character, who were virtuous and had the habit of desiring good things. The classical Greek philosophers recognized that it was possible to have dangerous and misguided wants and that such wants could distort the ability to apprehend what was a needed good.

Needs are sometimes closely related to rights, because they are argued to be essential. If the issue is sharing food or some other essential element, the failure to share such is seen as a social and moral failure. Arguing that something is a need (essential for the functioning of the world) is a powerful social tool, and, thus, has social, moral, and political implications. Many things argued to be needs, however, are not entirely objective, and the arguments occur in a social-historical context.

Food may be necessary to live, and a person may want a hamburger, but that does not mean that a person needs a hamburger. Children are commonly seen to say they need things that they, in fact, do not need, but only want. Parents, government officials, the clergy, scientific experts, and other authorities frequently claim that things are necessary, even though this may not be evident. Experts, or a whole society can argue that there are needs that are not matters of personal choice, but fundamental essentials to all individuals and the whole society. Some needs are socially-created. Social power, social knowledge, and needs are closely related. In a debate about global warming, some nations organize around the perceived need to reduce greenhouse gasses, while other nations focus on the need to increase the size of the economy. A disciplined debate on these issues may lead to the realization that one of these positions is not really a need, but a want.

LIBERALISM

The struggle over if something is a need or a want is formidable in history, and the struggles shape society. When something is agreed to be a want and not a need, it is reduced to a less important issue of debate. It moves from an issue of truth to an issue of taste. Issues of taste and personal preference cannot easily be disputed and are frequently recognized to be questions of subjective value. In liberalism, the individual is sovereign when it comes to issues related to taste, opinion, consumption, and personal choices, as long as they do not infringe on the rights of others.

Critics of liberalism point out that liberalism enables one to describe what people want, but it cannot prescribe what people should want. In liberalism, individual reason is frequently oriented toward self-interest, and need and right is the battle cry of the individual, sometimes enabling acts that hurt social values and solidarity. Liberalism is not well-suited for distinguishing individual from universal values. Conservatives think needs and rights ought to be determined from the organic history and tradition of culture as it transcends individuals and informs current human communities. Critics on the left also critique liberalism and the confusing of needs and wants. They have images of a post-industrial and post-capitalist society focused on equality and a collectively and democratically decided-upon definition of need, where tradition is superimposed by functional democratic politics.

Distinctions between needs and wants are not only made difficult by culture, history, and individuals, but also by the values of particular communities. Researchers in sociology and anthropology have long explored how needs and wants are shaped by the underlying values in different communities. Some argue that each society has underlying needs, but needs are expressed and met in different ways, depending on the culture. Each culture may agree on the need for food, but the food may be very different across cultures. While the differences look arbitrary and may distract the researcher, the differences mask the underlying need. The final question is not about the various social manifestations that attempt to meet needs, but whether or not needs are being met. The problem, however, is that the researchers are tempted to argue that they can identify the real needs of a foreign culture. Both needs and wants are defined and negotiated within each specific culture. Sociologists caution about defining needs and wants from outside a culture, or with abstractions, and are interested in how cultures define needs and wants internally.

As the world becomes more pluralistic, diverse, densely-populated, and in competition with itself, it is crucial to agree on universal needs. As more of the world industrializes and strives for a higher standard of living, there will be more competition over resources and other problems of an increasingly global nature. Developed and developing nations will increasingly be linked on issues of trade, immigration, and greenhouse gas emissions. The affluence of developed nations and poverty in the developing world will increasingly force moral discussions about the relationships between the world's haves and have-nots. Questions about poorer countries bearing the greater costs of climate change have already begun. The anticipated manifestations of climate change will intensify questions about the real needs and costs for industrial emissions and the needs of less-industrialized countries.

SEE ALSO: Climate Change Knowledge Network; Environmental Defense; Greenhouse Gases; Precautionary Principle; Social Ecology.

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Nepal

THE NEPAL HIMALAYAS, along with the mountains to the east, are called the Water Towers of Asia, as they provide water amounting to 2,298 x 28,002 cubic gallons (8.7 x 106 cubic meters) per year. The Nepal Himalayas have 3,252 glaciers covering 2,055 sq. mi. (5,323 sq. km.). Affected by global warming; some of these glaciers have shown signs of retreat, along with a diminution of ice fields, particularly in the Great Himalayan region of Nepal. Nepal, with an area of 55 sq. mi. (142 sq. km.). The population of 27 million (2005 est.) is affected by global warming differently in its four regions.

Warming of the Indian Ocean will accentuate monsoon precipitation-generated erosion activity in all four regions of Nepal. The southernmost narrow Terrai region (average height of 656 ft. or 200 m.) that borders India is a plain land, with extensive rice cultivation. Global warming-generated monsoon rain intensity and drought uncertainty will affect agriculture adversely. Moreover, flooding from excessive snow melting will increase until about 2035 in the Kosi, Gandak, and Karnali river basins; causing extensive damage to rice paddies and settlements. After 2035, fresh water flow in rivers will diminish, lowering the levels of Kosi River reservoir, situated only a few miles north of the Indian border. This will adversely affect agricultural activity.

Another narrow east-west stretching region north of Terai is Churia Hills and Inner Terai. This is known as the Siwalik foothills of the Himalayas. The hills reach an altitude of 4,000 ft. (1,219 m.). Siwaliks consist of deposits susceptible to heavy erosion, which will be further aggravated by heavier rainfall. Heavy silting of riverbeds downstream, both in Nepal and India, will aggravate river overflow. The mid-mountain region north of Siwaliks, in which two important valleys (Kathmandu, the capital, and Pokhra) occur, has a complex mountain system that rises up to 14,000 ft. (4,267 m.). This will also experience heavy erosion caused by greater precipitation. Terraced rice fields of this region will face erosion. Heavy snow-melting at the headwaters of Arun, Dun, Sun Kosi, Irisuli, Gandak, Beheri, and Karnali rivers will increase flood damage until 2035; parts of Kathmandu will also be further threatened. After 2035, the fresh water supplied by the rivers will diminish, affecting rice cultivation.

The Great Himalayas, the northernmost region, consists of the world's tallest permanent snow-clad

The Himalayas, in Nepal, are showing a change in the ice fields and signs of glacial retreat.

mountain ranges, where, apart from Mount Everest, there are eight others with peaks over 26,247 ft. (8,000 m.). A large chunk of this snow cover will diminish; the process has already started. Several glacial lakes are formed in the region as a result of glacial retreat. Overflow of these lakes leads to forest and farmland destruction, known as Glacial Lake Outburst Floods (GLOF). On August 1985, a GLOF originating from Langmorche glacial lake washed away 14 bridges and damaged a hydroelectric plant in Namche.

SEE ALSO: Floods; Glaciers, Retreating; India; Monsoons.

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Netherlands

THE NETHERLANDS IS a wealthy European country with unique vulnerabilities to climate change. The country is creating proactive responses to anticipated rise in sea levels and increased flooding. It is working to meet the Kyoto Protocol, creating new government offices, and spending significant sums of money to make itself climate-proof. The country hopes that, through international agreements and domestic innovation, it will meet the challenges of climate change.

The Netherlands is a prosperous, small, and densely populated river delta country in Northern Europe, with a parliamentary democracy, and a 2007 population of 16.5 million. It has the 16th largest economy in the world. The gross domestic product (GDP) in 2006 was approximately $688 billion. It ranks 10th in the world in GDP per capita. Its economy depends on industry, particularly metal and chemical processing, petroleum refining, and electrical machinery. It is also a region of intensive agricultural and horticultural use. It takes advantage of its water infrastructure and its geographic location at the center of Europe's transportation network.

The Netherlands is one of the countries that may suffer the most from climatic change. In the Netherlands, 26 percent of the land lies below sea level, and two-thirds of the country's population lives below sea level. The Dutch government is deeply concerned about the national and global consequences of climate change. The government faces immediate threats on at least three fronts: rising North Sea levels on its coast line, increased risk of flooding from melting glaciers, and heavy rain and droughts that can cause sea and river dikes to subside and crack. The Agricultural Minister has stated that the effects of global warming are already seen in the form of milder winters, warmer summers, and altered rainfall patterns. Dutch policymakers are planning on sea level rise in the coming century.

Internationally, the Dutch government is a vocal leader on the issue of climate change and wants the European Union to actively contribute to furthering the process leading to more international agreements. The Netherlands is one of over 170 countries that ratified the United Nations Framework Convention on Climate Change (Rio de Janeiro, 1992). The country is a member of the European Union, the North Atlantic Treaty Organization (NATO), the Organisation for Economic Co-operation and Development (OECD), and has signed the Kyoto Protocol. The Netherlands' emissions reduction obligation is 6 percent. The country is committed to meeting this goal and will employ Joint Implementation (JI), Clean Development Mechanism (CDM) and Emissions Trading, in addition to domestic policy.

The National Environmental Policy Plan (NMP) sets Dutch environmental policy. The NMP aims to cut all forms of pollution 80 to 90 percent in one generation. The National Inventory Report, "Greenhouse Gas Emissions in the Netherlands 1990–2003," published in 2005, concluded that total CO_2-equivalent emissions of the six greenhouse gases together increased in 2003 by about one percent relative to 1990. In 2005, emissions equaled 214 billion kg. of carbon dioxide. The Minister of Housing, Spatial Planning, and Environment claims that the country is meeting emission reduction goals, but more work needs to be done to meet the Kyoto goals. Some key Dutch cities and infrastructure facilities are particularly vulnerable to rising seas and flooding, such as The Hague, Schiphol Airport, and the Port of Rotterdam. In 2006, the government approved a new $19 billion increase in spending on water defense systems over the next 20 years. This is in addition to another $4 billion for other special related projects and the $1.36 billion for annual maintenance of water defense systems currently in place.

In July 2007, the Dutch Cabinet earmarked €50 million for a new climate change center over five years. In some locations, giant sea-blocking doors called sluices will be added 2008–13 to fend off rising seas and storms. The National Spatial Planning and Climate Adaptation Programme (ARK) is charged with making the Netherlands climate-proof, starting in 2008. Engineers are discussing the creation of breaker islands off the country's North Sea cost. Pumping sand into strategic locations offshore, where North Sea currents will sweep the sand into place and bulk up the dunes, can create breaker islands. Similar techniques could create a series of small islands off the coast. The Netherlands is also working to develop a hydropole, a city that can live on the rising waters. Discussions in The Hague are also underway about a massive evacuation drill to be held in 2008, should sea defenses fail.

SEE ALSO: Abrupt Climate Changes; European Union; Floods; Kyoto Protocol; Sea Level, Rising.

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Net Primary Production

PRIMARY PRODUCTION IS the production of organic compounds from atmospheric or aquatic carbon dioxide, principally through the process of photosynthesis, and, to a very limited extent, through chemosynthesis. All life on earth is directly or indirectly reliant on primary production. As the earth is an open system with regard to energy, this is constantly used up and lost as heat as it moves through ecosystems, and new energy is continually added to the earth in the form of solar radiation. The organisms responsible for primary production are known as primary producers or autotrophs (from the Greek *autos*, meaning self and *trophe*, meaning nutrition), and form the basis of the food chain. In contrast, organisms that cannot produce their own energy, but have to feed off other organisms are called consumers or heterotrophs. Organisms able to produce complex organic molecules from simple inorganic compounds (water, CO_2, nutrients) include plants, algae, and some bacteria. Such organisms require sunlight, carbon dioxide, water, and nutrients, and through photosynthesis, they produce reduced carbon compounds and oxygen. Light energy is converted into energy stored in chemical bonds within plant tissue. This energy activates the metabolic process of the organism or system. New compounds and structures are created, cells split, and the plant grows in size over time.

Primary production is distinguished as either net or gross. Net primary production (NPP) accounts for losses through processes such as cellular respiration and maintenance of existing tissues, while gross primary production (GPP) is the total amount of energy produced by primary producers in an specific area or ecosystem. NPP is the remaining amount of CO_2 after we deduct the quantity lost through metabolic activity. Thus, NPP is an important part of the global carbon cycle and is important to monitor. The fact that concentrations of atmospheric CO_2 and tropospheric ozone (O_3) are rising at the same time in the atmosphere produces potentially adverse effects on forest NPP and negative results for terrestrial carbon sequestration. Both gross and net primary production are in units of mass, area, and time. In terrestrial ecosystems, the mass of carbon per unit area per year (g C/m2/yr) is most commonly used. In terms of NPP per unit area, the most productive systems are estuaries, swamps and marshes, tropical rain forests, and temperate rain forests. To calculate the total NPP of the world, these values per unit area should be multiplied by the area that the various ecosystems occupy. The results show that the most productive systems are open oceans, tropical rain forests, savannas, and tropical seasonal forests. Human appropriation of net primary production (HANPP), through the consumption of food, paper, wood, and fiber, modifies the composition of the atmosphere and the levels of biodiversity.

SEE ALSO: Carbon Dioxide; Oxygen Cycle; Plants.

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Nevada

NEVADA HAS A unique geography that makes it extremely vulnerable to global warming and climate change. Much of the state is uninhabitable, and the United States government owns 86 percent of the 109,806 sq. mi. (284,396 sq. km.) land area. Nevada has more than 300 mountain ranges. The Great Basin Desert covers the northern part of the state, and southern Nevada contains a section of the Mojave Desert. With some sections of the state averaging only 4 in. (10 cm.) of annual rainfall, Nevada is the driest state in the United States, and meteorologists have noted a dramatic 7 degree F rise (3.8 degree C) in average annual temperatures in Las Vegas, the state's largest city, over the past three decades.

Scientists predict that the southwest will become even drier in the future, in response to global warming and climate change. Evidences of change are already present. The glacier at the Great Basin National Park has lost 90 percent of its ice over the last one and a half centuries, and it now disappears in the summer. The ecosystems within the basin are considered extremely vulnerable to climate changes. Droughts have become more frequent in Nevada, posing increased threats of wildfires. Reaction to global warming and climate change in Nevada is focused in large part on the promotion of renewable energy. The Union of Concerned Scientists has predicted that, by 2012, Nevada will rank third in the United States in the production of green power.

Although Nevada has the 13th lowest ranking of carbon dioxide (CO_2) emissions in the United States, overall pollution levels within Nevada have been on the increase since the 1960s. A 2006 publication of the U.S. Public Interest Research Group, a nonpartisan organization based in Washington, D.C., used data compiled by the U.S. Department of Energy to track pollution in all 50 states 1960–2001. PIRG reported that global warming pollution in Nevada rose 835 percent during the relevant period. Coal-burning power plants were responsible for the 43 percent increase in Nevada's CO_2 emissions, but emissions from oil and natural gas also contributed to the increase. PIRG announced in an updated report in 2007 that 1990–2004, CO_2 emissions in Nevada had increased by 639 percent, placing that state fifth in the nation in increased emissions. State representatives insist that Nevada's increased CO_2 emissions have been a result of the 73 percent increase in population 1990–2001, caused by the industry that precipitated the population explosion. Efforts to control CO_2 emissions led to a 21 percent increase in CO_2 efficiency in Nevada 1990–2001.

In April 2007, Nevada Power was fined $1.1 million to settle a joint lawsuit filed by the U.S. government and Nevada. A total of 70 percent of the settlement was paid to Nevada, and 30 percent to the federal government. Nevada Power also agreed to spend $85 million to install cleaner technology and pledged to donate $4 million over a seven-year period to energy conservation projects for the Clark County School District. The suit was filed in response to 56 violation notices issued by the Bureau of Air Pollution Control to Nevada Power at the Reid Gardner coal-fired electric generating plant, which is located 50 mi. (81 km.) from Las Vegas, the gambling capital of the United States. All plans to open new coal-fired power plants in Nevada are now facing opposition from both the government and environmentalists.

In Nevada, environmental responsibilities are shared between the Department of Agriculture and the Department of Conservation and Natural Resources. The Conservation Commission, the Division of Environmental

Protection, the Bureau of Corrective Actions, and the Division of Water Resources all operate under the auspices of the Department of Conservation and Natural Resources, which issues permits and enforces state and federal laws, monitors the environment, enforces pollution prevention, and remedies conflicts. Specific departmental responsibilities include monitoring air and water quality and overseeing the cleanup of hazardous materials.

PROGRAMS

In the late 1990s, Nevada began working with activists and environment-related industries to develop a statewide plan for renewable energy. By 2001, the legislature had bipartisan support to institute what was then the most aggressive renewable portfolio standard of the time. The standard promoted the use of biomass, geothermal, solar, and wind energy as a means of reducing toxic emissions from fossil fuels. The Nevada Public Utility Commission was ordered to work with individual electric service providers to increase renewable energy to five percent in 2003, seven percent in 2005, nine percent in 2007, 11 percent in 2009, 13 percent in 2011, and 15 percent each year thereafter. Five percent of each renewable energy requirement must be derived from solar sources. Utilities may earn credits for up to 25 percent of the standards by instituting efficiency measures, and the state helps to defray costs involved.

In April 2007, the governor of Nevada established the 13-member Climate Change Advisory Committee and charged them with making recommendations for reducing greenhouse gas emissions throughout the state. A major focus of the committee's work is directed toward identifying methods for developing renewable energy resources that will protect the environment without threatening economic stability. Individuals on the committee represent local governments, state agencies, the academic sector, environmental groups, and the mining and energy industries.

Mining has historically been one of the major industries in Nevada, and mining is generally considered a major threat to the environment. Nevada's Mercury Emissions Testing Program is designed to control toxic emissions in Nevada mines. The first stage of the project began in spring 2007 with testing at the state's largest precious metal mine. As mandated by law, the Division of Environmental Protection conducts annual tests of emissions from the exhaust stacks of all units that potentially produce mercury. One of the purposes of the initial testing is to identify the forms of mercury emitted in order to understand the environmental impact of the emissions and determine acceptable emission levels.

SEE ALSO: Carbon Emissions; Coal; Deserts; Energy.

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New Hampshire

NEW HAMPSHIRE HAS an area of 9,350 sq. mi. (24,216 sq. km.), with inland water making up 314 sq. mi. (813 sq. km.), and access to territorial water of 68 sq. mi. (176 sq. km.). The White Mountains region in the northern part of New Hampshire has dense forests and deep glacial valleys. The New England Upland in central and southern New Hampshire is hilly and contains many glacial-formed lakes and streams. The Seaboard Lowland covers the southeastern corner of the state and slopes down to sea level. New Hampshire's coastline on the Atlantic is only 13 mi. (21 km.) long, with islands and inlets.

New Hampshire has cool summers and long cold winters, though weather can have extreme variations. New England weather and climate is influenced by latitude (warm, moist air from the south and cold, dry air to the north), coastal orientation (position within the zone of the westerlies), and elevation changes. In winter, these waters remain warm relative to land areas, thereby influencing snow-rain boundaries, which are difficult for forecasters to predict. The highest temperature recorded in the state was 106 degrees F (41 degrees C) on July 4, 1911, and the lowest temperature recorded in the state was minus 47 degrees F (minus 44 degrees C on Mount Washington on January 29, 1934.

Land once used for farming is being returned to forestland. Remaining agricultural production includes dairies, livestock, Christmas trees, apples, and maple sugar products. Most of the commercial forestland is privately owned. Individual holdings are generally small, mostly less than about 80 hectares (about 200 acres). Some of these holdings were formerly unprofitable farmlands. More than two-thirds of the timber consists of softwoods, including pine, spruce, fir, and hemlock. In order to discourage indiscriminate cutting on private land, the state collects no tax on timber until after it is cut.

IMPACT OF CLIMATE CHANGE

New Hampshire is already experiencing the effects of higher temperatures and rising sea levels. During the last decade, 18 ski areas increased snowmaking to ensure good snow conditions. While climate models vary for the northeast on the amount of temperature increase during the 21st century from 5–12 degrees F (2.7–4.2 degrees C) during the winter months, to 3–14 degrees F (1.7–7.8 degrees C) during the summer months. Anticipated rising sea levels (7–14 in., or 17–36 cm., on the low end, and 10–23 in., or 25–58 cm. on the high end), is projected to increase shoreline erosion and wetland loss. Potential risks are more severe under the higher-emissions scenarios, with heat stress in cows decreasing milk production, and a climate no longer suitable for apples. Weeds and pests would proliferate. New Hampshire would lose winter tourism from skiing and snowmobiling. Under the lower-emissions scenario, changes would be less severe.

Among New Hampshire's most serious conservation problems is the destruction of forests by overcutting. This practice eliminates an important source of state revenue, destroys the habitat of many animals, and increases the possibility of erosion and flood damage. For these reasons, the state aids in the preservation of forest areas by encouraging selective forest cutting through special tax provisions. Global climate change may have a positive impact on certain New Hampshire forest areas. Certain trees and forests may flourish due to longer growing seasons, more abundant carbon dioxide (CO_2), and wet summers. White pine and red oak, two very profitable timber species in New Hampshire, could increase in number.

Health risks associated with rising temperatures include a potential increase in certain infectious diseases from water contamination or disease-carrying vectors such as mosquitoes, ticks, and rodents and heat-related illnesses. In addition, Portsmouth might expect to issue health advisories during summers to limit outdoor activity.

ADDRESSING HUMAN-INDUCED CONTRIBUTIONS TO CLIMATE CHANGE

Based on energy consumption data from Energy Information Agency released June 1, 2007, New Hampshire's total CO_2 emissions from fossil fuel combustion in million metric tons for 2004 was 21.83, made up of contributions by source from: commercial, 1.81; industrial, 1.14; residential, 3.40; transportation, 7.77; and electric power, 7.71.

New Hampshire's Greenhouse Gas reduction target is to meet 1990 levels of six greenhouse gases by 2010, to be 10 percent below 1990 levels by 2020, and 75 to 85 percent below 2001 levels in the long term. New Hampshire has joined New England and some mid-Atlantic states in the Regional Greenhouse Gas Initiative (RGGI), a mandatory cap-and-trade program. Carbon emissions from power plants will be capped at current levels 2009–15 and they will be incrementally reduced by 10 percent before 2019. New Hampshire joined the Climate Registry, a voluntary national initiative to track, verify and report greenhouse gas emissions, with acceptance of data from state agencies, corporations, and educational institutions beginning in January of 2008.

New Hampshire signed a 2001 compact between New England governors and neighboring Canadian provincial leaders requiring a collective reduction of global warming pollution in the region. In 2002, New Hampshire passed a law to reduce carbon pollution from power plants to their 1990 levels by 2006. The state also has a voluntary greenhouse gas reduction registry. The state's Building Energy Conservation Initiative allows state agencies to contract with a private energy services company to improve energy efficiency in state-owned buildings through retrofits and upgrades. New Hampshire has the potential to meet more than 72 percent of its electricity needs with renewable energy like wind and biomass.

The University of New Hampshire is home to the Climate Change Research Center (CCRC), dedicated to the study of the Earth's atmosphere. The CCRC engages in educational activities ranging from graduate level instruction to informal outreach at science centers. CCRC research focuses on understanding the fundamental properties of the atmosphere and how they have been affected by human activities.

SEE ALSO: Deforestation; Forests; University of New Hampshire.

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New Jersey

NEW JERSEY IS a densely populated state of almost 9 million on the Atlantic seaboard. It lies between the metropolitan areas of New York City and Philadelphia. It has a long barrier island shoreline exposed to the Atlantic Ocean to the east and is bordered by the Delaware River and Bay to the west and south respectively, the Appalachian Mountains in the northwest, and Hudson River on the northeast. The state has been particularly progressive on state-level greenhouse gas policies and regulations, and is also known as a site of a heavy industry and petrochemical production. It has the largest petroleum containment capacity outside of the Middle East, which is visible along the New Jersey Turnpike.

New Jersey has a long industrial legacy. Tributaries to the Hudson, Passaic, and Hackensack rivers fueled textile industries during the Industrial Revolution. Many large companies were founded in this state. John D. Rockefeller started Standard Oil of New Jersey as a result of the Standard Oil antitrust settlement of 1911. The company later became Exxon and eventually merged with Mobil, formerly Standard Oil of New York. The oil, chemical, and pharmaceutical industries remained the economic lynchpins of the New Jersey economy into the 21st century. The deep ports of Newark, Elizabeth, and Bayonne, and their proximities to dense populations also attracted industries that utilize the extensive transportation infrastructure for moving global commodities. Port Elizabeth is the largest container port in the eastern United States. It was the largest in the world as recently as 1985; today it is the world's fifth largest marine terminal. It moved over $100 billion in goods in 2006. Little of that economic benefit remains in nearby communities, which are some of the poorest urban communities in the New York metropolitan region.

EFFECTS OF CLIMATE CHANGE

The 130 mi. (209 km.) long, densely developed shoreline of New Jersey is particularly vulnerable to significant storm events such as hurricanes and the often more powerful Nor'easters. With rising sea levels, an extensive population will be increasingly vulnerable to these storms in the future. Much of the developed shoreline is built on barrier islands, giant sandbars that occasionally breach into the backside bays during the most intense storms. Although there is a substantial coastal infrastructure of bulkheads and sea walls, much of the valuable coastal real estate, including high-rise casinos and recreational beaches, could be severely damaged in the event of severe storms. In 1962, a Nor'easter, known as the Ash Wednesday Storm, destroyed 45,000 homes. The state is also frequently hit by moderate hurricanes, though they are typically less powerful than those that hit the southern United States.

The federal government heavily subsidizes the protection of the densely developed New Jersey coast. Taxpayers, through the Army Corps of Engineers, pay for shoreline erosion and beach replenishment programs. New Jersey's current plans for beach sand replenishment will cost about $60 million per mile, with a 50-year total of $9 billion. Many property owners also get subsidized insurance through the National Flood Insurance Program. Storms often result in the use of Federal Emergency Management Agency (FEMA) funds to rebuild in the same place, without important property modifications such as sand dunes and other shoreline protection infrastructure. FEMA suggests that a 1 ft. (30 cm.) sea-level rise on the northeast coast could raise flood insurance premiums.

Changes to temperature, sea level, and water regimes in New Jersey could affect its most important and unique ecosystems. Temperature increases and rainfall declines could make the Pine Barrens area on the outer coastal plains and the skylands area of the mountainous northwest more prone to catastrophic fires or biological invasion. This could affect rare and endangered species like the Pine Barrens tree frog. Sea level rise could cause salt water intrusion into freshwater wetlands, significantly affecting marine and avian species. The New Jersey landscape has been shaped by global change in the past, with the devastating unintended introductions of Chestnut Blight and Dutch Elm disease. Some of the most serious invasive species threatening New Jersey ecosystems today are the Asian Long Horn Beetle, Hemlock Woolly Adelgid, Japanese Honeysuckle, and Chinese Bush Clover. Climate change could make New Jersey habitats even more welcoming to these invasive species. The increase in temperatures may be responsible for expanding the habitat for mosquito-borne illnesses such as dengue, West Nile Virus, and malaria into urban areas. With an extensive area paved over and urbanized, New Jersey has many areas that have a blackbody-effect that keeps them warmer at night. Climate change will also likely cause increases in ground-level ozone levels in the congested areas of the state.

A 2007 legislative bill in New Jersey requires that state greenhouse gas emissions be reduced to 1990 levels by 2020, and 80 percent below 2006 levels by 2050. New Jersey is also a participant in the Regional Greenhouse Gas Emission Initiative, a 10-state program that is the first CO_2 cap and trade program in the United States. In addition, leading some of the state universities to adopt groundbreaking greenhouse gas policies, Governor John Corzine has also proposed a Governors' Climate Protection Leadership Council. A large number of New Jersey mayors have signed the U.S. Mayors Climate Protection Agreement. Activists in the state have organized the annual New Jersey Climate March.

SEE ALSO: Atlantic Ocean; Greenhouse Gases, Gulf Stream; Hurricanes and Typhoons; New York; Princeton University; Regulation.

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New Mexico

NEW MEXICO HAS an area of 121,590 sq. mi. (314,917 sq. km.), with inland water making up 234 sq. mi. (606 sq. km.). New Mexico's average elevation is 5,700 ft. (1,737 m.) above sea level, with a range in elevation from 2,842 ft. (866 m.) above sea level at the Red Bluff Reservoir, to 13,161 ft. (4,011 m.) at Wheeler Peak. New Mexico's topography is varied, including mountains, plateau, basins, and the Great Plains. New Mexico's major river is the Rio Grande, originating in southern Colorado, and flowing southward for through the state (with very low water flow), is used for irrigation. The Continental Divide (the separation mark of the Pacific and Atlantic watersheds) passes north to south through New Mexico. In addition to streams and rivers, small glacial lakes are in the Sangre de Cristo Mountains and several large reservoirs store water for irrigation and recreation.

The climate of New Mexico is generally mild, sunny, and dry. Temperatures vary in the different regions of

Enchanted Mesa: Much of New Mexico consists of desert terrain, however, there are forested plateaus and mountain regions.

the state; the annual average temperatures vary as much as 10 degrees F (minus 12 degrees C) from south to north, with the northern mountains cooler. The highest temperature recorded in the state was 122 degrees F (50 degrees C)on June 27, 1994 and the lowest temperature recorded in the state was minus 50 degrees F (minus 45 degrees C) on February 1, 1951. Most of the state has between 10 and 20 in. (25–51 cm.) of annual rainfall. The mountains also have a higher precipitation. Summer thunderstorms provide the larger portion of annual precipitation. Winter precipitation is in the form of mountain snowfall and rain or snow at lower elevations. Cold air masses from Canada may produce blizzards.

The dry climate does not preclude agriculture; commercial farming is more common along the river valleys for irrigation, and in the driest eastern part of the state, dry farming is common. Crops include corn, hay, sorghum, chili peppers, onions, and wheat. Ranching is important to the economy, and grazing rights are provided on National Forest land. The largest aquifer in the world, the Ogallala Aquifer, lies underground beneath eight states, including New Mexico.

IMPACT OF CLIMATE CHANGE

New Mexico's climate has changed over the centuries. The ancient native peoples began farming the area in approximately 1500 B.C.E. Optimum rainfall brought increased population and arable farmland. A Medieval climate anomaly in the southwest during the 8th and 12th centuries, caused human hardship. In approximately 1250 C.E., the changing weather pattern caused two decades of severe drought and the people moved from places like Chaco Canyon to water sources higher in the Colorado Plateau.

Climate models vary on temperature increase for New Mexico, from 2–7 degrees F (1–4 degrees C) in autumn, from 2–9 degrees F (1–5 degrees C) in summer and winter, and from 1–5 degrees F (0.5–3 degrees C) in spring by the end of the century. Potential risks include decreased summer water supplies. A warmer climate would mean more winter rain and less snowfall in the mountains for snowmelt in the spring to feed New Mexico's streams, the major source of surface water throughout central and southern parts of the state. The levels of reservoirs would drop because of increased evaporation caused by higher temperatures. Water supplies for municipal districts and irrigation in the densely populated Rio Grande Valley, where Albuquerque is located, would become more restricted, increasing reliance on groundwater, although decreasing spring and summer recharge would lower groundwater levels too, impacting the eastern and southeastern areas of the state, which rely on groundwater already.

Hotter, drier summers increase the risk for wildfires as well as droughts, and flooding could be caused by rapid snowmelt in the spring. More severe summer downpours could lead to more frequent flash flooding. Flooding increases the possibility of contamination of water supplies by sediment erosion, and also increases levels of pesticides and fertilizers and runoff from grazing, mining, and urban areas. The yields of some crops like wheat and sorghum would decrease as temperatures rise over the tolerance level for optimal growth. With less water available for irrigation, farming on the whole could decrease as well.

Human health risks include contracting certain infectious diseases from water contamination or disease-carrying vectors such as mosquitoes, ticks, and rodents (rodent-borne diseases are prevalent in New Mexico. Increased rodent populations have been associated with El Niño). Warmer temperatures would increase the incidence of heat-related illnesses and lead to higher concentrations of ground-level ozone pollution causing respiratory illnesses (diminished lung function, asthma, and respiratory inflammation).

ADDRESSING HUMAN-INDUCED CONTRIBUTIONS TO CLIMATE CHANGE

Based on energy consumption data from the Energy Information Agency released June 1, 2007, New Mexico's total CO_2 emissions from fossil fuel combustion in million metric tons for 2004 was 58.32, made up of contributions by sector from: commercial, 1.67; industrial, 8.27; residential, 2.31; transportation, 15.64; and electric power, 30.43. New Mexico's Greenhouse Gas reduction target is to lower emissions of greenhouse gases to 2000 levels by 2012. In addition, the legislators approved a state law requiring New Mexico power producers to generate 10 percent of energy from renewable sources by 2011.

By executive order in June 2005, the governor established the New Mexico Climate Change Advisory Group to propose options for reduction of greenhouse gas emissions. The group completed its work and filed a final report in October 2006. The executive order also required reports on possible impacts of climate change on New Mexico and water resources. The governor established the Climate Change Action Council in December 2006 to progress previous work toward implementation. New Mexico holds member status with the Western Regional Climate Action Initiative, in which the partners will set an overall regional goal for reducing greenhouse gas emissions and design a market-based mechanism to help achieve that reduction goal. New Mexico joined the Climate Registry, a voluntary national initiative to track, verify and report greenhouse gas emissions, with acceptance of data from state agencies, corporations and educational institutions beginning in January of 2008.

SEE ALSO: Desertification; Deserts; New Mexico Climate Center.

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New Mexico Climate Center

ESTABLISHED DURING THE 1980s, the New Mexico Climate Center is located on the campus of New Mexico State University and is in charge of collecting and disseminating data on the state's weather. The center is the home of the state climatologist, Ted Sammis. It collects its data through electronic data-logger machines, both from its own network of 27 weather stations at its Agricultural Science centers and from station networks from other agencies such as the Bureau of Land Management, the Natural Resource and Conservation Service, and NOAA. In total, the New Mexico Climate Center collects daily climate data from 138 automated climate stations around the state, including irrigation districts and NAPI (Navajo Agricultural Products Industry). These stations monitor air temperature, relative humidity, soil temperature and moisture, precipitation, solar radiation, and wind speed and direction. These data are then disseminated for the benefit of policymakers, administrators and the public. In addition to this electronic collection of data, more than 50 volunteers record their daily local temperature and rainfall across the state and send this information to the National Center for Data Collection. The services of the New Mexico Climate Center can be accessed through the world wide web. The center's web site processes climate data daily and makes it available to the public.

In addition to the state climatologist, the center is staffed by a group of students. The purpose of the center is to assist the state's efforts to understand and respond to natural and human-induced climate processes, including global warming, to cooperate with federal government activities relating to climate studies, and to promote and disseminate a general knowledge of the climatology of the state. Some of the activities carried out at the center are: assessing the impact of climate on the natural environment, agricultural production, land and natural resources, and human health; coordinating studies and schemes to understand more fully natural and human-induced climate changes, and the social and economic implications of climate changes; developing methods and procedures to encourage the participation of interested state agencies and public institutions of higher education in the climate-related programs; and disseminating climate data, information, advice, and assessments to state agencies, local public bodies, and the public.

During its two decades of operation, the State Climate Center has supplied climatic information for the needs of industry, tourism, state agencies, and private individuals. This information has contributed to the economic growth of New Mexico and the bordering regions through applied research and development. The center's web site receives an average of more than 6,000 requests for climate information per day. In addition to these, more than 300 requests are answered by phone and email each year. Besides climate data, the New Mexico Climate Center supplies information on irrigation arrangements for native, landscape, and commercial crops. It provides heat and cooling degree-day calculation, for the construction industry, and economic irrigation software. The center has a variety of teaching material on soil and land use, instrumentation, and irrigation science.

The efficient use of water has been a long-standing interest of the center, given that water is a scarce resource in the state and that droughts are often severe. The New Mexico Climate Center devotes part of its official web site for the New Mexico Drought Task Force with information about current drought status and future climatic conditions. The web site also provides tools to use climate data for determining when to apply pesticides, based on growing degree-day models. Researchers working at the center have developed water production functions (relationships between yield and crop water-use) and crop coefficients (for irrigation scheduling) for many crops. These functions can be used to assist in efficient irrigation management and in making important economic decisions related to water and crop production.

The center has acknowledged that global warming is a stark reality. The state climatologist and his staff have calculated that the temperature in New Mexico was 3.6 degrees F (2 degress C) hotter in the year 2000 than during the 1961–1990 period. Yet, the New Mexico Climate Center has been more cautious in making predictions about local weather. According to State Climatologist Ted Sammis, the global models that look at 50-year scenarios and indicate increased weather chaos are difficult to apply to state weather predictions.

SEE ALSO: Climate; National Oceanic and Atmospheric Administration (NOAA); New Mexico.

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New York

STRETCHING FROM THE Atlantic Ocean to the Great Lakes and the St. Lawrence Valley, New York State presents a wide diversity of climate features. Elevations range from sea level in New York City, to some of the highest peaks on the east coast in the Adirondacks. New York State has a continental humid climate, with the geography causing climate variation. Storms and frontal systems generally move from the west and north, bringing with them masses of cool, dry air. However, storms moving along the Atlantic coast and from the south bring warm, humid air masses. These storms and frontal systems often meet over New York. Average annual mean temperatures range from 40 degrees F (4 degrees C) in the northern Adirondacks, to 55 degrees F (13 degrees C) in the New York City region. Extreme lows can occur in winter months in the Adirondacks and warm conditions generally prevail in the summer months in the New York City area. The highest temperature recorded was 108 degrees F (42 degrees C)in east central New York (Troy) and the coldest temperature recorded was minus 52 degrees F (11 degrees C) in Herkimer County, northwest of Troy.

Precipitation is fairly uniform, without a distinct wet or dry season. Generally, lower precipitation occurs in the winter months in the western Finger Lakes and the eastern Lake Champlain regions (approximately 2.2 in. (6 cm.) per month). The maximum amount of rainfall (approximately 4 in. (10 cm.) per month) falls in the summer in the Hudson Valley. Winter precipitation is usually in the form of snow—especially in the north and west—and snowfall can measure as much as 175 in. (444 cm.) per month in the Adirondacks off of Lake Ontario and off of Lake Erie. The diverse weather patterns support a varied economy that includes agriculture, including grains and corn, grapes, tree fruits, and a dairy industry. The snowfall lends itself to winter recreational endeavors such as skiing, but variable snowfall results in many resorts relying on manmade snow.

EFFECTS OF CLIMATE CHANGE

New York, like the northeast as a whole, is warming. Historical records show that temperature in New York is increasing at a rate of about 0.2 degrees F (0.1 degrees C) per decade, and more recent data suggest even greater warming trends. If these trends, continue, the mean temperature of New York will be more like that of South Carolina by the end of the century. If rates are slowed by reduction of carbon emissions, the temperature will be more like that of Maryland.

Storm tracks of Atlantic storms, including hurricanes, are impacting the coastal regions of New

York, specifically Long Island. While records suggest that about a dozen major storms have hit the Atlantic coast of New York over the last several hundred years, the frequency seems to be increasing. Additionally, many of the areas impacted by such storms in the past were not as developed as they are now. This greatly increases the potential for damage to humans because of both their frequency and of people being put into harm's way, and the danger is not limited to rain storms alone. As there are wider swings in weather, winter storms can likewise impact both coastal and inland regions. Structural failure, incursions of water into transportation and utility systems, and travel are all critical in New York State, and all will be impacted from storms.

Rising mean sea levels are of major concern to the low-lying areas along the coast—most notably Long Island and parts of Manhattan. If current rates of rise continue, much of the lowlands will be under water. The rise of sea level, along with human activity, is already impacting many the salt marshes of Long Island Sound and the Atlantic coast of Long Island. Overall trends of precipitation are down in New York. This has definite impacts on agriculture and recreation. Heat stress has impacted the dairy cow industry and will continue to do so if current trends continue. Grapes are impacted by the change in weather—some varieties do better, others do worse. Skiing, a major recreational industry in New York has been impacted by the reduction of snowfall.

Health is affected by climate change. In New York, increased heat mortality may be expected if trends continue. The longer warm seasons will likely impact insect populations, thereby increasing the risks of mosquito borne diseases such as West Nile Virus (which has already adversely impacted New York). Increased heat can also lead to pollution, increasing an already escalating incidence of asthma and other respiratory problems. Specific events, such as flooding from rising sea levels, can increase mortality and morbidity significantly.

Energy demands go up with extremes of weather and peak load is impacted. Estimates suggest that, in the next decade, given the trend in summer temperature and population, overall demand may double. This will impact an already taxed energy infrastructure, which may not be able to respond. More brown outs or grid failures can be expected throughout the state. While some decrease overall can be expected due to reduced heating, a cooling trend would place the greatest burden on energy delivery systems.

Many of the climate changes are part of global trends impacting the nation as well as New York State. Because of its size and impact on the global economy, New York State has the opportunity to attempt to mitigate climate change where possible, as well as the risk of increased problems from climate change.

SEE ALSO: Diseases; Energy; Floods; Sea Level, Rising.

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New Zealand

NEW ZEALAND IS located in Oceania, southeast of Australia. The islands that make up the nation are mostly mountainous, with a few wide coastal plains. About 80 percent of the population of 4 million lives in urban areas, leaving most of the country free from major human intrusion. It is one of the most beautiful and pristine environments in the world, and its economy, based on tourism, agriculture, and forestry, is largely dependent on the stability of that environment.

As in neighboring Australia, New Zealand is confronting the probability of prolonged droughts in the near future. In the best-case scenario, severe droughts will be twice as frequent by 2080 as they are today, and in some areas, drought could become perpetual even before 2080. Not only will this lead to a decline in agricultural production, it will stress the nation's forests and increase the risk of forest fires. Like any island nation, New Zealand is particularly concerned

Waimangu Valley in Rotorua, New Zealand: New Zealand is one of the most pristine environments in the world.

with the possibilities of sea-level rise. Most of the major urban areas are located on the coasts. Government models indicate a 0.2 meter rise by 2050 and a 0.5 meter rise by 2100, and those figures are now used in planning along the coastline. Losses of structures already built along the coast are probable. Along with general sea level rise is the possibility of higher storm surges as tropical storms grow in intensity.

New Zealand anticipates a few positive outcomes for health, including fewer illnesses during the winter months as average temperatures rise. However, temperature rise also brings the threat of illness and death from heat stroke and vector-borne illnesses. Water contamination is also a possibility in some areas. Warmer temperatures will also increase the need for air conditioning, thus increasing electricity usage. Agriculture will see both benefits and losses from changing climate. While longer growing seasons and increased atmospheric carbon rates are somewhat positive for crops, the increased risk of drought and changing rainfall patterns could lead to significant crop destruction.

New Zealand is working toward sustainability and mitigation on many fronts, both in the public and private sectors. The government is supporting programs to construct energy-efficient housing and retrofit older structures. It also supports the development of more fuel-efficient vehicles, the increased use of biofuels, sustainable land management, healthy forest initiatives, and funding for research into alternative energy. It is also trying to set a good example by making government buildings carbon-neutral and reducing waste.

SEE ALSO: Australia; Drought; Hurricanes and Typhoons; Sea Level, Rising.

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Nicaragua

NICARAGUA IS BOUNDED on all sides by water: to the east and west lie oceans, and most of the northern and southern borders are large rivers. Although the country has experienced growth in export processing and tourism, Nicaragua remains reliant on agriculture and fishing. The country experiences seasonal climate shifts, with pronounced wet and dry seasons. There is a tendency for flooding in the east and drought in the west. Knowledge about climate change mitigation is poorly developed within the country, in spite of vulnerability to natural disasters due to poverty, low investment in infrastructure, and poor interagency coordination. International nongovernmental organizations provide a large portion of disaster relief.

There has been a recorded increase in temperature of 1.2–1.8 degrees F (0.7–1.0 degrees C) across Central America over the past century. This generates concern over agricultural transition, since warming many increase crop pests and diseases. A drier climate may also increase risk of damage from forest fires. Malaria levels are likely to rise. There has been documentation of annual variation in Nicaragua of dengue/hemorrhagic dengue related to fluctuations in temperature, humidity, solar radiation, and rainfall.

Research suggests that hurricanes and tropical storms originating in the Atlantic Ocean may bring more rain as a result of increasing water temperatures. There is already a loss of more then 1 percent of the gross domestic product (GDP) annually in Nicaragua due to flooding. Regional studies suggest economic losses as a result of natural disasters are eight times greater now, as compared to the 1960s.

Hurricane Mitch struck Nicaragua in 1998. Its impact has been researched as a model for what could occur from extreme weather events. In addition to the loss of 50 percent of GDP, major mudslides on the Las Casitas volcano led to the death of more than 2,000 people. There was also a documented increase in malaria, dengue fever, cholera, and leptospirosis. Conventional farms using chemical intensive monoculture had 60–80 percent more soil erosion, crop damage, and other water-caused losses from the hurricane than farms utilizing conservation practices such as polyculture, crop rotation, water conservation, terracing, and agroforestry.

Biodiversity reduction is a problem across Central America. Nicaragua has lost 50 percent of its forest cover in the last five decades. Research suggests an urgent need to reforest along the floodplains of rivers. Several forest conservation areas receive extensive foreign assistance, but marine reserves remain poorly protected. Mangrove swamps and coral reefs are particularly at risk.

Nicaragua ratified the Convention on Climate Change in 1995 and the Kyoto Protocol in 1999. Geothermal energy production is part of a national plan to combat climate change. New geothermal projects are under construction, with funding from the United Nations's Clean Development Mechanism (CDM). Other CDM projects utilize biodigesters and bagasse cogeneration to transform waste products from sugarcane processing into energy. In addition to rectifying low energy efficiency, Nicaragua needs to improve provision. About 20 percent of annual deforestation comes from fuel wood extraction.

SEE ALSO: Clean Development Mechanism; Deforestation; Floods; Hurricanes and Typhoons.

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Niger

NIGER IS LOCATED in western Africa, just north of Nigeria. This landlocked country is already one of the hottest and driest places on the planet. It lies within the Sahel region, which has seen increasingly damaging droughts, soil erosion, desertification, deforestation, and overgrazing during the last 30 years. Four-fifths of the terrain is desert, characterized by rolling sand dunes, with the remaining fifth fairly productive savanna. The 13 million residents of Niger are among the world's poorest, with over 60 percent living below the poverty level. Many already face food and water insecurity as a daily fact of life. Climate change is projected to put this already vulnerable people on the brink of collapse.

A study of rainfall patterns for 1965–2000 showed that the climate in Niger has already undergone significant changes, with a steady decrease in both the amount of rain and the number of days of rain per year. This trend is expected to continue in coming decades. The overall decline in precipitation, along with an increase in average temperatures, will strike Nigeriens in their most vulnerable areas: agricultural production and water sources. Modeling indicates declines in vital millet and sorghum crops as early as 2025. The more water that must be diverted from dwindling sources to irrigate crops, the less there is available for humans and livestock. This will naturally lead to conflict over water sources between communities.

Other impacts of climate change in Niger will be deficits in livestock fodder, the drying up and silting of watering holes and ponds, decreased fishing, loss of biodiversity and species extinction, the encroachment of sand dunes into agricultural areas, and increased threat of famine, viral diseases, malaria, and respiratory illness.

Niger is not a major contributor to global carbon emissions, releasing just 1,109,000 metric tons in 1998. About 56 percent of emissions come from liquid fuel sources, with 42 percent from solid fuel sources, wood fires being the primary method of cooking within the country.

Niger's financial resources are limited, and while the government has produced a mitigation plan as part of its participation in the United Nations Framework Convention on Climate Change (UNFCCC), implementation may be difficult. Some options include forming livestock and agricultural cooperatives to increase the efficiency of food distribution and irrigation and encouraging the planting of crops more suited to the Sahel's climate. The government has also indicated a willingness to explore the use of renewable energy sources, including wind and solar power.

SEE ALSO: Deserts; Drought; Nigeria.

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Nigeria

NIGERIA, IN WESTERN Africa, has a population of over 144 million. It has an area of 356,669 sq. mi. (923,768 sq. km.). Nigeria is not heavily industrialized; however, it contributes carbon dioxide (CO_2) to the atmosphere through gas flaring and deforestation. These actions have significantly added greenhouse gases to the atmosphere, contributing to global warming, as is apparent in Nigeria's coastal communities that have been threatened by rising sea levels.

Rising sea levels are a prominent consequence of increased surface temperatures, which could cause a submergence of low-lying communities, such as most settlements on Nigeria's Atlantic coastline from Lagos to the Niger Delta. Change in rainfall patterns, sea-level rise, saltwater intrusion, loss of biodiversity, drought, habitat loss, and freshwater depletion and pollution are possible changes Nigeria will face in the near future. In northern Nigeria, recent reports point to increased surface temperatures, which could result in droughts. The release of CO_2 into the atmosphere through uncontrolled gas flaring (especially in the Niger Delta) is capable of exacerbating the fragile climate elements in the country. For instance, the humid, tropical areas of southern Nigeria could witness variation in climate elements (precipitation and temperature), resulting in warming of the region. Increase in rainfall and change in precipitation by 2–3 percent might be expected for the humid zones of Nigeria, and could increase evapotranspiration, leading to droughts.

Nigeria's environmental problems are worsened by excessive cultivation (resulting in loss of soil fertility), deforestation (at a rate of about 2.4 percent), oil spills, the burning of toxic wastes at dump sites, gas flaring, and increasing urban air-pollution due to transportation, use of petrol and diesel generators, and industrial activities. The amount of CO_2 and sulfur IV oxide (SO_2) emissions are growing; Nigeria was listed among 50 nations as one of the world's highest emitters of CO_2 in the early 1990s, totaling about 96.5 million metric tons. Gas flaring has been another major source of anthropogenic emission of greenhouse gases; a report estimated that over 70 percent of the 3.5 billion standard cubic ft. of associated gas produced in 2000 was flared. The World Bank also estimated that, by 2002, flaring in the country had contributed more greenhouse gases to the Earth's atmosphere than all other sources in sub-Saharan Africa combined. These practices continue, and the environmental concerns they create are alarming, leading to extreme weather damage and the risk of further problems such as the increased spread of disease.

SEE ALSO: Deforestation; Niger; Oil, Production of.

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Nitrous Oxide

NITROUS OXIDE (N_2O) is a compound of two very abundant elements on Earth, which also compose most of the gases in the Earth's atmosphere—oxygen and nitrogen. It is a colorless gas with a sweetish odor. It is known by the common name of laughing gas. It occurs naturally, and has been implicated as a potentially significant agent in global warming. Joseph Priestly first synthesized it in the 1770s. Dentists and physicians have used it as a mild anesthetic for decades. It was first used in dentistry in 1844, and more commonly after 1860. It is still used in dentistry for minor oral surgery procedures.

Many uses have been found for nitrous oxide. Because it causes people to laugh, it has been used for public and private entertainment, with no lasting physical effects. The psychological effects may last for a few minutes. The physical effects include disorientation and imbalance, vision disturbance, throbbing or pulsating hearing with hallucinations that can be auditory, visual, or both, and a deepening of the voice while the gas is being exhaled. Several dangers associated with breathing nitrous oxide include physical imbalance that can cause injury from falling. If breathed though a bag over the head, death can occur. Frostbite from the rapid expansion of the gas from a compressed state can also occur. It is also used as a propellant in cans of whipped cream, and has other foodservice uses. While not a bactericide, it can act as a bacteriostatic, which prevents the growth of bacteria without leaving an odor. The dairy industry uses it as a foaming agent because it dissolves easily in the fatty cells found in buttery cream.

Deep-sea diving can kill if decompression sickness (the bends) occurs. The cause of decompression sickness is nitrogen in high-pressure environments. Bubbles of nitrogen gas form in the fatty tissue of the body, and if not expelled slowly, can cause terrible pain and death. Nitrous oxide can help prevent the bends in deep-sea divers. Nitrous oxide allows nitrogen in the blood stream to return to the tissues without causing as many bubbles. The sport of car racing uses nitrous oxide as a booster propellant. The compound is injected into the air intake of the car. Nitrous oxide is not flammable, but it does cause more oxygen to enter into the combustion chamber so that a richer and more powerful mixture of fuel is ignited. The firing of the mixture increases the power of the engine. Nitrous oxide is easily obtained and has been abused by some. As a result, many states have attempted to criminalize its abuse.

NITROUS OXIDE AND GLOBAL WARMING

Global warming is believed to be due to the increased use of fossil fuel resources, the production of industrial chemicals, and the use of chemical fertilizers. Among the greenhouse gases that are produced by burning fossil fuels and the use of chemical fertilizers, carbon dioxide is the gas most associated with global warming; however, nitrous oxide is also implicated. It is believed that N_2O is the cause of about 6 percent of current global warming. The amount of nitrous oxide in the atmosphere is of great concern, because a molecule of nitrous oxide can absorb over 300 times the amount of infrared energy absorbed by a carbon dioxide molecule. This means that a much smaller amount of nitrous oxide can contribute immensely more to global warming than carbon dioxide. A small increase in the level of nitrous oxide in the atmosphere can have a major impact upon the global environment.

The amount of nitrous oxide in the Earth's atmosphere is increasing. In the troposphere, it is a long-lived (up to 120 years) inert gas that can be removed by reactions with sunlight. It is removed from the Earth's atmosphere mainly in the stratosphere by photolysis. Nitrous oxide is contributing to global warming because it is increasing in volume. The amount in the atmosphere increased to over 1 percent 1940–2000.

The most important natural sources of nitrous oxide are found in the gaseous emissions of microorganisms and decaying vegetation; rain forests and the oceans naturally emit significant quantities of the gas. If the soil is nearly saturated, it emits nitrous oxide. Different soils emit different amounts of the gas. If the levels were high enough, it would harm crops, but these levels have not been reached. Human sources include nylon, nitric acid production, and adipic acid production. The burning of fossil fuels is another source, but not as significant a source as was first suspected. Probably only one percent of the current levels of nitrous oxide in the Earth's atmosphere are due to burning fossil fuels.

Other sources of nitrous oxide are burning vegetation, gasoline engine exhaust that is reduced with a catalytic converter, lightening activity, and sunspot activity. Regardless of the source, the current trend is for nitrous oxide to continue increasing. With its disproportionate contribution to global warming, it has a very negative consequences. Modern chemical fertilizers are another source of nitrous oxide. Most of them use some kind of nitrate compound(s) to feed plants. Agricultural usage has been growing as the world's population has rapidly increased its demand for food.

SEE ALSO: Agriculture; Automobiles; Global Warming; Greenhouse Gases.

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Nongovernmental Organizations (NGOs)

NONGOVERNMENTAL ORGANIZATIONS (NGOS), while a comparatively modern phenomenon, have existed in the form of charitable organizations or political associations since the 18th century. During the 18th and 19th centuries, many people formed specific, community-based organizations, designed to meet specific community needs, or to advance particular policies. The issues targeted by these groups were broad in scope and included women's rights, the status of the poor, local government reform issues, alcoholism, and, later, in the 18th century, trade union issues. Many of these groups converged to work together for a common goal. A good example is the anti-slavery movement, founded in England in the late 18th century, which galvanized the establishment of many groups, that worked together to develop the World Anti-Slavery Convention (1840). Other examples include the World Alliance of Young Men's Christian Associations (YMCAs), founded in 1855, and the International Committee for the Red Cross, founded in 1863.

The term was not officially coined until 1945, when the United Nation's Economic and Social Council (ECOSOC) tried to differentiate its relationship with and participation rights for, intergovernmental specialized agencies and international private organizations. Ultimately, ECOSOC decided under Article 71, Chapter 10, resolution 288 (X) of the UN Charter that an international NGO (INGO) was "any international organisation that is not founded by an international treaty." The UN also determined that NGOs should be given suitable arrangements to be consulted on key issues. According to the Organisation for Economic Co-operation and Development (OECD), NGOs also include "profit making organizations, foundations, educational institutions, churches and other religious groups and missions, medical organizations and hospitals, unions and professional organizations, cooperatives and cultural groups as well as voluntary agencies." Colloquial terminology that identifies different types of NGOs includes the terms INGO, International NGO; BINGO, Business NGO; RINGO, Religious NGO; QANGO, Quasi NGO, and ENGO, Environment NGO.

The status of NGOs was confirmed in the three conventions arising from the Rio Summit in 1992, which defined the nature of NGOs as "major groups" and as any organization that subscribes to the conventions' objectives. These major groups include indigenous people, groups representing women, youth, workers, and farmers, local governments, the scientific community, business and industry, grassroots and religious organizations, trade unions, and other NGOs (international, national and local). All three conventions call for active partnerships with NGOs to further implementation of the articles of the convention.

There are thousands of active NGOs operating at local to international scales. According to one estimate, some 25,000 organizations qualify as INGOs (with programs and affiliates in a number of countries), up from less than 400 a century ago. Amnesty International, for example, has more than a million members, affiliates or networks in over 90 countries and territories, and employs over 300 staff in its London office alone. The International Freedom of Expression eXchange (IFEX), which was founded in 1992, is a global network of more than 60 NGOs that promote and defend the right to freedon of expression. According to the 2002 UNDP Human Development Report, nearly one-fifth of the world's 37,000 NGOs were formed in the 1990s. A 1995 UN study on global governance reports that there are nearly 29,000 INGOs. This report also found that the United States has an estimated 2 million NGOs, Russia has

65,000 NGOs, and in countries such as Kenya, up to 240 NGOs come into existence every year.

NGOs have wide scope and appeal. RNGOs include the World Council of Churches, Caritas International, the World Jewish Congress, and the International Muslim Union, while examples of political NGOs include the Inter-parliamentary Union or the work of the Socialist International. Even in the cultural arena, NGOs play an active role, as the International Pen Club and the International Confederation of Authors and Composers highlight. Finally, the activities of Amnesty International in the human rights field as well as those of Greenpeace in the field of environmental protection are well known. Many NGOs such as the World Wildlife Fund (WWF) and Friends of the Earth investigate issues that affect human and environmental welfare, and often the nexus between the two.

NGOs are constituted and operate in diverse ways. Structurally, an NGO can be a global hierarchical organization, single- or multi-issue based, grassroots, or a formally-accredited body. While there are many active international organizations such as the Red Cross, or CARE, most NGOs operate within a single country and frequently function only within a local setting. Some NGOs, such as legal assistance groups, are service-based. Many are essentially neighborhood groups established to promote local issues, such as community improvement, or street safety.

ADVOCACY AND OPERATIONAL NGOS

The World Bank differentiates between operational and advocacy NGOs, where an operational NGO focuses on the design and implementation of development-related projects, such as service delivery, and an advocacy NGO defends or promotes a specific cause.

A good example of an operational NGO is that of the work of the International Medicine Corps (IMC) in Afghanistan. In this case, the IMC instituted a vaccination campaign against measles, a disease that was identified by the World Health Organisation (WHO), to be the leading cause of half of vaccine-preventable diseases in Afghanistan. IMC first trained 170 Afghani nationals in how to vaccinate children and then led a 15-day vaccination campaign, reaching 95 percent of children between 6 and 12 months of age in the capital of Kabul. Similarly, the Green Trust, founded in 1990 as a subsidiary of WWF South Africa, oversees on-the-ground conservation projects. Projects that the trust typically coordinates include species recovery and protection, such as translocation programs for black rhino, advancing indigenous knowledge, such as the Kruger National Park and Traditional Healers Partnership Project; support for subsistence and sustainable fisheries such as the Sustainable Mussel Harvesting by subsistence gatherers along the Northern Natal Coast; development of subsistence Gill Net fisheries in Lake St Lucia; and revegetation and rehabilitation projects, such as the Agulhas Plain Bio-diversity Conservation Project, and the Greening the Cape Flats Program.

Many advocacy NGOs are political or principles based, and campaign actively to achieve broad ideals within the human rights, social justice, and environmental movements. For example, the America's Development Foundation (ADF) works specifically to provide NGOs with advocacy training and technical assistance designed to increase citizen participation in democratic processes. In Croatia, as part of a campaign to return and reintegrate populations, ADF supported Croatian NGOs advocating for democracy and human rights. This support resulted in 100 NGOs forming a coalition that lobbied for change in the Association's Law, the formation of an NGO coalition focusing on the 2000 Croatian Presidential elections, and development of NGO advocacy campaigns aimed to achieve changes in Croatian public policy relating to refugee rights and return issues.

Many NGOs have a primary educational and research focus. For example, Earthwatch promotes community involvement and, therefore, awareness of environmental issues by organizing study and field research trips. In Australia, the Marine and Coastal Community Network, is a nongovernmental project that builds community, industry, and government support for the conservation of marine biodiversity and ecological processes, and the ecologically-sustainable use of marine and coastal environments. Other examples include California's Deadalus Alliance for Environmental Education, the Texas Center for Policy Studies, Santa Fe's North American Institute, and Tijuana's ECO-SOL (Educación y Cultura Ecológica) and Proyecto Fronterizo de Educación Ambiental).

THE DIFFERENCE BETWEEN NGOS AND NOT-FOR-PROFIT AGENCIES

Despite their diversity, it is important to distinguish between NGOs and not-for-profit agencies. Unlike

NGOs which tend to emerge specifically to address certain issues, offer specific services, or advance a cause, nonprofit groups may also include other organizations, such as museums, universities, and hospitals, service-based organizations that are not necessarily independent of government, or campaigning for a cause. An NGO should also not be mistaken for a social movement per se, despite the fact that it may perform an important functional role within such movements.

The term NGO also implies independence from government, which often enables NGOs to promote, or expose activities and events in ways the government cannot. NGOs, then, need to be resourced effectively. For instance, the budget of the American Association of Retired persons (AARP) in 1999, was over $540 million, and, in 2003, Human Rights Watch spent and received $21.7 million. As such, many NGOs rely heavily on membership funds, donations, fundraising, grants, and sponsorships to resource their activities. To some NGOs, it is important to maintain financial independence from government at all times. Greenpeace does not accept donations from governments or corporations, but relies on contributions from individual supporters and foundation grants. Nonetheless, many NGOs depend in part on government funding. For example, the British Government and the European Union (EU) donated a quarter of Oxfam's budget ($162 million) for famine relief in 1998. Medecins Sans Frontieres (MSF) operates with almost 50 percent of its budget coming from government sources.

NGOs also use a wide range of operational mechanisms to achieve their goals. For example, some NGOs will operate independently, while others will form alliances for mutual gain. While convention often constructs NGO activity as occurring in the form of picketing, protests, and demonstrations, many NGOs also focus on extension, education, or diplomatic work to achieve their aspirations. Many NGOs use the media to highlight and progress their campaign objectives. In many cases, an NGO will use a combination of these methods, when and as appropriate to meet their goals. NGO groups are also active on committees, meetings and in undertaking detailed studies that help inform and promote policy debate in different areas.

For example, in Australia, The Wilderness Society (TWS), a community-based environmental advocacy organization, uses many methods to campaign for the protection, promotion, and restoration of wilderness and natural processes across Australia. These include the use of Wilderness Action Groups, volunteering, policy development, political advocacy, committee work, election campaign work, letter-writing, postcard campaigns, protests and actions, and media work. Some NGOs, such as Greenpeace, employ spectacular and unilateral actions to get their message across. A good example is Greenpeace's call for a boycott of the Shell Oil Company, in order to pressure the company to halt its proposed dumping of an oil platform into the North Sea.

Many NGOs are important employers; in 1995, CONCERN worldwide, which is an international NGO campaigning against poverty, employed 174 expatriates and over 5,000 national staff across 10 developing countries in Africa, Asia, and Haiti. NGOs are also powerful players in the international policy arena. The UNCED (UN Conference on Environment and Development) meeting in Rio de Janeiro, Brazil (1992) is a good case in point. Over 22,000 representatives from over 9,000 NGOs of the developed north and the less-developed south gathered at this Earth Summit and in the parallel global forum as major contributors.

NONGOVERNMENTAL ORGANIZATIONS AS LOBBYING FORCES

The NGO movement has also emerged as a powerful lobbying force that can claim many achievements. For example, the NGO-led International Campaign to Ban Landmines (ICBL), first initiated in 1992, laid the groundwork for the UN 1997 International Mine Ban Treaty. In the United States alone, over 500 NGOs participated in the campaign, designed to ensure a global ban on antipersonnel landmines. This campaign illustrates how NGOs can affect international law, and utilize their access to policymakers and ability to leverage resources to good effect. Over 140 countries throughout the world have since ratified the treaty.

Bayne argues that the presence of NGOs were "particularly effective in hardening the EU's position on genetically modified food" and that NGOs had a major influence on the World Trade Organization (WTO) meeting in Seattle, by affecting the negotiating positions of governments. The formation of the Kyoto Protocol on Climate Change (1997) is often credited to the pressure brought to bear on governments by environmental NGOs. Many argue that NGOs have been very successful in ensuring that policy debate is now framed in environmental terms, and are particularly credited for changing the status of environmental issues, from being the domain of a politicized few, to that of the general interest of civil society.

NGOs often work collaboratively to achieve their goals. In Australia, a major conservation campaign effort from a coalition of environmental NGOs, including the Australian Marine Conservation Society (AMCS), the Australian Conservation Foundation (ACF), Cairns and Far North Environment Centre (CAFNEC), and the World Wildlife Fund for Nature (WWF), was a major force in the re-zoning of the Great Barrier Reef World Heritage Area. NGO lobbying helped ensure that the Australian Government rezoned the Great Barrier Reef World Heritage Area to protect 33 percent of the Great Barrier Reef Marine Park (GBRMP) in a network of no-take sea sanctuaries, or green zones. This was a major achievement, as previously, only 4.5 percent of the GBRMP was fully protected from fishing.

In the Americas, an extensive NGO campaign, the environmental right-to-know (RTK) movement has been mounted to ensure that Mexico's Pollution Release and Transfer Register (PRTR) is consistent with those in the United States and Canada. The only consistent lobbying for the PRTR in Mexico has been from the NGO sector, which, supported by funding from the UN Institute for Training and Research (UNITAR) and elsewhere, has undertaken a wide range of activities to further their goals. These included the development of a website, operation of a listserv, the conduct of conferences and workshops, meeting with United States and Canadian counterparts, providing training to corporate executives on inventories, and expanding public outreach through community organizing, as well as through media events. In response to these campaigns, the Mexican government, in 2001, reformed the environmental law to call for the mandatory public register. In this instance, Mexican NGOs operated on the basis of collaboration rather than confrontation, and, today, are seeking alliances with promoters of Mexico's new freedom-of-information act, as part of a broader campaign, in conjunction with Latin America, to further their aspirations.

Some NGOs are developing partnerships with industry, as with the Marine Stewardship Council initiative, which brings together the international NGO, World Wide Fund for Nature (WWF), and the multinational company, Unilever, which is one of the world's biggest buyers of frozen fish. Together, these groups have worked to address global issues of over-fishing, and have developed an eco-certification scheme for major fisheries. Over 40 fisheries are part of the MSC program, which constitutes about 3 million tons of seafood. A total of 14 of these fisheries, such as the Pacific Cod fishery, are now certified by the MSC as having attained a sustainable eco-standard.

NGOs, then, have emerged as significant actors in domestic and international societies. They have done so in both institutionalized and independent ways. In the human rights and environmental field, NGOs have served as agents of change and forces for the public good for the protection of human and environmental welfare. Amnesty International and WWF serve as good examples of human rights and environmental protection NGOs, respectively. While they are international NGOs, they operate by working locally to achieve specific goals in specific regions.

EXAMPLES OF IMPORTANT NGOS

The WWF has been campaigning on environmental issues for over 40 years. It has almost 5 million supporters across five continents, and is active in over 90 countries. Since 1985, this support has enabled it to invest over $1,165 million in more than 11,000 projects in 130 countries. The organization works in three interdependent areas: the preservation of biological diversity, the promotion of sustainable use of resources, and the reduction of wasteful consumption and pollution.

Conversely, Amnesty International is a worldwide NGO focusing on human rights campaigns. Amnesty International conducts its business within its vision of a world "in which every person enjoys all of the human rights enshrined in the Universal Declaration of Human Rights and other international human rights standards." The notion of independence is strongly articulated by Amnesty, which asserts that it is "independent of any government, political ideology, economic interest or religion. It does not support or oppose any government or political system, nor does it support or oppose the views of the victims whose rights it seeks to protect. It is concerned solely with the impartial protection of human rights." Amnesty International has more than 1.8 million members, supporters, and subscribers in over 150 countries and territories across the world. While it is an international NGO, Amnesty operates through national and local volunteer groups who also raise funds for the organization, while an International Council comprised of national representatives takes major policy decisions. Amnesty International runs a wide range of human rights campaigns, including: women's rights, anti-torture, economic globalization and human rights, refugee, and child soldier campaigns. Amnesty's work often achieves results. For example, since Amnesty started highlighting campaigning on specific cases of Guantánamo detainees, 15 of them have been released from U.S. detention.

Friends of The Earth (FoE) is an example of a NGO that works toward both human rights and social justice and environmental issues, recognizing that the two are intertwined and need to be addressed together. FoE operates as a federation of autonomous environmental organizations from all over the world, and has a membership of 1.5 million in 70 countries across the world. FoE members and local groups campaign on urgent environmental and social issues, while advocating a societal shift toward sustainable societies. While FoE campaigns on many issues, it is currently focusing on climate change, which it identifies as the biggest environmental threat to the planet. Campaign foci have included: demanding strong national emissions reductions targets, the initiation of lawsuits against major polluters, such as oil corporations, challenging a number of big oil projects around the world projected to accelerate climate change, and joining forces with climate-affected communities to facilitate a global movement that will redress social and economic equity issues between and within countries.

CRITICISMS OF NGOS

The NGO movement, however, is not without its critics. Many question the accountability of NGOs. For example, the work undertaken by World Vision, in coordinating the relief effort resulting from the Tsunami in South East Asia in 2005, has sustained attacks that the donated monies, millions of dollars in this case, were not reaching the intended victims. Many NGOs working in developing countries are partly funded by their own governments, and have been criticized as being a front for foreign government policy. Critics argue that this makes NGOs accountable to their funders, not the people they work with. This division has often been characterized within a debate about northern (Western) vs. southern (developing world) NGOs.

For example, many African governments see the establishment of NGOs from Western countries as Trojan Horses, designed to promote neo-colonialist agendas. Many developing countries also resent the fact that international NGOs will come into their own countries and establish programs, rather than funding local NGO groups to undertake the same work. As such, the arrival of NGOs can be perceived to actually deny local individuals, councils, and industries of employment, and other opportunities that now flow to and from the foreign NGO, while creating upheaval in local power relations in culturally inappropriate ways. Some countries such as Zimbabwe, Eritrea, and the Sudan have gone so far as to pass laws that effectively limit the operations of foreign-funded NGOs within their borders.

In some cases, NGO focus has been accused of being too narrow, ignoring the effects of their activities on other areas. For example, environmental NGO work can focus on biodiversity imperatives at the expense of cultural heritage or social justice needs. In Australia, the biodiversity work of environmental NGOs has occasionally been critiqued as opposing cultural heritage priorities, and constituting another form of indigenous dispossession. The dependence on donors of many NGOs also lays them open to criticisms that they are not independent, and, thus, may be inappropriately partisan in their approach. For example, CARE International came under attack for not acting to oppose the war in Iraq, with critics claiming this was due to CARE's dependence on U.S. and other funding. Oxfam has been accused of diluting its campaign against poverty in Africa as a result of being too close to the British government.

Finally, NGO effectiveness is often questioned. Again, this is an issue of accountability with which NGOs grapple. Thomas Carroll addresses this by defining an industry standard for the evaluation of NGO performance. These standards include: development services (measured by service delivery and poverty reach), participation and empowerment (measured by responsiveness and accountability), and wider impact (measured by innovation and impact on policy). Michael Edwards and David Hulme (1996) also outline some dimensions for determining the effectiveness of NGOs, including poverty reach, cost effectiveness, sustainability, participation, flexibility, innovation, and democratization.

While NGOs rarely have few formal powers within international or local decision-making structures, they have successfully advanced many human rights, and environmental agendas. These have included the promotion and development of core environmental agreements and policies; strengthening the rights of women, children, and the disabled; advancing indigenous rights and issues; establishing programs to address health, education, and poverty, and significant measures in the area of disarmament and peace negotiations.

SEE ALSO: Developing Countries; Friends of the Earth (FoE); United Nations; United Nations Development Programme (UNDP); United Nations Environment Programme (UNEP); World Wildlife Fund (WWF).

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North Atlantic Oscillation

THE NORTH ATLANTIC Oscillation (NAO) is quasi-periodic shifts in the relative strength of the quasi-permanent centers of high atmospheric pressure over the Azores and low atmospheric pressure between Greenland and Iceland (the Azores High and Iceland Low). It is a major large-scale mode of the atmospheric circulation over the extratropical ocean in the Northern Hemisphere. The NAO intensity is at a maximum in winter. It governs the large-scale variability of hydrometeorological fields over the North Atlantic, North America, and northern Europe, as became clear after a pioneer paper published by Sir Walker and co-author in 1932. Recently, the NAO has been set in a broader spatial context of hemispheric climatic variations, both at the surface and aloft as follows, for instance, from generalized publications of John Marshal, et al., and Alexander Polonsky, et al.

As a measure of NAO, a special index is often used. This index is the normalized (by standard deviation) difference between sea-level pressure (SLP) in the Azores High and Iceland Low. Difference of absolute values of SLP between Azores High and Iceland Low is a similar measure of NAO. It is sometimes called the Rossby index (in memory of famous meteorologist). The annual mean value of SLP in the Azores High 1890–1990 was about 1024 hPa, while in the Iceland Low it was about 1006 hPa. So, the yearly difference of SLP in the Azores High and the Iceland Low is about 18 hPa. Amplitude of annual harmonic of the Rossby index is about 5 hPa. The amplitude of the semi-annual harmonic is about half the annual one.

The Rossby index value is calculated as the SLP difference between meteorological stations situated in the vicinity of the Azores High and the Iceland Low (for example, Lisbon, Portugal, and Reykjavik, Iceland) is smaller by a few hPa in comparison with the value calculated as difference in centers of atmospheric action defined as positive and negative extremes of SLP in the subtropical and subpolar North Atlantic region. It is as a result of the temporal and space migration of atmospheric centers of action. The study of displacement of the centers of Azores High and Iceland Low using approximately 100-year data sets provided by Hunter Machel et al. and Alexander Polonsky et al. has shown that just the space state of these centers during different NAO phases plays the important role in generating of European climatic anomalies.

The NAO index (NAOI) has two relatively stable states, positive and negative. They are due to high and low NAO phases. The positive NAO phase is characterized by NAOI values exceeding the mean of the NAOI by the standard deviation or more. The negative phase is characterized by the opposite conditions. Long-term series of the NAO index show that it varies at all timescales, from days and weeks, to decades and longer. Typical scales of NAO variations that influence strongly the European climate are the interannual-to-decadal. Spectral and wavelet analyses of fluctuations of the NAO and Rossby indices for more then 100 yeas between the late-19th and early-21st centuries reveals dominant significant peak at the periods of approximately six to nine years. The same scales of variability are typical for different hydrometeorological fields over most of Europe. NAO dominates in winter, when a significant portion of North Atlantic and European climate variability is due just to NAO.

CLIMATE CHANGES ASSOCIATED WITH THE NORTH ATLANTIC OSCILLATION

Variations of zonal circulation intensity over the North Atlantic and displacement of centers of atmospheric action lead to significant climate changes over Europe. The pressure gradient between the Azores High and the Icelandic Low determines the strength of the mid-latitude westerly and, hence, the transport of relatively warm and humid air from the North Atlantic to Europe. During the mid-1990s James Hurrell and others showed that, on the interannual-to-decadal scale, the NAO intensification (or positive phase of NAO) is accompanied by displacement of the Azores High and Iceland Low to the north-northeast. At the same time, the zonal atmospheric circulation over the North Atlantic and Europe, and zonal winds in the low troposphere within the band restricted by 50 and 60 degrees N are strengthened. This accompanies displacement of pathways of most North Atlantic cyclones to northern Europe and associated increases in air temperature and precipitation there, while the anticyclonic hydrometeorological conditions prevail over central, southern Europe, and the Mediterranean region. The reverse tendency is observed during negative NAO phases, when the Azores High and Iceland Low shift to the south-southwest, and the westerly weakens. It is accompanied by more frequent cyclonic conditions over European regions close to the Mediterranean Sea and Middle East, while more frequent anticyclones occur over northern Europe.

Climate change is accompanied by a tendency of NAO strength and reduction of distance along latitude between the Azores High and Iceland Low in the 20th century. This and superimposed multidecadal North Atlantic variability lead to much more pronounced impacts of NAO on the European climate after approximately 1960. Some ideas about the NAO focus on the North Atlantic basin itself, invoking, for example, stochastic atmospheric forcing of the ocean, mixed, wind-driven, and thermohaline advection, and fully -oupled ocean–atmosphere modes in the North Atlantic region. It has also been suggested that the NAO may be teleconnected to the tropical Atlantic, as well as a local manifestation of a hemisphere-wide oscillation centered over the Arctic. At the same time, as shown by Gidon Eshel, NAO may be generated by processes in the North Pacific coupled system, which impacts the North Atlantic through the atmospheric bridge.

SEE ALSO: Agulhas Current; Arctic Ocean; Atlantic Ocean; Oceanic Changes; Oceanography.

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North Carolina

NORTH CAROLINA HAS an area of 53,819 sq. mi. (139,390 sq. km.), with inland water making up 3,960 sq. mi. (10,256 sq. km.), and territorial water 1,148 sq. mi. (2,973 sq. km.). North Carolina's average elevation is 700 ft. (213 m.) above sea level, with a range in elevation from sea level on the Atlantic Ocean, to 6,684 ft. (2,037 km.)at Mount Mitchell. North Carolina's topography separates the state into three regions: the Atlantic Coastal Plain (making up almost half of the state, where it is flat and slopes to sea level), the Piedmont (making up the other half of the state, inland from the coastal plain, rolling to hilly), extending to the mountain region (a very tiny area on the western border, part of the Appalachian Mountains). The shoreline has numerous bays and estuaries. The sandbars of Cape Hatteras, Cape Lookout, and Cape Fear extend far out into the Atlantic Ocean. Offshore are the barrier islands. The outermost barrier islands are called the Outer Banks, enclosing Pamlico Sound. Rivers and streams east of the Blue Ridge Mountains drain east toward the Atlantic. Those west of the Blue Ridge Mountains drain toward the Mississippi River. North Carolina has many natural lakes and swamps.

North Carolina has a humid subtropical climate with few temperature extremes and precipitation in all seasons. January temperatures average in the 40s to 50s degrees F (4–10 degrees C), cooler (mid- to high-30 degrees F, or 2–3 degrees C) in the mountains. Summers are hot (with daytime temperatures at lower elevations rising into the low 100s degrees F (about 40 degrees C), and the mountain areas staying cooler. The highest temperature recorded in the state was 110 degrees F (43 degrees C) on August 21, 1983 and the lowest temperature recorded in the state was minus 34 degrees F (1.1 degrees C) on January 21, 1965. The annual precipitation is fairly distributed over the state, with an average of 40–50 in. (102–127 cm.), though the mountains receive much more up to 80 in. (203 cm.) from air currents from the Gulf of Mexico. Rainfall is highest during the summer; autumn can be rainy along the coast. Winter snowfall is more prevalent in the mountains, though some can fall on the Atlantic Coastal Plain and the Piedmont.

North Carolina farmers produce a wide range of products (tobacco, soybeans, cotton, corn, poultry, hogs, and wheat). North Carolina takes advantage of its coastline for commercial fishing. Forests cover over half of North Carolina's land, lumber is produced in all areas of the state, and tree growth is rapid in the mild, moist climate. The state is known for furniture manufacturing, tobacco products, textiles, chemicals, industrial machinery, and electrical equipment. Fossil-fuel (mostly coal) burning steam plants, nuclear power plants, and hydroelectric power plants produce electricity.

IMPACT OF CLIMATE CHANGE

North Carolina is already experiencing the effects of rising sea levels (Long Bay raised 2 in. (51 cm.) in the last century) and eroding coastlines. In 1999, the Cape Hatteras Lighthouse was moved inland 2,900 ft. (884 m.) to prevent its collapse into the Atlantic. Rising temperatures and reduced rainfall 1999–2002 caused a severe drought. Climate models vary on temperature increases for North Carolina, from 1–5 degrees F (0.5–2.7 degrees C) in all seasons (less change in winter and summer, and more change in autumn and spring) by the end of the century. Potential risks include anticipated rising sea levels of an additional 12 in. or 31 cm., (causing loss of coastal wetlands, beach erosion, saltwater contamination of drinking water, and damage/decreasing stability of low-lying property and infrastructure) along with population displacement.

North Carolina's shoreline is especially susceptible to rising sea levels and tidal changes. Coastal marsh area could expand into low-lying areas and current coastal wetlands could disappear. North Carolina experiences frequent hurricane activity and landfall, and higher sea levels would have the potential to cause more damage with the storm surge. Higher temperatures could cause an increase in frequency and intensity of summer thunderstorms, causing flash flooding, decreased water supplies, changes in agriculture (cotton yield unaffected, rising corn and hay yields, and lower yields of wheat). While the forests may not change much, the types of trees growing in the forests could change with loss of trees unsuited to higher temperatures.

Human health risks include contracting certain infectious diseases from water contamination or disease-carrying vectors such as mosquitoes, ticks, and rodents. Warmer temperatures would increase the incidence of heat-related illnesses and lead to higher concentrations of ground-level ozone pollution, causing respiratory illnesses (diminished lung function, asthma, and respiratory inflammation).

ADDRESSING HUMAN-INDUCED CONTRIBUTIONS TO CLIMATE CHANGE

Based on energy consumption data from the Energy Information Agency released June 1, 2007, North Carolina's total carbon dioxide emissions from fossil fuel combustion in million metric tons for 2004 were 150.16, made up of contributions by source from: commercial, 4.99; industrial, 16.49; residential, 7.31; transportation, 51.99; and electric power, 69.38. The Renewable Energy and Energy Efficiency Portfolio Standard became law on August 20, 2007, creating a target for electric public utilities to supply 12.5 percent of electricity from renewable energy or energy efficiency measures by 2021, and electric membership corporations and municipalities that sell electric power in the state to supply 10 percent of electricity from renewable sources by 2018.

North Carolina passed a bill in 2005 to appoint a commission to explore issues related to climate change. North Carolina established the Global Warming Commission, with members representing policymakers and stakeholders, to evaluate options for dealing with the impact of global warming and mitigation of greenhouse gas emissions. North Carolina joined the Climate Registry, a voluntary national initiative to track, verify, and report greenhouse gas emissions, with acceptance of data from state agencies, corporations and educational institutions beginning in January of 2008. Incentive programs to increase energy efficiency include the Energy Improvement Loan Program, low interest loans for individuals and organizations to make energy efficient improvements and develop renewable energy systems including biomass, the use of methane production from agricultural waste to generate electricity.

SEE ALSO: Biomass; Greenhouse Gases; Sea Level, Rising.

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North Dakota

OVER THE LAST century, North Dakota has seen an average rise in temperatures of approximately 3 degrees F (1.6 degrees C), with some areas experiencing average increases of 5.5 degrees F (3 degrees C). Correlatively, during this time most of North Dakota has experienced a decrease in annual precipitation of 10 percent. While regional climate change forecast models are far from conclusive, it is estimated that North Dakota will prove highly susceptible to climate change through 2100, with average temperatures continuing to increase approximately 3–5 degrees F (1.6–2.7 degrees C). Conversely, future precipitation is expected to increase by 5–10 percent during the spring and summer months and 15–25 percent during the fall and winter, respectively.

The combination of rising temperatures and winter precipitation amounts therefore trends toward earlier and more dramatic spring snowmelts and higher stream-flow conditions in winter and spring, with an expected increase in potentially significant flood events such as the 1997 Red River flood of Grand Forks that destroyed nearly 90 percent of the city and caused over $1 billion in damage. Meanwhile, without large increases of precipitation, warmer summers and increased evaporation will lead to lower groundwater levels. This could have a variety of effects on both society and wildlife, causing lower water-quality and quantity levels and an increased need for irrigation practices, while ecologically threatening North Dakota's Prairie Pothole Region of wetlands, the key breeding home of over half of all U.S. waterfowl. A further concern is that such climate changes could increase the incidence of insects such as ticks and mosquitoes, leading to a rise in diseases such as Lyme disease, West Nile Virus, and malaria.

While North Dakota is one of the least populated states in the United States, ranking 47th out of 50, it produces enough greenhouse gas emissions to rank as a world-class polluter. This is largely in the form of methane from livestock production (a $1 billion industry comprising one-third of the state's agricultural sector), an ongoing net loss of carbon sequestered in soils (estimated at a near 20 percent loss over the last 150 years), and a dramatic increase in carbon dioxide emissions from coal production over the last few decades (now over 30 million short tons per year, up from fewer than five million tons in 1970). The state belongs to voluntary climate change initiatives such as Powering the Plains, developed by the Great Plains Institute, and the Western Governors' Association Clean and Diversified Energy Initiative. However, North Dakota has not yet committed to a strong mandatory policy for achieving suitable greenhouse gas emissions reduction.

Alternative energy sources such as solar and wind power could make valuable future contributions to North Dakota's economy and sustainability profile. North Dakota is believed to be the state with the largest overall capacity for wind power, and it has been estimated that, if wind turbines were maximally deployed, North Dakota could not only fully supply its own power needs, but it could generate upwards of 36 percent of the electricity currently required by the entire nation. However, wind energy has notoriously threatened birds. The state's 318 avian species provide not only important economic value through tourist bird watching, but occupy essential agro-ecological niches as plant pollinators, seed dispersers, and pest predators.

SEE ALSO: Alternative Energy, Wind; Floods; Policy, U.S.

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Norway

THE POPULATION OF Norway is less than 5 million. Norway emits only 0.2 percent of the world's greenhouse gases. However, greenhouse gas emissions increased approximately 10 percent 1990–2004. According to modeling scenarios, Norway will experience a 1.2 percent increase in yearly temperature degrees C compared to 1980–2000. Northern Norway will experience the highest yearly increase compared to other regions of the country. Norway has ratified the Kyoto Protocol and committed to stabilizing emissions at 1 percent above the 1990 emission level. Without new measures, emissions are expected to increase to 22 percent above the Kyoto commitment 1990–2010.

In the early 1990s, Norway began introducing policies to control greenhouse gas emissions. One of the first measures was a tax on carbon dioxide emissions introduced in 1991. Greenhouse gas emissions are also controlled through a license system under the Pollution Control Act, taxes to reduce methane emissions from landfills, and a system for emissions trading. From early 2005, an emissions trading system was introduced for 2005–07 (covering about 10–15 percent of Norway's greenhouse gas emissions). This is similar to the European Union (EU) emissions trading system, and includes carbon dioxide emissions from industries not subject to the emissions tax. Norway has a comprehensive policy for energy efficiency, focusing on the increased use of renewable resources and supports research and development into carbon capture and storage in North Sea geological structures, hydrogen technology, and wind power. Established in 2005, the Norwegian Commission on Low Emissions has committed to reducing emissions to two-thirds of 1990 levels by 2050 and has recommended the adoption of tax incentives for low-emission cars, electrifying oil fields with hydropower, and banning the disposal of organic waste in landfills.

Global warming will affect Norway's natural resources in diverse ways. Higher temperatures may result in the increased growth of fish, as well as more parasites and algal problems. While climate change will negatively affect cod (the most valuable catch in Norway), higher temperatures may have favorable effects for other species, including herring (the second most economically significant fish), and an increased growth rate of farmed fish. Warmer temperatures may result in the availability of more productive forestland, based on an anticipated higher tree line elevation and the expansion of the forest in northerly and westerly directions. Increased carbon dioxide concentrations and higher temperatures will likely result in an extended growing season, allowing harvesting twice a year, and increased plant productivity. An increased use of pesticides and herbicides and discharge of nitrogen would be expected due to erosion and loss of nutrients through runoff, and because higher temperatures speed up soil processes.

SEE ALSO: Kyoto Protocol; European Union; Emissions, Trading.

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Nuclear Power

PRESIDENT GEORGE W. Bush, in a June 2005 speech delivered to a group of nuclear power plant workers intoned, "The 103 nuclear power plants in America produce twenty percent of the nation's electricity without producing a single pound of air pollution or greenhouse gases." Experts in the nuclear energy field, both for and against nuclear energy, find this statement lacking credibility. Nuclear energy critics cite the significant amount of greenhouse gases produced by the nuclear fuel cycle in aggregate. Not surprisingly, proponents of nuclear power generation focus on the reactors themselves, which produce nothing but water vapor from the cooling towers.

NUCLEAR POWER AND THE ENVIRONMENT

As a stand-alone device, nuclear reactors do not emit greenhouse gases. The nuclear reaction is contained and the heat generated is used to boil water to turn turbines and produce electricity. Instead of a chemical reaction, an atomic reaction is required, produced by a process of fission using uranium fuel. Due to the splitting of atoms and the radioactive movement of neutrons, no carbon dioxide, methane, or other greenhouse gases are produced. However, the byproducts are toxic, radioactive wastes requiring storage for thousands of years. Analyzing the entire nuclear cycle, including the upfront uranium mining and refining, reveals that large amounts of fossil fuels are required. This, in part, is where the greenhouse gases come from. Such steps are also required to produce aluminum. The difference is that aluminum-based products can be recycled and reused in other forms.

With uranium, the atomic alteration it undergoes to boil water cannot be reversed. Like fossil fuels, uranium is a non-renewable resource. Recent reports from the International Atomic Energy Association (IAEA) reveal that the mining of easy uranium in places like Saskatchewan, Canada and Australia will run out around 2020, while the cost to extract it rises significantly. This uranium supply aspect of the nuclear cycle is like that of the disappearing petroleum feed stocks.

Another aspect of nuclear power production is the dangerous chlorofluorocarbons (CFCs) dumped into the atmosphere during the enrichment of uranium, a complex technique needed to make the uranium suitable for use in fission reactors. It is so complex that only the United States, Britain, France, Germany, the Netherlands, and Russia export enriched uranium to other countries for use in their reactors. Regardless of the source, the enrichment process itself produces CFCs, which destroy the ozone layer. Furthermore, the CFC byproducts are 10,000 to 20,000 times more capable of holding heat in the atmosphere than carbon dioxide.

Like the oil industry, the nuclear industry is highly subsidized. This was reinforced in the U.S. Energy Act of 2005, which allocated $13 billion in subsidies. One of the rationales given is that nuclear-generated electricity will wean Americans from dependence on oil and strengthen national security. Looking at electricity generating statistics published by the Department of Energy (DOE) refutes this fallacy. In 2005, petroleum products fueled only 3 percent of electrical consumption. The bulk of the nation's petroleum is used for transportation, not for the production of electric power. In this energy-hungry sector, gas-electric hybrids and revitalized electric vehicles are being called upon to reduce petroleum consumption.

Nuclear power supplies 18 percent of the world's electricity, with countries such as France deriving 78 percent of their supply that way. In America, no new plant has been brought online since 1996, even as 19 percent of U.S. electrical production is derived from nuclear power. However, the dynamics of the nuclear industry have intensified with the rising public awareness of global warming. Relatively speaking, nuclear power is a kinder, gentler source of power for the climate. With this in mind, and the desire to meet its Kyoto commitment, Finland recently approved the world's largest nuclear reactor, at 1600 megawatts, to be brought online by 2009. Furthermore, the United States is giving nuclear technology to India to support their plans to build eight new reactors, in a deal struck in 2005. Comedians regularly lampooned the 2007 Bush administration for promoting nuclear energy as the foil to global warming, yet the federal government refuses to sign the Kyoto protocol.

RENEWABLE ENERGY SOURCES AS AN ALTERNATIVE TO NUCLEAR POWER

Building and commissioning massive, complex nuclear plants requires huge government subsidies. Contrast this with wind or solar energy that are distributed and less dense supplies of energy. The amount of solar panels produced on an annual basis is equivalent to the construction of two nuclear facilities. The renewable solar approach seems simpler and safer, and not one requiring subsidies. Such sound

Approximately 30 new nuclear power plants are under construction and another 200 are in the planning phase around the world. The United States has 49 new nuclear plants in the planning stages.

bytes are bolstered by the Rocky Mountain Institute, which believes that none of the centralized generating technologies, be it nuclear, coal, or natural gas, can compete with solar, wind, or other renewable sources in their efficiency and projected price drops over the coming decades. Already, in places like California, even without government subsidies, the 30-cent per kilowatt-hour crossover point has been achieved. Pacific Gas and Electric (PG&E) produces electricity in the summer at this cost, which is inline with the cost of a residential solar installation. While utility rates are trending upward, the cost of solar installations is dropping. Many advocates believe the time has come to shift from a centralized model of power distribution to a distributed one.

Renewable energy is everywhere, easy to tap, cheap to harness, and above all, human and climate friendly. It has the added bonus of feeding surplus electricity back into the electric grid. Nuclear power, however, provides tough competition with its powerful lobby claiming it is the best carbon displacer. A 2003 Massachusetts Institute of Technology study revealed that people concerned about global warming are neutral on the role of nuclear as either a solution or a problem in the climate crisis debate. What is not highlighted for the public is that for every $1,000 spent on nuclear reactors, another 10 tons of carbon dioxide is released into the atmosphere because renewable energy investment was denied these funds. Some executives, such as the head of PG&E, who manage nuclear reactors, have concluded that global warming is a major threat. While PG&E has not advocated the building of new nuclear facilities, the company is investigating the use of solar thermal, a technology relying on focused sunlight to boil water and drive a turbine to produce electricity. The head of the Southern Company holds the opposite position. In their 2005 annual report, this large utility in the southeastern United States claimed that, "... nuclear energy must remain an option for expanding our generating fleet because it has proven to be safe, reliable, and cost-effective, with relatively low environmental impact." Here are two different views from two different coasts on generating power for the future of American consumers, and both claim to want to better address the environment.

Global warming makes it tricky operating nuclear power plants. The European heat wave of 2003 caused river levels in France to fall, more so than usual, owing to the lack of rainfall. Electricité de France, the French power company, employed reservoir-fed high-pressure hoses to cool its nuclear plants. This partial solution was not enough and heated, secondary cooling water was discharged into the river. This 25 degree C water is a source of thermal pollution and a danger to aquatic life, and in an ironic twist, one of the symptoms of global warming is rising water temperature. Nuclear cooling water can contribute directly to warmer water, rather than indirectly doing so via the carbon dioxide route. In fact, global warming itself may be the reason for closure of nuclear power plants in the future.

Another factor when considering closing plants is the safety concern raised about nuclear facilities operating in geographies prone to earthquakes. A 6.8 temblor in July 2007, injured and killed people in Japan and forced the evacuation of thousands of people, while igniting a fire in a nuclear power plant. Japan operates 55 nuclear reactors within its boundaries, which generate 30 percent of its electrical supply. Although all of the affected reactors were shut down, more than 300 gallons of low-level radioactive water was dumped into the sea. While investigations continue, people remain jittery about the ability of nuclear facilities to remain safe during an earthquake. Furthermore, the reliance on nuclear as a centralized power source is hampered when plants are shut down. Power is removed from areas beyond a natural disaster, just when emergency workers and hospitals need electricity most.

For each ton of solid reactant carbon, 3.7 tons of carbon dioxide gas products are released into the atmosphere. The prevailing theory for global warming is based on the fact that an increase in atmospheric carbon dioxide concentrations leads to an increase in the average global surface temperature. Although carbon dioxide accounts for half of the associated temperature rise, other gases contribute to the balance. Methane from rice paddies and herds of cattle and chlorofluorocarbons from the nuclear fuel cycle and other industrial processes contribute, in part, to the second half of the temperature rise. Some analysts of the nuclear fuel cycle believe that as less accessible uranium is mined after 2020, more fossil fuel will be required to extract the uranium than would be to burn the petroleum directly. Going forward, the receding source of uranium will result in the production of more greenhouse gases those that produced by petroleum-fired generating plants.

THE FUTURE OF NUCLEAR INTERESTS

Safety concerns aside, the perceived atmospheric-friendly power produced by nuclear means that the next few decades for nuclear power generation and production of uranium are solid. Approximately 30 new nuclear plants are under construction and another 200 are in the planning phase around the world. Even the nuclear reticent United States has 49 such facilities in the planning stages, the last one was approved almost 30 years ago in 1979. The resurgence of nuclear power, owing directly to rising energy costs and the global warming phenomenon, has bolstered the stocks of uranium mining companies. These operators have seen spot prices for processed uranium ore rise from $10 a pound to over $130 a pound. Uranium has become a hotter commodity than silver, gold, or steel during the early 21st century because forecast demand will rapidly escalate as new nuclear plants, added to the existing 434 facilities worldwide, are brought online.

Government interest is high in promoting nuclear power, too. As part of the Bush Administration's 2005 Energy Bill, the White House authorized the Department of Energy to achieve the following: ensure by 2050, that the United States and the rest of the world's electricity needs are met by more than 30 percent of it being driven by nuclear power, establish an effective international proliferation regime, where there are nuclear fuel states and nuclear reactor states, and reestablish the United States as the leader in nuclear energy.

The current open fuel cycle used by the United States for its 103 nuclear power plants creates a massive problematic waste stream. If the United States started to store spent nuclear fuel at Yucca Mountain, the proposed U.S. Department of Energy storage facility for spent radioactive waste, it would immediately fill the facility. The challenge is to shift the process from an open to a closed fuel cycle. If not, 10 Yucca Mountain nuclear storage facilities would have to be built, with 10 times the space available at Yucca to store nuclear materials. With this in mind, the move to a closed fuel cycle will likely be made, and a smaller, cooler nuclear waste stream could result. The nuclear industry is pressing for this outcome, as well as for the use of Yucca Mountain as soon as possible.

It appears the U.S. government is on a fast track to implement strategies that make nuclear research, development, and deployment happen. This quest is reminiscent of the Space Race of the 1960s, when the United States sought to overtake the Soviets. Nuclear power in the eyes of the public has gone from the status of a pariah to a savior. Industry and government policy reinforces this perception. By looking at nuclear power plants through green-colored glasses, many see the reactor's performance of producing greenhouse gases at an outstanding level of zero. Without the glasses, those viewing the entire nuclear cycle see it as a contributor to global warming and the depletion of the world's uranium stocks as another example of unsustainable behavior.

SEE ALSO: Alternative Energy, Overview; Automobiles; Climatic Data, Atmospheric Observations; International Institute for Sustainable Development (IISD).

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Ocean Component of Models

CLIMATE MODELS ARE computer simulations representing the Earth in layers and boxes. These models use complex mathematical equations to determine future climate possibilities based on parameters of baseline conditions and changing variables, like increased greenhouse gases, and rising temperature. The equations in the separate cells are used to mathematically calculate numerous conditions including the flow of heat, moisture, sunlight, wind, and the condition of the adjacent cells. Early climate models provided uncertain projections because the equations failed to include the dynamics of the little-understood ocean circulation. Two-thirds of the Earth is covered by ocean, which acts as a heat reservoir and a heat transport system; changes in the ocean can cause widespread changes in climate. Every few years, a warming of the eastern Pacific near the equator creates El Niño conditions, altering rainfall and temperature patterns.

The ocean plays a central role in climate variability, modifying the flux of heat into the atmosphere, stimulating changes in the atmospheric circulation, which, in turn, modify the general circulation of the ocean. Studies of annually-averaged air-sea heat exchange have shown that a large transfer of heat from the ocean to the atmosphere occurs downstream from the subtropical western boundary currents.

EXAMPLES OF MODELS WITH OCEAN COMPONENTS

The addition of ocean circulation to climate models is the result of numerous studies that determined the circulation patterns of the ocean with fluid motion. These include the World Ocean Circulation Experiment, with nine years (1990–98) of observations (physical, chemical, and satellite), by approximately 30 nations to determine the baseline conditions for assessing future climate change. The second phase of the World Ocean Circulation experiment was Analysis, Interpretation, Modeling, and Synthesis, ending in 2002. Sophisticated numerical ocean models were also developed to provide a framework for the interpretation of the observations and for the prediction of the future ocean state.

The World Climate Research Programme is studying climate variability and predictability (CLIVAR), with research focusing on interactions between the ocean and the atmosphere and collaboration with companion research projects to study the role of the land surface, snow, ice, and stratospheric processes in climate.

The Global Ocean Data Assimilation Experiment (GODAE) began in 1997, to develop better ocean observations and ocean forecasts utilizing improved technology (in-situ and remote) to observe, measure, model, and assimilate data available worldwide to researchers needing comprehensive ocean and marine data and forecasts.

The Argo project, begun in 2000, deploys 3,000 profiling floats (spaced approximately 3 degrees apart throughout the world's oceans) to collect temperature, velocity, and salinity measurements on the physical state of the upper ocean, with emphasis on seasonal and decadal variability. The collected data will be used for initializing ocean and coupled ocean-atmosphere forecast models, data assimilation, and model testing.

With increasing data on ocean physics, chemistry, and biology, improved models are being created, incorporating the ocean component into computer models, and using more complex computing systems. The Parallel Ocean Program is a publicly available model developed at Los Alamos National Laboratories, using ocean circulation with depth as the vertical coordinate. Researchers, in adapting the Parallel Ocean Program for parallel computers to improve performance, also enhanced the model's physical representation of the real ocean. Higher resolution simulations have shown greater agreement with observations of sea-surface height variability in the Gulf Stream.

The Open Ocean Slab model includes sea ice in its component for figuring the ocean component mixed-layer temperature, including density of ocean water, heat capacity of ocean water, annual mean ocean mixed-layer depth, fraction of the ocean covered by sea ice, net atmosphere to ocean heat flux, internal ocean mixed-layer heat flux, simulating deep water heat exchange and ocean transport, heat exchanged with the sea ice (including solar radiation transmitted through the ice, and heat gained when sea ice grows over open water). The resulting mixed-layer depths in the tropics are generally shallow, while at high latitudes, in both hemispheres, there are large seasonal variations.

The Hadley Center Ocean Carbon Cycle (HadOCC) model includes ocean biology to provide a more accurate estimate of the chemical reactions of carbon dioxide in the surface waters, and for carbon dioxide entering at the surface to reach deep ocean waters. By using a reduced resolution from versions used for climate prediction, the model allows for greater testing of the carbon cycle, though it does show less accuracy in representing ocean physics. The model uses a simplified biological system, using only phytoplankton (nutrient and waste products). Dissolved inorganic carbon is taken up by phytoplankton growth and returned with biological breakdown. The model tracks the amount of carbon in dissolved inorganic carbon and in the four biological components. Even with the multiple simplifications in the model, the correlation with ocean observations for both Atlantic and Pacific models is good. The model does vary widely with observation at the equator, with the model showing excess surfacing of deep-water rich in carbon and releasing that carbon into the atmosphere.

The numerous complexities of interactions and the increasing ability to include these interactions in computer models provides a better picture of climate change possibilities, while maintaining the limitation of including so many real-life variables in a simulation.

SEE ALSO: Climate Models; Computer Models; Oceanic Changes; Oceanography; Wind-Driven Circulation.

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Oceanic Changes

OCEANS ARE CONNECTED bodies of saline water that cover about three-quarters of the Earth and comprise more than 97 percent of the world's total water resources. Although continuous, the global ocean is divided into five oceans based on geographic location, geological barriers, and other criteria, into the Arctic, Atlantic, Indian, Pacific, and Southern oceans. Oceans have great influence on global weather patterns and climate. This influence stems from variations in ocean temperature caused chiefly by the movement of radiant solar heat absorbed by the ocean's surface. Recently, atmospheric changes and resultant changes in chemical and physical attributes of the oceans, including temperature, salinity, and acidity have threatened the global ocean's stability. For example, sea level has been rising due to thermal expansion and melting of the world's ice. This retreat of ice causes further absorption of radiant energy from the Sun into the darker colored sea that might otherwise have been reflected by ice. This then creates a positive feedback in the warming of the atmosphere and further melting of ice. A warming atmosphere has been linked to changes in rainfall and storm frequency and length. Changes like these have the potential to cause the ocean to change dramatically over a relatively small span of time.

CARBON CYCLING

The past two centuries have witnessed a significant rise in the amount of global carbon emissions and subsequent absorption by oceans around the Earth. The global ocean plays a vital role in the Earth's carbon cycle, about 50 times greater than that of the atmosphere. The oceans absorb from the air about half of carbon deposits from fossil-fuel burning sources. The ocean contains the largest pool of carbon on the Earth's surface; however, these carbon concentrations are not distributed equally. The surface of the ocean exchanges carbon with the atmosphere more rapidly because of mixing by winds at the surface, and because the temperature, chemistry, and pressure of water; all of which vary by depth, affecting the solubility of carbon dioxide and carbon-containing ions. In areas of upwelling (where colder water moves to the surface), carbon is released into the atmosphere, whereas in areas of downwelling (where water piles and sinks), carbon is absorbed from the atmosphere. Oceanic upwelling and downwelling illustrate that changes in distribution of water in one area are always accompanied by compensating water changes in another area. This process is called mass continuity.

The speed at which the ocean can exchange carbon with the Earth's atmosphere is important in regulating the pH level (or acidity) of the ocean and its nutrient and chemical stability. Once the ocean absorbs carbon dioxide, it combines with water to form carbonic acid and a series of acid-base products. Prior to the Industrial Revolution, global carbon emissions and uptake were in relative balance, which made for a healthy chemical and nutrient stasis. Currently, however, ocean carbon absorption is at a higher rate than its atmospheric exchange capabilities. Although this mediates the amount of carbon dioxide in the atmosphere, the imbalance has increased production of carbonic acid, which has resulted in a gradual decrease in pH, or the acidification, of ocean water.

RADIANT ENERGY AND OCEAN CURRENT

Radiant energy from the Sun is not uniformly distributed across the globe, because the Earth is spherical. Specifically, more energy per a given surface area arrives at the tropics, where the Sun is more directly overhead, than arrives at the poles where sunlight strikes the Earth at a greater angle. This has a number of effects. Evaporation is higher in these tropical waters, thereby affecting the concentration of ions in the water. This concentration of ions, in turn, increases tropical waters' ability to dissolve carbon dioxide. Heating and evaporation at the surface also creates chemical and physical differences in adjacent water masses by latitude and depth. These differences, along with prevailing winds caused by the Earth's rotation, are the primary drivers behind movements of water masses in the oceans.

Currents are the steady flow of ocean water in a prevailing direction. Ocean currents have been identified as the single most influential mechanism in the global climate system via their role in transferring heat to and from geographic regions. Long-term patterns in currents are dependent upon maintenance of the chemical and temperature gradients. Changes in the Earth's atmosphere can alter these gradients. For example, warmer air above the oceans affects evaporation, and, thus, the chemical content and temperature of water. A warming atmosphere can also alter the temperature and chemistry of water by diluting saline, or salty ocean with cold, freshwater from melting ice.

WATER DENSITY

The majority of the movement and circulation of water and energy throughout the ocean is driven by differences in density between adjacent water masses. Density is dependent on the salinity and temperature of the water. The thermohaline circulation, or Global Conveyor Belt, is initiated by density differences and distributes heat energy between tropical and polar regions. Rainfall is higher in the tropics, and this addition of freshwater into the ocean decreases the salinity, and, therefore, the density, of the ocean waters in these areas. The colder oceans receive less rainfall because of lower evaporation, and, thus, are saltier and denser. The higher density of colder portions of the oceans relative to the tropics creates a difference in sea height, with colder oceans depressed, and warmer oceans elevated, relative to each other.

The density of near-surface water in the tropics is further decreased by solar heating; however, its salinity is increased by evaporation. This upper, less dense, but more saline tropical water, thus moves in a poleward direction over the colder water. As it moves north, it releases heat to the atmosphere and the lower ocean and is thereby cooled. As it cools, its high salt content makes it denser relative to the water it is flowing over, and therefore sinks. This overturning circulation varies from year to year and as well as longer timescales. Changes in precipitation, runoff, ice melt, solar heating, and winds can strengthen or weaken the conveyor belt. This can affect short-term weather conditions, but can also alter climate in the long term if the circulation pattern settles into a new equilibrium.

OCEAN ECOLOGY

Oceans are home to the majority of plant and animal life on the planet. Climate change is expected to alter marine ecology both directly, through lower pH and elevated temperatures on the organismal level, and indirectly, via changes in community dynamics and food and habitat alteration on the aggregate level. A major concern is the possible effect climate change may have on ocean productivity. Phytoplankton, small plants found near the ocean's surface that comprise the basis for the marine food web, are the foundation for almost all ocean life, and play a key role in regulating global carbon levels. It is unknown how these organisms will react to changes in ocean acidity, increased nutrient mixing, and changes in temperature. However, any dramatic short-term alterations in foundational food web interactions are expected to have cascading effects through the food chain.

Species migration and shifts or expansion in species range are also expected as global ocean temperature continues to rise. Scientists expect that some organisms will thrive, as others will suffer. This is expected to upset ecological equilibrium in certain areas and likely affect commercial and recreational fisheries and tourism in susceptible areas. Warm water species are expected to move toward the poles. This trend has already been witnessed over the last decade in certain fisheries closer to the equator.

ACE Basin National Estuarine Research Reserve: A view of wetlands and tidal streams, Ashe Island, North Carolina.

SEE ALSO: Atlantic Ocean; Current; Glaciers, Retreating; Indian Ocean; Ocean Component of Models; Oceanography; Pacific Ocean; Southern Ocean.

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Oceanography

THE OCEAN IS arguably the largest habitat on the planet, and it houses an astounding array of life, from microbes to whales. Oceanography is the branch of Earth science that studies the Earth's oceans. It is the systematic scientific study of the oceans and deep sea with the goal of understanding their processes and phenomena. The relationship of oceans with other aspects of the Earth's environment is also highlighted in oceanographic studies. Biology, chemistry, geology and physics together make oceanography a richly interdisciplinary science. Although they contain most of the Earth's water and carbon and surface heat, and much of its biomass, the oceans do not operate alone. Together with the atmosphere, continents and ice-cover, they form a working platform, driven mostly by energy from the Sun.

Earth science has four main components: hydrosphere, solid earth, atmosphere and biosphere. Water at the Earth's surface or near it, is termed the hydrosphere. It includes oceans, water vapor, ground water, lakes, rivers, and polar icecaps. The water distribution in the hydrosphere is as follows: oceans—97.54 percent, icecaps—1.81 percent, groundwater—0.63 percent, others—0.02 percent. It is obvious that we live on a water planet.

Oceanography is studied in order to understand how oceans operate and how they interact with other aspects of the Earth system. Again, oceans are a vast source of food for the world's population. The oceans hold an enormous reservoir of minerals and they also hold reservoirs of fossil fuels or the potential for harnessing forces for energy development.

The study of oceanography may be divided into four branches: biological oceanography, chemical oceanography, geological oceanography and physical oceanography. Biological oceanography is the study of marine organisms and productivity, life cycles, and ecosystems. Biological oceanography spans studies of all levels of biological organization, from that of single genes, to organisms, to their population dynamics. It includes studies on how organisms interact with, and contribute to, essential global processes.

Chemical oceanography deals with water chemistry and biogeochemical cycling. It is the study of everything about the chemistry of the ocean and is based on the distribution and dynamics of elements, isotopes, atoms, and molecules. This ranges from fundamental physical, thermodynamic and kinetic chemistry to two-way interactions of ocean chemistry with biological, geological, and physical processes. It encompasses both inorganic and organic chemistry. Chemical oceanography includes processes that occur on a wide range of spatial and temporal scales; from global to regional to local to microscopic spatial dimensions and timescales from geological epochs to glacial-interglacial to millennial, decadal, interannual, seasonal, diurnal, and all the way to microsecond time scales. Geological oceanography is the study of the geology of the ocean floor including plate tectonics, ocean basin geology, and ocean history, while physical oceanography studies the ocean's physical attributes including temperature-salinity structure, water properties, mixing, waves, tides, and currents. Physical oceanography studies the physics of the ocean, the kinds of motions of water, the speed, and the direction of the water. Physical oceanography is the study of the fluid motions of the ocean. Its goal is to understand the processes at all time- and space-scales, to simulate these processes, and to make predictions if possible. Physical oceanographers are also interested in determining how much heat enters the ocean and where the heat is transferred.

These diverse topics reflect many basic disciplines (biology, chemistry, geology, meteorology, and physics) that oceanographers utilize to further knowledge of the world ocean and understanding of processes within it. Oceanography is born out of scientific curiosity and aids in the understanding of marine resources and their impact on humans and global climate changes. The aim of oceanography is an understanding of the oceanic circulation and the distribution of heat in it, appreciation of the interaction of oceans with the atmosphere, and the role they play in maintaining our climate.

Origin of the ocean basins is traced to many theories. In the cosmic school of thought, it is believed that the moon blew out of the Earth, only to be caught by the Earth's gravity as a natural satellite. The hole is said to be located in the region of the Pacific Ocean. This idea was popular until the evidence supporting the theory of plate tectonics gained support. In the plate tectonics theory, oceans are produced as diverging plates open the space between them. Triple junction theory states that a crack begins on a continental plate, joining cracks from three different directions, until a series of these cracks eventually separates the plate and produces a proto-ocean.

The supercontinent Cycle theory notes that the breaking apart of Pangaea has occurred several times with the production of supercontinents over and over, and with oceans breaking up the spaces between them. The most viable hypothesis for explaining the origin of the ocean water is that it is from the interior of the Earth. Earth's distance from the Sun and its mass were obviously crucial in the formation of the oceans.

The major oceans are Pacific, Atlantic, Indian, and Artic oceans. The Pacific Ocean is the largest and deepest, and covers 50 percent of the surface area of the world's oceans. Marine environments could be classified by light and location. Inhabitants of marine zones include planktons, nektons, and benthos. Water is found everywhere on Earth and is the only known substance that can naturally exist as a gas, liquid, and a solid, within the relatively small range of temperatures and pressures found at the Earth's surface. Oceans contain nearly 98 percent of all the water on or near the surface of the Earth. The residence time of ocean water is about 37,000 years. Changes to the coastal environment occur from the movement of ocean waters against the shore. Surface ocean currents are broad, slow, drifts of surface water, set in motion by the prevailing winds, but rarely causing erosion deeper than 164–328 ft. (50–100 m.). The gases that make up the oceans were trapped within the Earth as it formed. The major trapped volatile was water; others included nitrogen and carbon (IV) oxide. Seventy-one percent of Earth's surface is covered by water, and 29 percent of the surface area is land.

As a result of different water masses, the ocean can be viewed as stratified, with layers of water extending great distances with similar temperatures, or salinities, or most of water properties. There is unequal warming of the ocean; this leads to heat transfer, changes in density, and ultimately, movement of water masses via the thermohaline circulation process. Ocean and atmosphere form a coupled system. The coupling occurs through exchange processes at the interface. Ocean and atmosphere are coupled in climate models and circulation models; the computer models become the meeting point for observations, theory, and prediction. These exchange processes determine the energy and mass budgets of the ocean. Quantities exchanged between the ocean and the atmosphere in the energy budget are radiative energy and momentum, while in the mass budget quantities include evaporation, condensation, precipitation, and river run-off. The ocean plays a role in the climate system, which is complementary, and of comparable importance to that of the atmosphere. It transports heat in amounts comparable with atmospheric transport. It absorbs and releases carbon (IV) oxide. When it is heated, the ocean responds by storing some of the heat and by increased evaporation. Because the heat is mixed for some distance by the wind, temperature rises much less than it does on dry land under the same heating conditions. The evaporation has profound effects on the atmosphere and on climate.

When the ocean is cooled, it responds by generating vertical convective motions, which resupply heat to the surface. Thus, the temperature drop is much less than over land under the same cooling conditions. The overall result is that for the two-thirds of the Earth's surface covered by ice-free ocean, the temperature over the whole ocean ranges only from 28 degrees F (minus 2 degrees C, the freezing point of salt water) to 86 degrees F (30 degrees C), and at any one place by hardly more than 1.8 degrees F (1 degrees C) during the course of a day and 10.8 degrees (10 degrees C) during the course of a year. The relatively slow response of the ocean to heating and cooling results in the oceanic annual cycle being delayed, relative to that in continental regions.

The ocean plays a key, but frequently understated, role in determining the Earth's climate. Indeed, any possibility of predicting the evolution of climate beyond a few weeks demands that ocean behavior also be taken into account. With respect to sensitivity and contribution to long-term climate change, there is reason to believe that the ocean is now changing, in response to climate changes over the past few hundred years. It can be expected to change further as anthropogenic influences become increasingly marked. The effect of the ocean on the atmosphere could be either to moderate or to intensify these changes; it will certainly modify them.

The oceanic environment places unique demands on instrumentation that are not easily met by standard laboratory equipment. As a consequence, the development and manufacturing of oceanographic instrumentation developed into a specialized activity. Available equipment for observing the ocean and marine life include research vessels, moorings, satellites, submersibles, towed vehicles, floats, and drifters. Reversing thermometers are used to measure hydrographic properties. Nansen and Niskin bottles, CTDs, multiple water sample devices, thermosalinographs, remote sensors current meters, wave measurements, tide gauges, remote sensors and shear probes are all employed for measuring the dynamic properties of the ocean. The first international organization of oceanography was created in 1902, as the International Council for the exploration of the sea.

Scientific graduates have directly applied their training in teaching positions on M.Sc and Ph.D courses, in industrial research laboratories; in government research laboratories, including the Water Boards and in environmental protection agencies. Other Oceanography graduates apply their knowledge in a wide range of jobs within business and industry and in the military. Oceanography is a relatively young discipline, shaped by a continual flow of exciting discoveries. Oceanographers continue to help us understand the precarious balance of oceans, the atmosphere, ice, solid earth, and living organisms—the Earth system that affects our lives and the future of our planet.

SEE ALSO: Current; Oceanic Changes; Salinity.

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OECD Annex 1 Expert Group on the UNFCCC

THE ANNEX 1 Expert Group (AIXG) of the Organisation for Economic Co-operation and Development (OECD) was created in 1994, as an ad hoc cadre of government officials from the departments of environment, energy, and foreign affairs of countries that have committed to Annex 1 of the United Nations Framework Convention on Climate Change (UNFCCC). Annex 1 acknowledges the impact of human behavior on global warming and climate change. The UNFCCC treaty of 1992 attempted to develop well-articulated methods of reducing global warming and formulating specific responses to climate change. Most OECD member states have signed Annex 1, as have other nations from Eastern Europe and the Commonwealth of Independent States, which was created after the break-up of the Soviet Union. Most nations who have signed the UNFCCC have also signed the more powerful Kyoto Protocol.

Countries who commit to the UNFCCC officially acknowledge that climate change is of major concern to all humans, recognize that human behaviors have led to increasing atmospheric concentrations of greenhouse gases (GHG) and warming temperatures, and admit that these phenomena are having a negative impact on the world's ecosystems and human health. Signatories from developed countries accept that industrialization has been, and continues to be, a major contributory influence to global warming and climate change, and understand that highly-industrialized nations are required to accept the lion's share of the blame for both phenomena. Without infringing on national sovereignty, parties to the UNFCCC accept responsibility for committing their own governments to international cooperation, to encourage domestic efforts to mitigate the potential for future environmental damage, while developing technologies and coping strategies for dealing with the impact of global warming and climate change on human health, the environment, society, and the economy.

Upon its creation, the Annex 1 Expert Group of the UNFCCC was charged with addressing the analytical issues raised by the UNFCCC, particularly those relating to fulfilling commitments of Annex 1. Official meetings are held twice a year, but group work continues throughout the year. The OECD and the International Energy Agency (IEA) provide secretariat support for the group by preparing informational and analytical papers directed toward member countries and other interested parties. The Annex 1 Expert Group has been instrumental in standardizing the reporting of national emission inventories and in developing GHG mitigation policies, such as those included in the Kyoto Protocol. Other efforts have focused on providing member nations with assistance in policy design, implementation, and performance. The group is also involved in providing assistance to countries in using the Clean Development Mechanism (CDM) and emission trading to meet the objectives of the UNFCCC and in educating government officials and the public about global warming.

AIXG programs are generally designed to deal with long-term issues concerning global warming and climate change and with the specifics of meeting goals of individual projects. Examples of long-term issues include understanding the relationship between GHG emissions and deforestation, supporting the development of alternative energies, generating cooperation from the private sector, as well as governments, in dealing with global warming and climate change, and using existing literature, forums, seminars, and case studies on climate change from specific countries and regions to develop plans for international cooperation in mitigating the effects of global warming and climate change.

Policy formation continues to be a major priority of the Annex 1 Expert Group, and much of the focus is on providing support to transition economies and on monitoring compliance with the terms of the UNFCCC. Because the Kyoto Protocol contains stronger monitoring and compliance measures, those activities are generally conducted through provisions specified in the Kyoto agreement. In addition to Kyoto's provisions, Annex 1 parties to the UNFCCC agree to regularly provide GHG projections and reports and furnish estimates of potential effects on emissions and sinks. Within those guidelines, member countries have developed a myriad of responses to dealing with UNFCCC requirements.

CURRENT AND ONGOING AIXG EFFORTS

Ongoing Annex 1 Group projects deal with developing policies on technology and climate change, gauging institutional capacity for dealing with climate change issues, keeping an eye on international emissions trading and the Clean Development Mechanism (CDM) and Joint Implementation, assessing specific roles in mitigating the effects of climate change, devising both short- and long-term strategies for meeting goals, and conducting seminars that bring experts from developed and developing countries together to discuss relevant issues. Past AIXG studies have dealt with assessing the role of electricity and aluminum in global warming and climate change, international cooperation in climate mitigation, technological collaborations on energy, wind power integration, the future of international cooperation on climate change, emissions trading, progress in implementing CDM, strategies for dealing with domestic greenhouse gas emission, and cooperation in the agricultural sector.

In March 2003, AIXG was involved in the OECD "Global Forum on Sustainable Development: Emissions Trading," which met in Paris, France. The forum served as a venue for bringing together OECD members with representatives from non-member nations to encouraging cooperation in dealing with common concerns such as GHG emissions and air pollution. In March 2007, the Annex 1 Expert Group again met in Paris to sponsor the seminar, "Working Together to Respond to Climate Change." Some 150 non-Annex 1 members attended the seminar, which focused on four major issues: ways to make the CDM operational, the potentials of sectoral-crediting mechanisms, technology and adaptation, and opening dialogues between AIXG members and non-members on technical and analytical issues. That same year, the Annex 1 Expert Group on the UNFCC, released two major reports dealing with methods of gaining political support for implementing the group's priorities and on developing techniques for overcoming non-technical barriers to the diffusion of energy-efficient technologies.

SEE ALSO: Clean Development Mechanism; Ecosystems; Greenhouse Gases; Kyoto Protocol; OECD Climate Change Documents.

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OECD Climate Change Documents

THE ORGANISATION FOR Economic Co-operation and Development (OECD) was established in 1960 and is based in Paris, France, with a membership of 30 countries. The organization continued the activities of the Organization for European Economic Cooperation (OEEC), which had administered the American and Canadian funds of the Marshall Plan for the reconstruction of Europe after World War II. OECD's main commitment is to foster cooperation among countries that adhere to the principles of democracy and free market economy. OECD's aims are to support sustainable economic development, to expand the job market, to raise living standards and contribute to the growth of global trade. In addition to working with its member countries, OECD also lends its expertise to more than 100 other countries.

One of OECD's branches is the Environment Directorate, which aims to supply governments with the analytical information to develop policies that are effective and economically efficient, as well as respectful of the environment. The Directorate compiles country performance reviews, data collection, policy analysis, projections, and modeling, and encourages the development of common approaches. Within the Environment Directorate, the Department of Climate Change, Energy, and Transport specifically assesses the impact of global climate change on economies, societies and the environment in the 21st century. The Department supports the integration of climate policy targets within larger policy areas. OECD also works closely with the Annex I Expert Group on the United Nations Framework Convention on Climate Change (UNFCCC), the group of government officials from Environment, Energy, and Foreign Affairs ministries from countries that are listed in Annex I to the UNFCCC, and those that have accepted the Annex I commitments. OECD provides secretariat support to the Annex I Expert Group. It offers analytical papers on issues relevant to the ongoing climate change negotiations, but that can also be useful to national policymakers and other decision-makers. In particular, OECD has suggested ways to share information under the Convention on greenhouse gases emission performance among countries, for example, through standardized reporting of national emission inventories and on greenhouse gases mitigation policies.

OECD DOCUMENTS AND POLICY

OECD's documents on climate change include both international policy issues, as well as national and sectoral policies. Guidelines on international policy issues emphasize the importance of identifying and analyzing policy frameworks that can facilitate adaptation to climate change impacts. In this area, OECD devotes particular attention to developing countries, and to particularly crucial sectors of intervention, such as water. The organization claims that climate change does not yet feature prominently within the environmental or economic policy agendas of many developing countries. This fact is a great disadvantage for developing countries, as data show that they might be particularly vulnerable to climate change impacts, and that climate change will likely affect the development potential for their economies. OECD documents and research address the points of convergence, as well as the opposing claims, of development and climate change, both with respect to mitigation of greenhouse gas emissions and adaptation to their effects. OECD's Development Co-operation and Environment Directorates work closely to identify linkages and explore effective policy responses in the areas of development cooperation and climate change. The focus is on natural resource management and climate adaptation responses.

In its "Domestic Policy Framework for Adaptation to Climate Change in the Water Sector. Part II: Non-Annex I Countries" (2006), for example, OECD has recommended an integration of the current meteorological trends and information on future water availability in the processes of water resources management and policy development. The document includes suggestions that an efficient way to start addressing adaptation in developing countries is through the strengthening of the fundamental building blocks of civil society. An effective adaptation to climate change can only be achieved through transparent governance based on the rule of law, cooperation among government agencies, and involvement of stakeholders (including local communities) in the decision-making process. The authors also stress the importance of accessible schooling, basic professional training, and medical care as essential elements in building community-level capacity and in adaptating to climate variability and change.

The OECD volume *Bridge Over Troubled Waters: Linking Climate Change and Development* (2005) points out that although climate change may seem a remote topic compared to pressing problems, such as poverty, disease and economic stagnation, it "can directly affect the efficiency of resource investments and eventual achievement of many development objectives." The authors argue for establishing a link between climate change and development priorities. They suggest ways in which development can be made more resilient to the impacts of climate change, taking into account the engineering and policy-making sectors. For example, at the engineering level, the impact of climate change in sea-level rise and glacial lake outburst floods should be taken into account when choosing the location and design of bridges and other infrastructure. Policy-makers should instead consider the implications of climate change on a variety of development activities, including poverty reduction, sectoral development, and natural resource management. The activities of OECD in this area aim to bridge the gap between the phenomena of climate change and development communities. The policies of climate change and those of development communities should attempt to consider their different priorities, time- and space-scales.

OECD documents aim to provide specific information "on the significance of climate change for development activities along with operational guidance on how best to respond to it within the context of other pressing social priorities." All too often, OECD researchers argue, development activities overlook climate change and the risks involved in the phenomenon. This is why *Bridge Over Trouble Waters*, among other OECD documents on climate change, argues for the adoption of longer-term perspectives than the ones generally adopted by developing communities. These often fail to integrate suitable policies of climate change adaptation into national development plans and poverty reduction strategies. Development priorities and policies of climate change adaptation are also sometimes perceived as polar opposites. The pressing challenges of poverty and inadequate infrastructure tend to overshadow the importance of investments in measures whose importance will not become clear until climate change impacts become fully evident.

In contrast with this existing situation, OECD recommends that information on climate change should be made more relevant for development initiatives and provide a more complete estimate of the cost effectiveness of including measures of climate change adaptation/limitation into development planning. In addition, the OEDC encourages the development of improved screening tools to identify the likely climate risks for development activities, in general, and for specific projects. Climate information should be made relevant to Environmental Impact Assessments (EIAs). EIA guidelines and checklists, however, would need to be modified to include the implications of projects for greenhouse gas emissions and the impact of the environment on a given project (at present only the impact of the project on the environment is taken into account). OECD documents point out that often the phenomenon of climate change does not need entirely new responses, but simply reinforces the need to implement measures that are already recognized as development or environmental priorities. Measures such as water or energy conservation, forest protection, flood control, building of coastal embankments, improvement of river flow, and protection of mangroves have already been listed as priorities in national and local planning documents, but have rarely been implemented. Thus, what the OECD argues for is not so much radically new plans for climate adaptation, but an effective implementation of measures that, in most cases, have already been approved.

To be more effective, OECD points out that the activities for climate change adaptation and mitigation should combine national goals with a bottom-up approach to the needs of local communities. In line with its free-market economy philosophy, OECD encourages the participation of the private sector in such activities. The organization also stresses the importance of trans-boundary and regional coordination. At present, most climate change action and adaptation plans are at the national level, while many impacts cut across national boundaries. Meaningful integration of a range of climate risks, from flood control, to dry season flows, to glacial lake hazards, can only be achieved through greater coordination on data collection, monitoring, and policies at the regional level. Finally, joint building of experience and sharing of tools and experiences, within and among governments and development cooperation agencies are needed for a successful implementation of climate change adaptation policies.

A relevant selection of OECD documents on climate change are specifically concerned with economic factors involved in the adoption of the Kyoto Protocol. "A Multi-gas Assessment of the Kyoto Protocol" (2000), for example, extends the analysis of the economic impact in limiting gas emissions, including not only carbon dioxide, but also methane and nitrous oxide. The document thus covers up to 80 per cent of greenhouse gas emissions listed by the Protocol. The inclusion of these gases reduces the estimated economic costs of implementing the Kyoto Protocol. The document points out that if each Annex I country or region takes individual action to respect its emission target under the Protocol, real income may, on average, be 0.33 per centlower. This compares favorably with previous estimates covering only carbon dioxide that showed 0.5 percent reduction in real income. In "Action Against Climate Change: The Kyoto Protocol and Beyond" (1999), OECD has stressed that the Kyoto targets alone will not be enough to avert climate change, but are best described as first steps in a global action. The document's authors argues on the necessity to achieve world-wide consensus for taking action and the economic impacts such action may have. Yet, even if this ambitious goal is reached, climate change may take place anyway, so that countries need to be prepared to face climate change impacts.

Several OECD documents have attempted to develop an implementation framework for a global greenhouse gas emissions trading system. "Linking Greenhouse Gas Emission Trading System and Markets" (2006), for example, takes as its point of departure the several different emission trading schemes (ETS) currently in operation, and those likely to emerge in the near future. In spite of the different sizes, design characteristics, and geographical scopes of these systems, the few existing links among them should be expanded. OECD has shown that linking the domestic ETSs of different countries or regions can be beneficial for all the parties involved. Establishing links between different markets increases their size and fluidity, so that the same environmental benefits can be gained at a lower overall cost, producing economic benefits.

In addition to these documents on general topics related to climate change, OECD has produced several statements on the impact of climate change on specific economic and social sectors. For example, the organization has studied ways to reduce greenhouse gas emissions from deforestation in developing countries (RED), usually by exploiting a market-based approach stressing efficient land-use options and incentives available to reduce emissions from deforestation. OECD has also produced documents that attempt to foster international collaboration regarding energy technologies in the context of climate change mitigation. Sharing information, costs, and efforts can facilitate a technical shift towards more climate-friendly technologies. It may also drive governments to allocate more funds in support for basic research and development. These forms of cooperation between countries are also recommended to engage more countries into action to mitigate greenhouse gas emissions. OECD has particularly focused on solar power technologies; the use of environmental-friendly technologies in agriculture and the development of seeds of high-yielding varieties (HYV); appliances that can bring significant greenhouse gas emission reductions at low cost to society, without compromising on quality standards, clean coal technologies; and wind power integration into electricity systems.

SEE ALSO: OECD Annex 1 Expert Group on the UNFCCC; Organisation for Economic Co-operation and Development (OECD).

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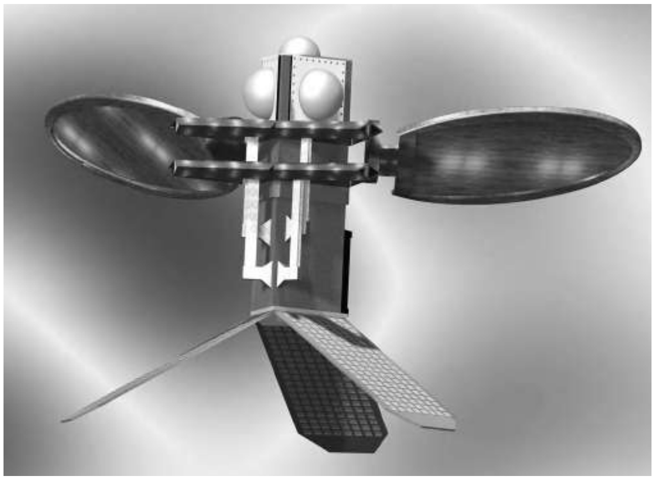
Office of Naval Research

THE OFFICE OF Naval Research (ONR) is based in Arlington, Virginia, and supports research conducted by the Navy and the Marine Corps. It was established in 1946, and serves as the technical adviser to the chief of naval operations and to the secretary of the Navy. Communication to the secretary of the Navy is via the assistant secretary of the Navy for research, development, and acquisition. The ONR mission is to "foster, plan, facilitate and transition scientific research in recognition of its paramount importance to enable future naval power and the preservation of national security."

The ONR has funded numerous scientists who have eventually won the Nobel Prize for their research. The first example is Felix Bloch, awarded the Nobel Prize for physics in 1952. He worked on magnetic mea-



Robofly is the Navy's stealth robotic flyer the size of an actual fly, capable of searching for chemical and biological warfare agents.

surement in atomic nuclei; for naval interest his work was in the field of naval medicine and nondestructive inspection. Two years later, Linus Pauling was awarded the Nobel Prize for chemistry for his research on the nature of the chemical bond. His work was of naval interest for its contributions to the foundations of chemical engineering. In 2005, John L. Hall and Theodor W. Hansch shared the Nobel Prize for physics for their work in laser-based precision spectroscopy. There was naval interest in this work because of its applications for precision timekeeping, as well as precision measurements.

There are four branches within the ONR: the Naval Research Laboratory (NRL), ONR Global (ONRG), Science and Technology (S&T), and the Naval Reserve S&T Program. There are seven main departments of research in the ONR S&T Division: Command, Control Communications, Intelligence, Surveillance, and Reconnaissance; Expeditionary Warfare and Combating Terrorism; Naval Air Warfare and Weapons; Ocean Battlespace Sensing; the Office of Transition; Sea Warfare and Weapons; and the Warfighter Performance Department. Within each department are subdepartments, or divisions. For example, within the Ocean Battlespace Sensing Department are the Ocean Sensing and Systems Applications Division and the Ocean, Atmosphere, and Space Research Division.

The ONR is led by a chief of naval research, a vice chief of naval research, an executive director, an assistant chief of naval research, a director of research, a director of transition, and a director of innovation. Additionally, an ONR inspector general acts to ensure efficient and ethical proceedings at the ONR, to oversee the ONR operations and programs and to "prevent and detect fraud, abuse, mismanagement, and waste."

SEE ALSO: Air Force, U.S.; Department of Defense, U.S.; National Aeronautics and Space Administration (NASA); Navy, U.S.

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Ohio

OHIO HAS AN area of 44,825 sq. mi. (116,096 sq. km.), with inland water making up 378 sq. mi. (979 sq. km.), and Great Lakes Coast water of 3,499 sq. mi. (9,062 sq. km.). Ohio's average elevation is 850 ft. (259 m.) above sea level, with a range in elevation from 455 ft. (139 m.) above sea level on the Ohio River, to 1,549 ft. (472 m.) at Campbell Hill. Most of Ohio is flat or gently rolling, with some rougher terrain between the major rivers and in the divide between the Great Lakes and Ohio River drainage systems. Lake Erie borders Ohio on the north and the Ohio River borders the south. Most of the rivers that drain into Lake Erie are short. Those flowing into the Ohio are comparatively long. Lake Erie is Ohio's most important lake, with many artificially created ports and interior lakes.

Warm to hot summer and mild to cold winters come from alternating dry polar air from Canada and warm-humid air from the Gulf of Mexico. In winter, polar air is dominant, often coming into conflict with modified gulf air, causing frontal or cyclonic storms. Gulf air is dominant in the summer. In fall, polar air passing over Lake Erie is modified, delaying the killing frost along the adjacent shoreline. The average annual precipitation is 48 in. (122 cm.), with distribution throughout the year, and snowfall usually melts quickly.

Western Ohio is part of the Corn Belt. Other major industries include agricultural crops (including corn and soybeans), dairy, and livestock. Vineyards and orchards (mainly cherry and peach), are found along Lake Erie, where the growing season is longest. Southern and eastern Ohio has woods, though forestry is a minor industry. Mining is important to Ohio's economy with coal, crushed stone, natural gas, sand and gravel, petroleum, lime, salt, and clays. Oil and natural gas are mined in eastern Ohio. The Gavin power plant in southeast Ohio burns coal supplied to the plant by a conveyor from 10 mi. (16 m.) away.

IMPACT OF CLIMATE CHANGE

Ohio experienced the effects of higher temperatures in 1993. While other states flooded, Ohio had the driest August on record since 1895. While climate models vary on the amount of temperature increase possible, potential risks include having decreased water supplies, increased risk for wildfires, population (both human and animal) displacement, changes in food production (with agriculture improving in cooler climates and suffering in warmer climates), and changes in rain patterns to downpours, with the potential for flash flooding and health risks of certain infectious diseases from water contamination or disease-carrying vectors such as mosquitoes, ticks, and rodents, and heat-related illnesses. Warmer temperatures can cause heat-related illnesses and lead to higher concentrations of ground-level ozone pollution, causing respiratory illnesses, especially in Ohio's major cities, where air pollution problems already exist.

Higher temperatures and more frequent heat waves could raise average summer temperatures in Cleveland to Cincinnati's level, and Cincinnati's summer temperature to Atlanta's levels. With increased rain, the state's water supply would recharge, potentially causing increased soil erosion, providing additional flooding in places where flooding already occurs on an almost annual basis. Warmer temperatures would increase summer soil temperatures and increase evaporation rates, possibly requiring costly investment in irrigation systems. The coal mining and utility sectors would suffer losses with increasing global warming mitigation. Metal industries would particularly benefit from increased demand for metals, machinery and other components that would result from increased demand for products such as wind turbines and energy-efficient equipment. The increase in demand for alternative fuels such as ethanol would benefit the state's agricultural sector. Ohio is the nation's sixth largest corn producing state, and because of its location, it can easily serve the east coast.

ADDRESSING HUMAN-INDUCED CONTRIBUTIONS TO CLIMATE CHANGE

Based on energy consumption data from Energy Information Agency released June 1, 2007, Ohio's total carbon dioxide (CO_2) emissions from fossil fuel combustion in million metric tons for 2004 were 261.96, made up of contributions by source from: commercial, 11.43; industrial, 38.08; residential, 20.30; transportation, 71.16; and electric power, 120.98.

Ohio joined the Climate Registry, a voluntary national initiative to track, verify, and report greenhouse gas emissions, with acceptance of data from state agencies, corporations, and educational institutions beginning in January of 2008. Ohio legislators in the 2007–08 General Assembly will be considering a bill to form the Ohio Climate Commission to study impacts of global warming on the state, to recommend the appropriate state response to global climate change and associated impacts. Ohio has a long shoreline on Lake Erie, but the lake's water quality deteriorated so badly as a result of industrial and urban wastes that the fish population has declined. Efforts by the United States and Canada to clean the lake have shown results.

Current regulations in place require Ohio electricity suppliers to provide their customers with periodic environmental disclosure labels at the beginning of each calendar year, with quarterly disclosures in March, June, September, and December comparing actual environmental data and projected data. These disclosures indicate the generation resource mix and environmental characteristics associated with the electricity for which the customers are paying. Information supplied by the U.S. Department of Energy for 2005 indicated electric generation in Ohio originated from the following resources: 87 percent coal, 9 percent nuclear, 2 percent natural gas, 1 percent petroleum, and 1 percent hydroelectric and renewables. Although Ohio has historically relied to a great extent on coal-fired generation, the majority of new facilities constructed in Ohio over the past few years have been natural gas-fired. In addition, the Ohio Biomass Energy Program (OBEP) has been working to promote the use of biomass in Ohio.

SEE ALSO: Biomass; Ohio State University; Pollution, Water.

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Ohio State University

OHIO STATE UNIVERSITY (OSU), founded in 1870, is one of the United States' premier academic institutions for the study of global warming and climate change. Researchers and students strive to slow the climate change process, seeking alternative forms of energy, and affecting policy decisions in Ohio and beyond. The university has many well-known climate scientists, including Dr. Ellen Mosley-Thompson and Dr. Lonnie Thompson. OSU is also home to the Byrd Polar Research Center, a collaborative effort of polar and alpine scientists to understand global warming and climate change. In recent years, Ohio University has moved toward building new structures that meet the energy-saving guidelines of the Leadership in Energy and Environmental Design (LEED) program. Ohio State University focuses a significant amount of resources on comprehending climate change mechanisms and searching for feasible solutions.

Ohio State University features many majors, graduate degrees, programs, and co-curricular activities to educate students about the problems associated with global warming, the processes that cause climate change, and ways to mitigate the effects. Majors in the School of Environment and Natural Resources, the Department of Geography, the College of Math and Physical Sciences, and the College of Engineering have climate change components. OSU hosts an interdisciplinary Environmental Science Graduate Program that combines the physical, biological, and social sciences to address environmental research needs. This is one of the only programs in the nation of its kind. The Honors and Scholars Program expanded to include the Environment and Natural Resources Scholars program, which caters to high-ability undergraduate students with an interest in the environment, regardless of major. OSU is moving toward an academic curriculum that places global climate change and environmental issues at the forefront of teaching and research.

Two professors who work to better understand climate change are Dr. Ellen Mosley-Thompson and Dr. Lonnie Thompson. Ellen Mosley-Thompson is a professor in the Department of Geography and with the Environmental Sciences Graduate Program. Her research focuses on paleoclimatic reconstruction of chemical and physical properties in preserved ice cores. She is a fellow of the American Association for the Advancement of Science, has received multiple Distinguished University Awards, and, in 2003, she was inducted into the Ohio Women's Hall of Fame. Dr. Lonnie Thompson, professor in the School of Earth Sciences, is a member of the Ice Core Paleoclimatology Group. He is a Distinguished University Professor; in 2005, Thompson received the Tyler Prize for Environmental Achievement, which is considered by many in the field to be the equivalent of the Nobel Prize. His work is highlighted in Al Gore's documentary *An Inconvenient Truth*, and he is also a fellow of the American Association for the Advancement of Science. Both Dr. Mosley-Thompson and Dr. Thompson work with the Byrd Polar Research Center at OSU.

The Byrd Polar Research Center is an international leader in global climate change, polar, and alpine research. The center is named for renowned polar explorer Admiral Richard E. Byrd. Scientists, faculty, and students interact to further understand what the Earth's climate was like millions of years ago and how it is changing. Researchers collect an enormous amount of data, including ice-core samples, fossils, and evidence of change in geochemical and hydrological cycles. The center also uses satellite-generated images and computer models to construct detailed information about cloud formation, glacier size and movement, and storm system development.

Ohio State University has initiated the development of two green buildings on campus. The first building is the Nationwide and Ohio Farm Bureau 4-H Center. It opened in early 2008. This building includes carbon-reducing features, such as geothermal heating, the use of recycled rainwater, and environmentally-sound building materials. The student union, known as the Ohio Union, is under construction. The new Ohio Union will feature a location that discourages driving and encourages public transportation and walking, energy-saving lighting, and the reuse of existing union building materials. This building will open in 2010.

SEE ALSO: Green Design; Ohio; Paleoclimates.

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Oil, Consumption of

IN 1970, THE United States became unable to meet its total oil energy needs, and became an oil-importing nation. Until then, American oil fields in Texas, Louisiana, and California had been able to meet the national need. By 2012, it is likely that the world as a whole will consume around 100 million barrels of oil per day. Humans have known about oil and some of its uses for millennia, but it only became identified as a consumable unit, in terms of extraction, refining, and then commercial use, in the late 19th century. The first commercial oil wells were in Pennsylvania; the industry soon spread to Ohio, and then jumped south and west to the Gulf Coast, which still has the bulk of U.S. oil refineries.

HISTORY OF OIL CONSUMPTION

American and British engineers led the way in searching for new deposits of oil around the world, a process that rapidly accelerated around 1900. By then it had become obvious, to engineers at least, that oil was a safer (on average), cleaner, and smoother form of energy than that produced by coal. Big Coal remained dominant at the start of the 20th century, and most Americans continued to heat their homes with coal well into the 1930s, but those who switched over to oil found it cheaper, easier, and safer to use.

World War II proved an immense boon to the oil industry, both American and foreign. Thousands of new engineers received on-the-job training during the war, and governments as different as those of Nazi Germany and the United Kingdom perceived the need for more oil, something made evident by the dramatic success of Blitzkrieg, the German method of lightning warfare made possible by use of the combustion engine. The Age of Oil began sometime in the 1940s, and shows no sign of retreating today.

The 1950s and 1960s were, for American consumers, a golden age of oil use. Whether it was for the gas that ran their automobiles, or for home heating, oil cost Americans about $.25 a gallon, amazingly cheap by today's standards. Vehicles produced in the 1950s and 1960s reflect this fact; Americans delighted in long, over-built cars, complete with fins and tails. Few people worried, or even thought, about the future of oil consumption, for it seemed that there was plenty of oil to go around.

The switch from coal to oil was complete by the 1960s, with the vast majority of Americans heating their homes with oil. It was just about the same time that the nation, and much of the world, suffered through the coldest decade of the 20th century. Little-discussed today, the winters of the 1960s were so severe that some people, including scientists, spoke of a coming ice age (those discussions were renewed during the brutally cold winters of 1978, 1979, 1982, and 1983). Americans did not feel the pinch during the 1960s because gas and home heating oil remained at roughly the same low prices during that decade, but their European counterparts saw the prices of the same commodities double in the 1960s. By 1970, Europeans were making smaller, more fuel-efficient automobiles, while the American auto industry continued to go for size and impressive performance on the highway.

In many ways, the great turning point was in 1970. By that time, Americans were consuming about 8 million barrels of oil a day, and, for the first time, the nation became a net importer of oil. Americans were mildly surprised to learn that the great Gulf Coast oil fields and refineries were no longer able to meet the national energy needs, but there was little concern because the oil importing nations, such as Iran, Iraq, and Saudi Arabia, did not immediately raise their prices. Those nations lowered the boom in winter 1973–74, imposing the first oil embargo against Western nations that favored the state of Israel in its long struggle with its Arab neighbors. The oil embargo of that season doubled oil prices for Americans, who suddenly paid about $.58 per gallon at the pump, and literally tripled oil prices in many European countries. Of all the industrialized nations, Japan, with no oil reserves whatever, was the hardest hit by the 1973–74 embargo.

Conservation suddenly became the watchword of the day. Americans flocked to buy new, smaller automobiles, and a national campaign to keep thermostats lower had some success. Americans grumbled at the sudden onset of austerity, but throughout the mid-1970s, energy conservation and the exploration of alternative energy sources remained a national priority. American oil consumption remained steady, at about 9 million barrels per day, in the 1970s, and some milder winters (those of 1975, 1976, and 1977) provided some respite from the situation. However, the "failed" presidency of Jimmy Carter (1977–81) proved to be the breaking point, both in terms of the public attitude and public action. Carter came into office wearing cardigan sweaters, and he urged his fellow Americans to do the same. There was some movement toward his position until the Iran Hostage Crisis of 1979–81, which decisively altered American attitudes toward Arab (or in this case Persian) oil-producing nations. American national policy switched from energy conservation to aggressive defense of American oil conduits around the globe.

The 1980s saw a steady rise in American oil consumption, with the nation reaching about 15 million barrels per day in 1986. The suburban minivan appeared on the car market around that time; and the Sport Utility Vehicle (SUV) began to rule the road in the 1990s. After the triumphant result of the First Persian Gulf War, in which the United States led a coalition of forces to defeat Saddam Hussein's Iraq, oil prices fell to their lowest in almost a decade, and did not recover through the entire decade. In 2000, the United States hit a record of 20 million barrels of oil per day (in overall use), and about 50 percent of that was imported. Few concerns were registered at the time.

CONTEMPORARY HISTORY OF OIL CONSUMPTION

Yet all along, there had been the warning issued by geologist M.K. Hubbert back in 1960. Pointing out that new deposits of oil were scarcer by the year, Hubbert predicted that the industrial world would soon encounter oil peak, a moment at which the maximum daily amount could be extracted from the Earth, a moment from which the industrial world would have to accommodate itself to gradually lower levels of oil use. Few people wanted to believe Hubbert's theory, because there seemed to be no good alternative; the world had never enjoyed a fuel so usable as oil; and it seemed unlikely to find another. So, oil use continued to expand, and by about 2005, the rapidly-emerging industrial nations of China and India were together using as much as 10 million barrels a day.

Optimists had, in the past, expressed the view that Third World nations could not compete in the demand for oil because the price would rise so dramatically that they would fall behind. This was proven wrong early in the 21st century's first decade; oil use expanded everywhere, around the globe, and it was apparent that Third World nations, in some ways, had the upper hand. This was especially the case with China, which held a large part of the U.S. national debt.

Europeans and Japanese had long accustomed themselves to driving smaller cars and to making do with alternative methods of home heating, but Americans remained somewhat blasé till the disaster created by Hurricane Katrina in the early fall of 2005. Gasoline prices rose to the highest level ever seen in the United States, sometimes as much as $3.50 per gallon. Public outrage was directed at major oil companies like Exxon and Chevron, but congressional investigations found, as had always before been the case, no obvious evidence of price gouging. Rather, it was concluded, the United States needed a new energy policy.

No new policy emerged during the first 7 years of the administration of President George W. Bush. A former oil man, and with a former oil man as his vice-president, President Bush seemed content to continue in the same direction, with U.S. oil consumption rising to as much as 27 million barrels of oil per day around 2007. Many claimed that this consumption was unsustainable. The nation had to expand its repertoire in the area of energy use. Solar power, wind power, and other alternatives had to be employed before it was too late. Many authors spoke to this belief, two of the best known books being *The Long Emergency* and O*ut of Gas*. However, some claimed that oil was the best source of convertible energy ever discovered, and it had endured through a number of ups and downs in public sentiment since 1970. Oil would continue to be the backbone of American energy use. Some pointed to Jeff Goodell's *Big Coal*, which pointed out the shortcomings and dangers of relying on coal for the foreseeable future.

Most scientists were unsure of the sustainability of oil use. The critical factor was how much oil remained under ground, and how much of it could be rapidly converted into oil and natural gas. If new deposits were found, and if oil-rich nations like Saudi Arabia could be persuaded to pump more barrels per day, then the worldwide use of oil could continue, at least for a few decades to come.

Saudi Arabia remained the biggest single question mark. The House of Saud was notoriously secretive when it came to the total extent of its energy reserves. Some scientists believed that the oil fields of Ghawar, the largest ever found, might still be producing 20 years into the future, while others heeded the words of Matthew R. Simmons, whose *Twilight in the Desert* described what might soon be seen as the Saudi oil collapse. Many people disagreed with Simmons's figures, but they concurred that his statistics were correct, and if Saudi Arabia had to significantly lower its oil output, the industrial world would be shaken. Without enough oil to run its cars, heat its homes, and make numerous oil-rich products, the Western world would be in serious trouble.

Oil continues to have its defenders. There are those who point out, accurately, that oil is safer and cleaner than coal, at least once it is on land (there have been some disastrous spills from oil tankers over the decades). But their arguments run up against some fundamental, painful facts. Oil is running out quite rapidly. It has lasted longer, in some respects, than scientists of the 1970s thought. Oil may remain a big part of the energy use of industrial nations well into the future, but that will only be so if there are other energy sources to complement it. Otherwise, the world's oil reserves will be exhausted at some point in the 21st century.

SEE ALSO: Automobiles; Developing Countries; Energy; Oil, Production of; Saudi Arabia.

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Oil, Production of

THE PRODUCTION AND consumption of oil are regarded as contributing to global warming and climate change. Associated greenhouse gas emissions and alteration of the landscape in some regions are the contributing factors. Exploration, production, and refining have some impact, but the consumption, through combustion, is occurring at a staggering rate. Air samples, covering many years, have been analyzed from Antarctic ice cores. These data provide a strong correlation between increasing greenhouse gases and increasing supply and demand for oil.

Crude oil is a hydrocarbon fossil fuel also known as petroleum. It is a natural substance that requires millions of years to form or mature. Oddly enough, crude oil is organic, although many think of it as inorganic. It is not renewable, considering the millions of years necessary for it to mature. The maturation process is an environmentally-friendly process because the organic matter decays without releasing gases to the atmosphere. This is known as an anaerobic condition, meaning in the absence of oxygen. In essence, the organic matter does not release carbon dioxide (CO_2)or other gases to the atmosphere while maturing into oil. It is sequestered, keeping its contents locked in place. As time passes, if the deposit of organic matter is buried deeper and deeper, the temperature will also increase, leading to the generation of oil. Therefore, the existence of organic material, lack of oxygen, high temperature, and a long period of time, all combine to create crude oils of different characteristics. Many view crude oil as simply the black liquid extracted from the Earth that is then refined into gasoline. But, it has many uses, from plastics to pharmaceuticals, although it is most known and revered for its energy content. Its use as a source of energy results in greenhouse gas emissions, which are thought to contribute to, or cause, global warming.

CRUDE OIL

The existence of oil has been known for centuries, since there are many natural seeps in the world. The LaBrea tar pit in California is an example of a natural seep. Early use included sealing seaworthy vessels, but demand was minimal until the development of the combustion engine. The growth in demand for gasoline and diesel has driven the exploration, production, and refining of crude oil.

As a fuel, the combustion is an instantaneous oxidation process that then releases heat and greenhouse gases. These greenhouse gases, stored for millions of years, are now being released at an alarming rate. Crude oil was forming and accumulating beginning about 600,000 million years ago. The first major oil company, Standard Oil, was founded in 1870. If it is assumed that global oil reserves will last another 100 years, then the entire recoverable deposits of oil will have been consumed in less than 250 years. So, in a fraction of the history of the Earth, millions of years of stored heat and gas are being released to the atmosphere. Oil is just one of the fossil fuels that have contributed to the greenhouse gas inventory. Natural gas and coal also contribute.

The standard unit of measure for oil is a barrel, which contains 42 gallons. Within a barrel of oil are many different hydrocarbon chains, and although a liquid, a barrel of oil can also contain gases and solids at certain temperatures. Hydrocarbons are molecules of hydrogen and carbon atoms in many different combinations. The longer the chain, the greater the weight, and the greater the number of carbon atoms. The lighter hydrocarbon molecules are the gases, such as methane and ethane. The heavier molecules in oil are known as bitumen or tar. In essence, the heavier the hydrocarbon, the greater the potential greenhouse gas emission, because it is a function of available carbon atoms. However, tar and asphalt are not intentionally burned, but their use as paving and roofing materials also contributes because radiated heat is then trapped by the greenhouse gas effect.

The reserve (supply) of oil is finite, but the amount left in the world to produce is uncertain, and to some degree is dependent on commodity price. There will be new discoveries where oil flows or is pumped in what is known as primary production. There will also continue to be production from old fields through enhanced oil recovery methods. Enhanced oil recovery involves some type of stimulation, usually through improved production technology, that is applied to old fields "squeezing" additional oil out of reservoirs. Increasing price justifies more squeezing and the development of new techniques to recover even more oil. However, at some point in the future, the world annual production will begin to decline. There is more oil being produced today through enhanced recovery then there is from primary production.

One type of enhanced recovery uses carbon dioxide in what is known as a CO_2 flood. The CO_2 gas is injected into oil reservoirs, giving them extended life by increasing the amount of oil production. The gas acts as both a piston to move fluid, and as a cleansing agent to collect oil from rock pores. Much of the CO_2 can be recycled, and, ultimately, a portion could be sequestered in an abandoned oil reservoir.

The American Association of Petroleum Geologists estimated that the cumulative world production of oil exceeded 750 billion barrels by 1993. Production since that time has raised the cumulative figure to approximately 1,100 billion or 1.1 trillion barrels. This represents a volume of over 42 cubic mi. of oil, equal to covering the state of Illinois in 4 ft. (2.2 m.) of oil. Proven reserves, that is, oil remaining to be pumped out of the ground, are estimated at approximately 1.1 trillion barrels. Assuming that exploration and continued technological advances result in a further 1.1 trillion barrels of oil, ultimately 126 cubic mi. of oil will have been produced. Gasoline accounts for almost half of a barrel, and with other fuels included, such as diesel, the percentage is over 75 percent. The majority of oil produced is combusted and releases greenhouse gases.

OIL BYPRODUCTS, GREENHOUSE GASES, AND GLOBAL WARMING

About 33 percent of the global energy supply is from oil. Gasoline, diesel, and jet fuel are refined oil products and, together, these fuels power the majority of transportation in the world. The greenhouse gases from oil are CO_2, nitrous oxide, and even minor amounts of methane. CO_2 and nitrous oxide are byproducts through combustion. Petroleum fuels are the largest contributor of CO_2; coal is second, and natural gas a distant third. Nitrous oxides are also a significant issue from engine combustion. Conversely, the amount of methane released from oil operations is generally small. Minor amounts may be released during production operations, but usually it is flared if a market does not exist to gather for transmission in a pipeline.

Crude oil also can contain impurities such as sulfur. Sulfurous crude oil is known as sour crude, while oil that lacks sulfur is the more desirous sweet oil. In addition, impurities such as nickel, paraffin, and salts can be present in certain crude oils distributed around the world. It depends on the host environment and the type of organic matter. Oil with significant amounts of impurities creates additional concerns for local environments. Sulfur, in particular, can damage vegetation.

LAND USE ALTERATION

Alteration of landscape through the destruction of vegetation is thought to cause climate change, so the production of oil and the emissions from its eventual combustion are both concerns. The search for oil has literally covered the globe. Geologists and wildcatters have pursued the hunt for oil and natural gas on land and sea in all climates. There is an adage: "oil is where you find it," and the search for oil includes tropical rain forests and arctic tundra. These and other locations create significant challenges to production, while maintaining the ecosystem. To begin the search for petroleum, geologic basins are identified. These are large regions where layers of rock were formed through compaction of sediment and chemical action over millions of years. These regions were subsiding and were seas or swamps, so that sediment (material for rock formation) and organic matter (material for petroleum formation) could be deposited.

These geologic basins exist throughout the world on continents and continental margins. The Gulf of Mexico is a geologic basin that is active today because it is a depression that is collecting sediment from drainage off a significant part of North America. It is also receiving deposits of marine organic matter. The Illinois Basin, on the other hand, has thousands of feet of sediment and organic matter, but has not been an active basin for millions of years. In most regions, the surface conditions are not like the conditions that existed at the time the organic material and sediment were deposited.

When a discovery is made, if economic, it is developed. Development requires building roads, drilling wells, and installing separation equipment, storage facilities, and possibly pipelines. In delicate ecosystems, the development and production can potentially harm that system, changing

The oil industry has worked to reduce and eliminate traces of crude oil in the sea from offshore production facilities.

the landscape, and contributing to climate change. Helicopters are often used to minimize clearing of vegetation and minimizing footprints. Also, drilling technology has improved so that it is now possible to drill a number of wells from one location through a technique known as directional or horizontal drilling.

Other operations also can impact the air and the land. Petroleum may need to be artificially lifted from deep in the Earth. The lifting of petroleum can require enormous amounts of energy. Electricity is used to pump petroleum, and that electricity may come from the electric grid or from generators fueled by diesel or natural gas on location. Over time, the fluid pumped out of the ground will contain an increasing percentage of water and a decreasing percentage of oil. This fluid is separated in the field so that only the oil is transported. The produced water must be properly treated and disposed. Over time, vegetation may be stressed by contaminants related to oil production. Highly mineralized water and sulfur are two potential contaminants that can damage or destroy local vegetation, contributing to a change in the local climate, and possibly the global climate. If not properly cased, well bores can be an unwanted conduit for moving fluid from one rock layer to another, and, thus, saline water can contaminate fresh water. If after abandonment, the integrity of plugging operations is flawed, then near surface aquifers can become contaminated and be a potential threat to vegetation.

Oil is transported for refining by truck, pipeline, and tanker. Tankers can be of enormous size, holding over 2 million barrels of oil. As a comparison, an onshore discovery of one million barrels would be considered respectable today in the United States onshore setting. Albeit small, it might require 20 years to deplete. Although the threat of a supertanker breakup is very low, if such an event were to occur, it would be a concern in the climate change debate. The ocean's plankton create oxygen and its destruction through toxicity or smothering from the oil will kill the plankton. Although a supertanker spill would be a huge scale environmental catastrophe, many can argue that the ocean's massive volumes and surface area reduce such an event to a minor, temporary problem. The oil industry has worked to reduce and eliminate all traces of crude oil in the sea from offshore production facilities. This oil is in trace amounts in the water that is released.

Refineries crack the hydrocarbons into products for marketing. Again, energy is consumed in the process and flares may be needed to burn gases in quantities too small to capture. It is the refined products, primarily gasoline and diesel fuel, that are of concern in the global warming and greenhouse gas debate.

CHANGING ATMOSPHERE

Based on trapped gases in ice cores in Antarctica, there has been a dramatic increase in greenhouse gases in the global atmosphere since the beginning of the Industrial Revolution. Samples indicate that in the last 200 years, CO_2 has increased by 35 percent, methane by 600 percent, and nitrous oxide by 18 percent. Data for CO_2 suggest that about 100 years ago there was an increase in the growth rate of atmospheric concentration, followed by another rate increase beginning about 50 years ago. About 50 years ago, the world consumption of hydrocarbons, combined oil and gas, surpassed coal in terms of energy content. The trend appears to be growing at an increasing.

A number of factors and processes unrelated to oil contribute to the rise in greenhouse gases, but the combustion of oil contributes to the concentration of CO_2. The production of oil also contributes to atmospheric methane through the escape of light end hydrocarbons in the logistics. A portion of nitrous oxide gas is also indirectly produced as a result of oil in the form of fertilizers and exhaust from gasoline and diesel engines.

CO_2 is the major source of greenhouse gas. It is possible to use CO_2 in the production of oil from mature oil fields where production is marginal. This is known as enhanced oil recovery in a process known as a CO_2 flood. The CO_2 is pumped into the reservoir where it moves fluid by expansion and pressure, and by acting as solvent, collecting oil in the gas. The fluid is then brought to the surface where the CO_2 is recycled to continue the process. Long-term, the CO_2 is sequestered in the reservoir so that it is not part of CO_2 inventory in the atmosphere.

SEE ALSO: BP; Coal; Natural Gas; Oil, Consumption of.

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Oklahoma

OKLAHOMA HAS AN area of 69,903 sq. mi. (181,048 sq. km.), with inland water making up 1,224 sq. mi. (3,170 sq. km.) Oklahoma's average elevation is 1,300 ft. (396 m.) above sea level, with a range in elevation from 289 ft. (88 m.) above sea level at Little River, to 4,973 ft. (1,516 m.) above sea level at Black Mesa in the Panhandle. The topographic features include the Interior Plains, making up the largest part of the state (hilly with changes in elevation to the High Plains); Coastal Plain (relatively flat and sometimes swampy); and the Interior Highlands (mountains, ridges, and valleys). Oklahoma has numerous smaller rivers and two major tributaries of the Mississippi River (the Arkansas River and Red River). The larger lakes are man-made by dams to control navigation, decrease flooding, and improve the water supply.

Oklahoma's climate conditions vary depending on the time of year and region of the state; it is warm and dry in most of the state. Northwestern Oklahoma is cooler and drier than southeastern Oklahoma. Temperatures range in the extremes from below 0–100 degrees F (minus 17 to 38 degrees C). The highest temperature recorded in the state was 120 degrees F (49 degrees C) on June 27, 1994 and the lowest temperature recorded in the state was minus 27 degrees F (minus 33 degrees C)on January 18, 1930. Oklahoma occupies a transitional precipitation zone, with a humid sub-tropical east and a semi-arid west. The length of growing season, in the warm and wet southeastern Oklahoma, averages 238 days, in the colder dryer panhandle the growing season lasts only 168 days. The amount of precipitation varies; the southeastern part of the state averages 50 in. (127 cm.) of moisture per year, and the Panhandle averages 15 in. (38 cm.) of moisture in the year.

Major industries include agriculture (wheat, corn, hay, and melons). Oklahoma ranks fourth in the United States for cattle production and second in the production of wheat. The state is rich in fossil fuel deposits (petroleum, oil, natural gas, and coal). The Arkansas River contains a system of lakes and dams to control flooding, ensure waterway transportation, provide water, and generate hydroelectric power. The largest aquifer in the world, Ogallala Aquifer, lies underground beneath eight states, including Oklahoma. The level of water in the aquifer has been dropping steadily for decades, and it is a limited resource. With conservation measures, the rate of depletion has slowed, but not stopped.

IMPACT OF CLIMATE CHANGE

Oklahoma experiences periodic droughts, occurring particularly in semiarid areas of western Oklahoma, the most famous of which occurred during the Dust Bowl. The Dust Bowl is the name coined for the seven-year period of severe drought that affected areas of the Midwest during the 1930s. A combination of below-normal rainfall, higher summer temperatures, strong winds, and erosion-causing agricultural and ranching practices devastated fertile land. Topsoil from Oklahoma and other states was picked up by the wind and carried away.

Climate models vary on temperature increase for Oklahoma, from 2–6 degrees F (1–3 degrees C) in the winter, from 1–5 degrees F (1–2.7 degrees C) in summer and fall, and from 1–4 degrees F (1–2 degrees C) in spring by the end of the century. Potential risks include possible increase in frequency and intensity of summer thunderstorms; decreased water supplies (eastern Oklahoma has plentiful surface water for supplying Oklahoma City, western Oklahoma relies on groundwater for irrigation, and the panhandle relies on groundwater from the Ogallala aquifer); flooding in urban areas and along tributary streams, more intense rains would increase contamination of water supplies by erosion, chemicals, and runoff from mining, oil, and gas areas. Temperature changes could decrease wheat yields and cause drier conditions. This could lead to drier soil, and a need for additional irrigation. Health risks include certain infectious diseases from water contamination or disease-carrying vectors such as mosquitoes, ticks, and rodents, and heat-related illnesses.

ADDRESSING HUMAN-INDUCED CONTRIBUTIONS TO CLIMATE CHANGE

Based on energy consumption data from the Energy Information Agency released June 1, 2007, Oklahoma's total carbon dioxide emissions from fossil fuel combustion in million metric tons for 2004 were 98.97, made up of contributions by source from: commercial, 2.31; industrial, 19.79; residential, 3.72; transportation, 28.92; and electric power, 44.23. All areas had improved over 2003 estimates. Oklahoma ranks eighth in the nation in terms of its potential to produce wind energy, with the ability to provide 17 times the state's entire annual electricity consumption through well-sited wind farms.

Oklahoma joined the Climate Registry, a voluntary national initiative to track, verify, and report greenhouse gas emissions, with acceptance of data from state agencies, corporations, and educational institutions beginning in January of 2008. A number of private-sector initiatives to reduce carbon pollution have been started in Oklahoma, inspiring the use of renewable and alternative forms of energy. In 2001, the state passed the Oklahoma Carbon Sequestration Enhancement Act, a voluntary program allowing agriculture and industry to join forces in reducing harmful carbon pollution by restoring vegetation that absorbs carbon dioxide in the soil. The principal soil conservation effort is directed toward covering the badly eroded lands with pasture grasses or trees to prevent further soil removal. Contour plowing, strip cropping, terracing, crop rotation, no-till farming, and other soil-conserving measures are also actively encouraged.

Oklahoma lawmakers have shown their reticence to implement climate-change reduction schemes before adequate research is completed. Republican U.S. Senator James Inhofe, representing Oklahoma, is concerned with the implications of creating federal laws with economic impact to address the global warming issue. Inhofe is skeptical of the impact of human action on global warming, and has submitted arctic climate assessments from a variety of scientists for support of current global warming being part of a natural cycle. When Representative Dennis Adkins, Oklahoma's state house energy chairman, testified in Washington, D.C., he indicated federal global warming legislation passed in a hurry could be costly to the economy and the people. He also pointed to advances that Oklahoma and other states are making with renewable energy options and their limitations. He urged federal lawmakers to consider the impact of regulations on the economy and the environment.

SEE ALSO: Carbon Sequestration; Drought; University of Oklahoma.

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Oman

THE SULTANATE OF Oman, located on the Arabian Peninsula, has a land area of 119,498 sq. mi. (309,500 sq. km.), with a population of 2,595,000 (2006 est.), and a population density of 21.5 people per sq. mi. (8.3 people per sq. km.). The country is largely covered by arid desert. However, there is heavy subsistence farming throughout the country. Oman's economy is dominated by the petroleum industry, although the government has sought to diversity the economy to remove its dependence on oil for its power industry. In spite of its small population, Oman contributes to global warming, with the per capita emission of carbon dioxide at 5.6 metric tons in 1990, rising to 6.1 metric tons in 1992, 7.3 metric tons in 1995, 8.7 metric tons in 1999, and 12.5 metric tons in 1993.

The generation of electricity in Oman comes entirely from fossil fuels, with the production of electricity making up 30 percent of the country's carbon dioxide emissions. An increase in the electricity network was implemented in the first and second Five Year Plans undertaken by the Omani government in 1976–80 and 1981–85, respectively. In addition, 28 percent of emissions came from manufacturing and construction, 17 percent from non-electricity energy industries, and 12 percent from transportation. Some 58 percent of Oman's carbon dioxide emissions come from gaseous fluids, with 28 percent from liquid fuels, and 11 percent from gas flaring. Coral reefs off the coast of Oman, located in both the Gulf of Oman and the Indian Ocean, have experienced serious bleaching as a result of a rise in water temperature.

The Oman government took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992. They accepted the Kyoto Protocol to the UN Framework Convention on Climate Change on January 19, 2005, which took effect on April 19, 2005.

SEE ALSO: Deserts; Oil, Consumption of; Oil, Production of.

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Orbital Parameters, Eccentricity

THE SUN SHOWERS the Earth in solar energy with varying intensity over time, while the Earth's orbital motion about the Sun affects how that energy is received. Eccentricity is the degree that the orbit deviates from a perfect circle. Seasons on Earth are modulated by the eccentricity of the orbital path around the sun, the precession effect, and the position of the solstices in the yearly revolution. Eccentricity plays not only a role in the diversity of the seasons, but also in the degree of climate change affecting Earth over the long term.

Johannes Kepler (1571–1630) discovered, through astronomical observations, that the Earth moved in an elliptical path around the sun. This could be expressed mathematically, and one of the parameters, eccentricity, ranges between a value greater than zero and a value less than one. A zero value produces a perfectly circular orbit, while unity ensures a parabolic encounter with the sun of a celestial body, such as a comet, that will never return. The smaller the value of eccentricity, the more circular is the orbit. Earth's eccentricity has been measured to be 0.0167 and so its orbit is not quite circular.

A not quite circular orbit means that the Earth is closer to the Sun at some times of the year, and farther away during other times. The perihelion, the closest approach to the sun, happens in January. This results in Northern Hemisphere winters that are slightly milder than if the orbit was perfectly circular. Over time, changes in the occurrence of perihelion, called the precession of the equinoxes, takes place every 22,000 years. This means that 11 millennia from now, the perihelion will occur in July instead of January and produce seasons even more severe than they are today.

KEPLER'S LAW OF EQUAL AREAS

Kepler's Law of Equal Areas says that an imaginary line drawn from the center of the Sun to the center of the Earth will sweep out equal areas in equal time intervals. This means that the duration of the seasons is proportional to the area of the Earth's orbit swept between the solstices and equinoxes. Consequently, when eccentricity is greatest, seasons occurring furthest away, at aphelion, are longer in duration. Northern hemisphere summers are slightly longer than the winters, because summer occurs at aphelion, when the Earth is furthest from the Sun and moving at its minimum orbital velocity. In 2006, summer was almost five days longer than winter. However, changes in the Earth's orbit over time will alter the location of the solstices and equinoxes. Eventually, Northern Hemisphere summers will become shorter, and winters will become longer, alternating duration, and changing how much solar radiation is absorbed by the Earth's surface. Any cooling effect derived from such changes will be negated by an eccentricity that will be almost reduced by a factor of two. A reduction in the average orbital radius tends to raise average surface temperatures in both hemispheres and cause changes in climate for thousands of years. Global warming ebbs and flows over a millennial time scale.

Planetary eccentricity is modulated by the gravitational pulls among the planets in the solar system. Earth's eccentricity alternates between nearly zero, to almost 0.0500. Consequently, the eccentricity of Earth's orbit is governed by the mathematical timing of 100,000- and 400,000-year periods. This, in turn, affects the strength of the Earth's seasons. Coupled with the varying tilt of the Earth's axis over time, and the changing precession of the Earth's orbit, the changing severity of summer and winter throughout the ages is thought to control the expansion and contraction of the polar ice sheets. Cooler summers in the Northern Hemisphere enable snow and ice to last longer. Since the greater land mass is located there, huge ice sheets over thousands of years are built up, covering the darker land and reflecting more sunlight. This process tends to lower the Earth's average surface temperature. On the other hand, warmer summers in the future will contribute to shrinking ice sheets, uncovering of landmass, and the absorption of more solar energy rather than its reflection. The average surface temperature of the Earth will rise.

Whatever the conclusion as to the ultimate cause of global warming, the orbital mechanics of the solar system will play a big role over the long-term. Such factors as eccentricity are understood, but there is little humanity can do to control the motion of the Earth.

SEE ALSO: Climatic Data, Historical Records; Earth's Climate History; Glaciology; Ice Ages; Orbital Parameters, Obliquity; Orbital Parameters, Precession.

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Orbital Parameters, Obliquity

THE EARTH'S ORBIT and orientation around the Sun affects how solar energy is received. Obliquity is the degree of the Earth's tilt as it completes its daily rotation and yearly revolution around the Sun. It is the angle an imaginary rotational axis would make with the plane of the Earth's orbit. The axial tilt, which varies over time from 21.5 to 24.5 degrees and back again, is the reason for the seasons. A complete tilt cycle takes 41,000 years to complete. In concert with the eccentricity of the orbital path around the Sun and the precession effect, obliquity is a factor of climate change affecting Earth's average surface temperature over the long term.

Chinese astronomers in the 11th century determined Earth's obliquity of the ecliptic. They observed that during the changing seasons, the extreme northern and southern declination of the Sun defined the obliquity. Astronomers also deduced that the difference of the peak height of the Sun on the longest day and shortest day of the year was double the obliquity factor.

The Earth's obliquity is about 23 degrees and 26 minutes. Its axial tilt is consistent during the year as it revolves around the Sun. During an annual orbit, each hemisphere alternates between being tilted towards the Sun and then tilted away from the sun. This changing exposure to the direct rays of the Sun is the cause for the seasonal variety and why the Northern Hemisphere enjoys summer while the Southern Hemisphere experiences winter, and vice versa. The half of the Earth's sphere tilted toward the Sun receives more sunlight in a given day and accepts it an angle closer to the vertical. The longer days and more direct rays of light deliver more heat, which contributes to global warming. Fortunately, the Earth is currently in an orbital cycle where the summer-time tilt occurs when it is furthest from the Sun, thereby moderating potential temperature extremes.

Obliquity is a major factor in climate change with the ebb and flow of ice ages on a planetary scale. When obliquity is low, the higher latitudes receive less solar energy. The days are shorter and the sunlight is less direct. The loss of summer heat is much greater than the milder winters experienced during periods of lower obliquity. Furthermore, the warmer winters do not reduce the snowfall enough in the higher latitudes to offset melting. Over time, ice ages dominate the Northern Hemisphere and as the obliquity increases again, interglacial periods return. Earth is currently experiencing one of these interglacial cycles.

Earth's tilt, or the obliquity of the ecliptic, changes over time. The effect is gradual and its changes are not felt on a daily or yearly basis, but on the scale of thousands of years. Although the obliquity and the precession of the equinoxes are related, their respective movements are independent of one another. The tilt is a back and forth movement in a plane perpendicular to the orbital plane, while the changing of the equinoxes is a wobble, or circular rotation, about a plane at right angles to the line of axial tilt.

Milutin Milankovitch (1879–1958), a mathematician, looked for patterns in Earth's orbital variations.

He determined the amount of light energy received for each aspect of Earth's orbital variations, including its tilt. In his 1930 book, *Mathematical Climatology and the Astronomical Theory of Climate Change*, Milankovitch claimed that ice ages occurred when variations in the Earth's orbit caused the landmass-laden Northern Hemisphere to receive less sunshine during the summer months. Such shorter and cooler summers left some winter snow for the following winter to build upon, thereby accumulating thick ice sheets over the years. The snow's white reflective surface would redirect solar radiation back into space and average surface temperatures would continue to drop over the millennia. An ice age would eventually dominate the Northern Hemisphere. Milankovitch predicted ice age cycles overlapping every 100,000 and 41,000 years, with additional mini-cycles occurring every 19,000 to 23,000 years.

The directional angle that Earth's rotational axis tilts defines, in part, these extreme cold periods and the relatively warm periods the planet experiences. The rare warm period currently being experienced has led to the rise of human civilization on Earth. The complex interaction of orbital variations, solar intensity, and the unprecedented increase in greenhouse gas concentrations in the atmosphere is yet to be fully understood. While humanity cannot control celestial mechanics, it can modify its own behavior when it comes to greenhouse gases emissions.

SEE ALSO: Glaciology; Ice Ages; Milankovitch, Milutin; Orbital Parameters, Eccentricity; Orbital Parameters, Precession.

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Orbital Parameters, Precession

THE ORBIT AND rotational behavior of the Earth moving about the Sun affects the amount of solar energy received. Precession is the phenomenon where the Earth wobbles about on its axis, just like a spinning top. Consequently, the solstices and equinoxes occur earlier each year. The winter solstice occurs a few weeks before perihelion, the closest approach Earth makes to the Sun. Over time, the summer solstice will occur closer to perihelion and the summer heat will become even greater. This precession of the equinoxes takes 25,800 years to complete. During the period of a precessional cycle, the North Pole follows a circle in space, perpendicular to Earth's imaginary axis of rotation. In concert with the eccentricity of the orbital path around the Sun, and the varying tilt of the Earth's axis in space, precession is a factor of climate change affecting Earth's average surface temperature over the long-term.

The Greek astronomer Hipparchus (c.190–c.120 B.C.E.) compared astronomical observations 169 years apart, and found that the Earth's axis around which the night sky appeared to rotate shifted gradually. He discerned a 2-degree shift by looking at the Earth's shadow on the moon during a lunar eclipse. From this observation, Hipparchus could determine the Sun's position among the stars and identify Earth's changing axial position.

Earth is not a perfect sphere and its equatorial bulge is a factor in the precession phenomenon. Centrifugal force generated during Earth's daily rotation creates the bulge and provides the force that wobbles Earth ever so slightly. The gravitational forces of the moon (responsible for the tides) and the Sun (responsible for Earth's orbit) on the bulge provide the impetus for Earth's precession.

The Earth achieves perihelion on January 3rd, which is close to the Northern Hemisphere's December 21st winter solstice. This timing of Earth's closest approach to the Sun and the shortest day of the year reduces seasonal differences in the amount of solar radiation received by the Northern Hemisphere. The fact that the Northern Hemisphere is closer to the Sun in winter than in summer, produces a relatively warmer winter, thereby reducing the overall variability of the yearly seasons. By contrast, 11,000 years ago, the Earth reached its closest point to the Sun during the Northern Hemisphere summer, increasing both the summer heat and the overall seasonal variability of Earth's climate.

Changes in Earth's orbital eccentricity over time, by itself, has little impact on the total amount of radiation received. The effect is on the order of .01 percent. However, as the eccentricity cycle is modulated by the precession cycle, the effect can be greater or lesser as time passes. When Earth's orbit is highly elliptical (eccentricity is high), the effect of precession on the seasons is strong. When Earth's orbit is almost circular (eccentricity is low), the effect of precession on the seasons is negligible.

Milutin Milankovitch (1879–1958) understood these changing orbital parameters and saw the effect that the precession of the equinoxes had on climate, as well as the ebb and flow of the ice ages. When climate extremes were maximized by the right combination of factors, including the summer solstice occurring during perihelion, the time was ripe for an ice age. With the corresponding winters colder in the Northern Hemisphere, more snow fell, for a longer duration, overwhelming the extreme season of summer heat and, in turn, feeding the glacial ice sheets. Because snow is an effective reflector of sunlight, the snow-covered landmasses of the Northern Hemisphere did not warm as they once had when winter ended. Milankovitch argued that this was just enough to cause the periodic cycle of the ice ages.

Sediment and ice cores have been a useful tool to find Earth's temperatures for the past half-million years. These datapoints highlight how rare Earth's present warm spell is, allowing human civilization to flourish for the past 11,000 years. This relatively warm period is due, in part, to the wobble of Earth's rotational axis over time. The associated precession of the equinoxes has aligned the Earth-Sun pattern such that the Earth's Northern Hemisphere points away from the hot Sun while it is furthest away from it. This moderates both the summer heat and winter cold to provide a more livable climate.

SEE ALSO: Glaciology; Ice Ages; Milankovitch, Milutin; Orbital Parameters, Eccentricity; Orbital Parameters, Obliquity.

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Oregon

OREGON'S AVERAGE ELEVATION is 3,300 ft. (1,006 m.) above sea level, with a range in elevation from sea level along the Pacific Ocean, to the peak of Mt. Hood at 11,239 ft. (3,426 m.). Mountain ranges, including the Coast Range, and the Cascades, divide Oregon. Inland from the Coast Range of mountains is the Willamette Valley, which includes the Willamette River, flowing toward the Columbia River. The Columbia Plateau is northeast of Willamette Valley and west

Mountain ranges divide Oregon. West of the Cascades, Oregon's climate is moderated by the Pacific Ocean.

of the Cascades. East of the Cascades is high plateau, and the Great Basin, an area of high desert.

Oregon's mountain ranges absorb moisture and precipitation. West of the Cascades, the climate is moderated by the Pacific Ocean, giving cool summers (average summer temperatures below 70 degrees F or 21 degrees C) and mild winters (above freezing even during the coldest months). The Willamette Valley receives almost 48 in. (123 cm.) of rain per year. The Columbia Plateau northeast of Willamette Valley, and west of the Cascades has a mild climate. The Cascades experience below freezing temperatures in the winter months, with heavy snowfall (up to 50 ft. or 15 m.), and snow remains for many months. East of the Cascades and the Great Basin, an area of high desert has dry air and extremes of hot and cold, while receiving less than 10 in. (25 cm.) of rain per year. The highest temperature recorded in the state was 119 degrees F (48 degrees C) on July 29 and August 10 of 1898, and the lowest temperature recorded in the state was minus 54 degrees F (minus 48 degrees C) on February 9 and 10, 1933.

The state supports a population of over 3.5 million people. Forests used for logging cover more than 40 percent of Oregon. The Grand Coulee Dam retains some water from spring runoff for summer use, and supplies hydroelectric energy throughout the west.

IMPACT OF CLIMATE CHANGE

The flood of 1996, caused by a combination of heavy snowstorms followed by warm temperatures and rain, resulted in the overflow of most of Oregon's waterways. Low-lying areas like Tillamook became lakes. In addition to the weather, logging and road-building may have been contributing factors.

Lumber is a major industry and preservation is a concern. Commercial logging started in the 1800s and has claimed 90 percent of the forests that once grew in the Pacific Northwest, creating checkerboards of clear-cut and uncut forest vulnerable to environmental pressures. More than half the remaining untouched forest areas in Olympic National Forest are slated for cutting during the next 50 years, as is 69 percent of the old growth in Oregon's Siuslaw National Forest. Trees absorb carbon dioxide (CO_2), and as more trees are cut, the less CO_2 can be absorbed.

Climate models vary on the amount of temperature increase during the 21st century, from 2.5–10.4 degrees F (1.4–5.8 degrees C). Potential risks include smaller snow pack (average water content of the Northwest snow pack declined by 30 percent between 1950 and the 1990s); rising sea levels between 4–35 in. (10–89 cm.); decreased water supplies; increased risk for wildfires; population displacement; changes in food production (with agriculture improving in cooler climates and decreasing in warmer climates); and changes in rain patterns to downpours, with the potential for flash flooding and health risks of certain infectious diseases from water contamination or disease-carrying vectors such as mosquitoes, ticks, rodents; and heat-related illnesses.

With a predicted decrease in Cascade snow pack, access to fresh water will diminish and affect crops, forests, and potable water supplies, and possibly cause decreased hydroelectric output. Rising sea levels will change the coastline, including beach erosion and land loss, making infrastructure (roads and buildings) vulnerable with the possible displacement of populations. The impact of climate change on agriculture will be mixed; some crops, like potatoes and wine grapes, could be negatively impacted by rising temperatures, decreasing yields. By comparison, the orchard crops will mature more quickly at higher temperatures, with increased quality and market share value. Some areas may need to change crops for those with higher drought resistance and adaptability to a warmer climate.

ADDRESSING HUMAN INDUCED CONTRIBUTIONS TO CLIMATE CHANGE

Based on energy consumption data from Energy Information Agency, Oregon's total CO_2 emissions from fossil fuel combustion in million metric tons for 2004 were 42.50, made up of contributions by source from: commercial, 1.78; industrial, 7.32; residential, 2.58; transportation, 22.80; and electric power, 8.03. In 1997, the state legislature adopted a CO_2 emissions performance standard of 675 pounds of CO_2 per MWh for electric generating units. Oregon's Greenhouse Gas reduction target is to stabilize by 2010, fall to 10 percent below 1990 levels by 2029, and fall to 75 percent below 1990 levels by 2050.

Oregon's governor appointed the Climate Change Integration Group in June of 2006 to develop a climate change strategy for Oregon that provides long-term sustainability. Oregon holds member status with the Western Regional Climate Action Initiative, in which the partners will set an overall regional goal for reducing greenhouse gas emissions. Oregon joined the Climate Registry, a voluntary national initiative to track, verify, and report greenhouse gas emissions, with acceptance of data from state agencies, corporations, and educational institutions beginning in January of 2008.

Portland, Oregon is the base for Earth Share of Oregon, a nonprofit federation of 68 local and national environmental conservation groups for workplace fundraising. Founded in 1989 to provide stable funding sources, Earth Share has raised over $8.5 million. Earth Share supports groups seeking to reduce global warming (through tree planting, recycling, proposing energy policies, monitoring industry practices, preserving natural habitats, and ensuring the availability of clean water).

SEE ALSO: Climate Change, Effects; Oregon Climate Service; Oregon State University.

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Oregon Climate Service

THE OREGON CLIMATE Service at Oregon State University offers monthly climate statistics for various stations in Oregon. It is located on the Oregon State University campus in Corvallis, Oregon, and is the state depository for weather and climate information. It is affiliated with Oregon State University's College of Oceanic and Atmospheric Sciences (COAS). Oregon Climate Service data may be accessed on the World Wide Web. They include a monthly means and extremes dataset for stations throughout the state for the years 1961–90. Parameters contained in this dataset are mean temperature, extreme mean, precipitation, and degree days. There are also two other monthly datasets dealing with precipitation and temperature for individual years. The time period varies for each observation station. The daily precipitation dataset dates back to 1961 and consists of precipitation evaluations measured in hundredths of an inch for various locations in Oregon. Daily data are also available for Corvallis, Oregon beginning July 1, 1996 to the present.

The OCS mission is to collect, manage and maintain Oregon weather and climate data, to supply weather and climate information to those within and outside the state of Oregon, to educate the people of Oregon on current and emerging climate debates, to perform independent research related to weather and climate topics. OCS liaises with: National Climatic Data Center, Western Regional Climate Center, National Weather Service, Natural Resources Conservation Service, Climate Prediction Center, American Association of State Climatologists and other state climate offices. On average, the Oregon Climate Service receives approximately 6,000 telephone or mail enquires per year. It publishes the Oregon Weather Summary, a monthly report on the current climatic conditions in Oregon. In addition, OCS has published numerous data summaries and special reports, which include climate zone summaries, agricultural regions summary, local climatological data, precipitation maps of Oregon, Oregon counties, U.S. States, and the United States in general.

The OCS is partially funded by the State Government. It has been active in crucial areas of research for the understanding of global warming, such as El Niño/Southern Oscillation and its influence on Western climate, climate change, drought and flood studies, precipitation mapping (the PRISM project), and wind modeling. George H. Taylor is the State Climatologist for Oregon and directs the OCS, supervising its staff of 10. He is in favor of trying to reduce the human impact on climate, but he is not persuaded that anthropogenic greenhouse gases either from coal-fired power plants or motor vehicles emitting carbon dioxide are the main causes. Taylor believes that natural variations and cycles of climate have a bigger role. He describes climate system, as "very, very complex," and states that "the more we learn, the more we see that we really don't understand it." This is why he is skeptical of models that stress human impact on weather as the main cause of global warming.

SEE ALSO: Climate; Oregon; Oregon State University.

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Oregon State University

OREGON STATE UNIVERSITY (OSU) is a four-year research and degree-granting public university, located in Corvallis, Oregon in the United States. Total student enrollment (undergraduate and graduate) is more than 19,000. Eighty-one percent of students are Oregon residents. OSU offers more than 200 academic degree programs and is most noted for engineering, environmental sciences, forestry, oceanography, and pharmacy. The university has more majors, minors, and special programs than any other college in Oregon. OSU is one of only two universities in the United States to be designated as a land-grant, sea-grant, space-grant, and sun-grant institution. Cornell University is the other. The Environmental Sciences (ES) Graduate Program provides curricula leading to M.A., M.S. and Ph.D. degrees in environmental science.

The curriculum integrates thinking across disciplines, especially life, physical, and social sciences. Environmental science explores natural processes on Earth and their alteration by human activity. OSU has exceptional strength in many of the disciplines, including science, agriculture, forestry, engineering, public health, liberal arts, social science, and oceanography and atmospheric science. The degrees administered by the program are OSU's contribution to the Joint-Campus Graduate Program for Environmental Sciences, Studies, and Policy, which links environmental graduate programs among the major research universities in Oregon. The ES Graduate Program develops scientists who will be able to analyze and understand environmental systems, predict environmental change, and participate in the management of the environment. Each student completing a major in the ES Graduate Program will perform research and complete a thesis, dissertation, or research project. Each student will complete a core of ES graduate courses that will integrate concepts across the physical sciences, life sciences, and social sciences. Each student will also develop depth in a carefully designed, interdisciplinary area of concentration or track. Tracks that are currently available include ecology, biogeochemistry, social science, quantitative analysis, water resources, and environmental education.

Oregon State University College of Oceanic and Atmospheric Sciences (COAS) is one of the leading oceanography and atmospheric sciences institutions in the nation. Graduate research programs leading to a Masters degree in science or a Doctoral degree are offered at OSU. Advances in understanding and simulating atmospheric boundary layer processes directly support applications to geographically-localized studies of climate and weather, which is of particular value to agriculture, forestry, and the economic development of the Pacific Northwest. Major research initiatives in the area of climate variability and change require expertise in observing and modeling of physics and chemistry of the atmosphere, and in the modeling and analysis of climate variability.

Courses offered at Oregon State University that focus on Global Warming and Climate Change include the following:

ATS 320: Man's Impact on Climate: Survey the climate and the factors that influence the climate. Examine sources for changes in atmospheric composition, the expected consequences of these changes, problems predicting future changes, and what can be done about the changes.

ATS 412: Atmospheric Radiation: Radiative transfer in the Earth and planetary atmospheres, absorption and scattering of sunlight, absorption and emission of terrestrial radiation, absorption and scattering cross sections for molecules, cloud droplets and aerosols. Applications include enhancement of photochemical reaction rates in clouds, remote sensing, and the Earth's radiation budget, radiative-convective equilibrium, radiative forcing due to changes in atmospheric composition and climate change.

SEE ALSO: Climate Change, Effects; Global Warming.

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Organisation for Economic Co-operation and Development (OECD)

THE ORGANISATION FOR Economic Co-operation and Development (OECD) was tasked by its founding convention (December 14, 1960) with assisting member countries with sustaining economic expansion, increasing employment, raising their standards of living, and maintaining financial stability while developing a sustainable global economy benefiting humankind. The OECD seeks to meet these goals by the collection, evaluation, and dissemination of pertinent data, by fostering cooperation between governments and economies, and by assisting governments in developing and evaluating policies that positively and negatively impact these goals. In 1961, the OCED absorbed the Organization for European Economic Cooperation (OEEC) that starting in 1947 had administered American and Canadian aid for the post-World War II Marshall Plan reconstruction of Europe.

OECD INSTITUTIONAL ORGANIZATION

The OECD promotes democracy and local, regional, national, and global market economies and maintains co-operative relations with more than 100 countries and economies, including 70 developing and emerging market economies with which it exchanges views and shares its expertise and accumulated experience. The OECD currently has 30 member counties (Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland Ireland, Italy, Japan, Korea, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, United Kingdom, and the United States) and invited five more countries (Chile, Estonia, Israel, Russia, and Slovenia) to join in May 2007, and is investigating offering membership to Brazil, China, India, Indonesia, and South Africa. Membership in the OECD is by the invitation of the OECD governing body, the Council. The Centre for Co-operation with Non-Members (CCNM) is responsible for the OECD's relationship with non-members. The CCNMs Global Forums examine trans-boundary issues that impact members and their relationships with non-members.

The Council is comprised of one representative from each member country, plus a representative of the European Commission, and meets per a regular schedule. The OECD Secretariat, who is also charged with accomplishing the Council dictates, chairs the Council. All Council decisions are by consensus. The overall direction of the OECD is set at an annual meeting of the Council attended by member representatives at the ministerial level. The OECD Forum held during the ministerial meeting allows access to OCED ministerial attendees by outside business, labor, and nongovernmental organizations. The OECD is headquartered in Paris, France, and employs a secretariat staff of 2,500, conducting business in French and English, with a 2007 budget of €340 million.

The OECD uses approximately 200 policy-specific committees to review and evaluate all policies and developments pertinent to fulfilling the OECD mission statement. These committees review, evaluate, request, participate in, and contribute to the work of the OECD. Approximately 40,000 senior member state representatives participate in these committees each year and continue their interaction and access to information online through a dedicated and secure OECD internet network. These committees create new rules of governing international co-operation, develop and negotiate formal agreements between countries, develop agreed upon standards, create models, or produce guidelines for all of the topics pertinent to the OECD mission statement.

The OECD monitors and analyzes all events that impact the economies of its member states and the global economy making short- and medium-term economic projections for its member states and the global economy. The OECD Secretariat is responsible for the overall collection, analysis, and dissemination of the data. OECD committees review the data and assess possible national and international policy ini-

The signing of the Organisation for Economic Co-operation and Development (OECD) by 20 countries at the Salon de l'Horloge, Quai d'Orsay, Paris, on December 14, 1960. The OECD currently has 30 member countries.

tiatives based on the data. The OECD Council recommends policy initiatives based on the work of the committees, and governments choose whether or not and how to undertake the policy initiatives. The OECDs four decades of collecting, monitoring, and comparing of economic and social data has made its statistical database of trends, forecasts, and analyses in economics, societal evolution and norms, trade, the environment, agriculture, technology, governmental policies, taxation, poverty, and development the largest in the world.

FULFILLING THE OECD MISSIONS

The OECD seeks to fulfill its missions by concentrating on seven major areas: the monitoring, collection, analysis, and collection of data; assisting constituent and corresponding governments; promoting employment, education, and social welfare; promoting sustained economic development without harming the environment; assisting in financial matters relevant to its mandate; promoting efficiency and fairness in governments and business; and fostering innovation.

The OECD is one of the largest hardcopy and online publishers in economics and public policy and maintains an innovative online library of statistical databases, books, and periodicals, as well as providing online consultations. Key OECD publications include: OECD Economic Outlook; OECD Factbook; OECD Economic Surveys; Going for Growth. The OECD assists constituent and corresponding governments by sharing comparative policy experiences, solutions to common problems, and effective practices and policies. The OECD also seeks to harmonize national and international policies and to coordinate their implementation. The OECD promotes employment, education, and social welfare by advocating policies that foster: equal access to education, accessible quality health care, social inclusion, employment, and the introduction of information technologies to the world's impoverished. The OECD is not a source of funding source and does not grant or lend money.

The OECD promotes sustained economic development without harming the environment by advocating policies that foster: the application of science and technology; creating markets based on sound environmental practices; and decrease over-consumption, pollution, and waste. The OECD also sponsors for its member states discussions on energy issues through the International Energy Agency (IEA) and the Nuclear Energy Agency (NEA).

The OECD Environment Directorate provides governments, policymakers, academics, businesses, and interested parties with the statistical database necessary for evaluating economic and development growth and how this growth or lack thereof relates to governmental policies and innovations. Country performance reviews, policy analyses, modeling, projections, and cooperative approach analyses are examples of the information available. This allows governments and interested parties to compare policy experiences and initiatives so as to improve their own domestic management and international cooperative efforts by learning from the positive and negative policy and practice experiences of others.

The OECD seeks to provide member states and developing countries greater access to financial services. The OECD promotes best practices in the international financial arena, facilitates greater access to financing through investment policy reforms, analyzes the effect of domestic tax structures on domestic markets and labor, and seeks to provide better insurance and pension options for aging populations.

The OECD promotes efficiency and fairness in governance, administration, and management, by encouraging fair competition ethical practices, citizen-participation in policy-making, and fair tax structures. The OECD encourages companies to manage themselves more effectively, discourages corruption, and seeks to make weak public administration more effective. The OECD encourages its committees to mutually examine and evaluate governmental performance through peer reviews.

The OECDs current regional initiatives concentrate on Europe, the Caucasus and Central Asia, Asia, Latin America, the Middle East and North Africa with special attention given to relationships between OECD member states and West Africa. The OECDs Support for Improvement in Governance and Management (SIGMA), a joint venture with the European Union, helps addresses management and governance issues in Central and Eastern Europe. The OECD also assists Brazil, China, and Russia on these issues programs individualized to each country.

The OECD also maintains relationships with various international assemblies, organizations, and bodies, such as the Council of Europe, the Economic Committee of the NATO Parliamentary Assembly, the International Labour Organization, the Food and Agriculture Organization, the International Monetary Fund, the World Bank, and the International Atomic Energy Agency. The OECD cooperates with many United Nations agencies and coordinates the European Conference of Ministers of Transport. The OECD fosters innovation in biotechnology, information and communications technologies, and evaluates the improvement in these areas by setting benchmarks keyed to each country.

The OECD is funded by formalized assessments on its member states that are based on the size of the member's economy. The United States assessment pays for 25 percent of the OECD budget, with Japan paying the second largest assessment. Special projects approved by the OECD Council are funded by contributions designated for the specific programs. The OECDs budget is determined biennially and is audited by the Office of the Auditor-General under the auspices of the OECD Board of Auditors, comprised of four members of national audit offices of member states. The Board certifies the audit to the Council, which, assuming there are no problems, approves the management of OECD.

SEE ALSO: Intergovernmental Panel on Climate Change (IPCC); International Energy Agency (IEA); OECD Annex I Expert Group on the UNFCCC; OECD Climate Change Documents.

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Oxygen Cycle

THE OXYGEN CYCLE allows for the regeneration of freely available diatomic oxygen (O_2) in the atmosphere. Oxygen accounts by volume for approximately 21 percent of the atmosphere, is reactive with myriad inorganic and organic substances, and is vital to living organisms for aerobic respiration and energy production. The cycle involves any source of oxygen within the world, and is not limited to the oxygen animals must breathe to sustain life; any compound containing an atom of oxygen is considered part of the oxygen cycle. Furthermore, the cycle is composed of many distinct biological and geological chemical reactions that together allow oxygen initially consumed and lost from the atmosphere to be released back into the atmosphere.

These reactions take place among the three different primary reservoirs, or storage areas of all of Earth's oxygen. These storage areas are varied and differ in physical and chemical form. The lithosphere, which contains the vast majority of the Earth's total oxygen, comprises the entirety of the Earth's crust and the uppermost portion of the mantle (tectonic plates can be viewed as lithospheric plates); in this reservoir, oxygen is bound in the form of rocks and minerals, primarily in silica (SiO_2) and alumina (Al_2O_3). The second reservoir is the biosphere, in which all living matter resides, including bacteria, plant life, animals, and human beings. The oxygen bound in this reservoir is found in the macromolecules of life, including nucleic acids, carbohydrates, proteins, and water. The last oxygen reservoir is the atmosphere, which is composed of approximately 20.95 percent oxygen gas, .038 percent carbon dioxide (CO_2), and water vapor (H_2O).

All of the reactions that drive the oxygen cycle occur between any two different reservoirs of oxygen. However, two chief reactions account for most of the activity in the use and regeneration of oxygen on Earth; these are cellular respiration and photosynthesis, both of which occur between the atmospheric reservoir and the biospheric reservoir. Other notable reactions contributing to the cycle include the commonplace reaction between the atmosphere's free oxygen and the lithosphere in the form of the oxidation of minerals and carbon dioxide emissions (for example, from volcanic eruptions). The biosphere and lithosphere interact in the oxygen cycle through weathering and absorbed soil nutrients for organisms and deposition of organism shells and bones into the lithosphere.

The primary action of the oxygen cycle occurs through photosynthesis and cellular respiration. Together, they represent the ability of diatomic oxygen gas to be used and produced by living organisms from the oxygen present in the air. Cellular respiration is the process by which an organism consuming food generates energy to sustain life. Most organisms use oxygen to maximize the amount of energy the food can yield, using oxygen as an electron acceptor in the electron transport chain, and using oxidative phosphorylation. Photosynthesis involves combining atmospheric carbon dioxide with water to generate carbohydrate sources and oxygen gas. The reactions are complementary:

Cellular Respiration: $C_6H_{12}O_2 + O_2 \text{ -> } CO_2 + H_2O$
and
Photosynthesis: $CO_2 + H_2O \text{ -> } C_6H_{12}O_2 + O_2$

There are other reactions involving oxygen that are vital for life that occur within a single reservoir. The ozone-oxygen reactions allow for stratospheric ozone to absorb ultraviolet light radiated from the sun, in addition to the visible light photosynthesis requires, which can cause damage to DNA, and break other important chemical bonds. The net reaction for the generation and breakdown of ozone by the absorption of ultraviolet light is:

O_3 (ozone) + UV Light Energy -> O_2 + O (reactive radical)
O (reactive radical) + O_2 (atmospheric oxygen gas) -> O_3 (ozone)

Other important reactions include the dissolving of oxygen in bodies of water, which allows for aquatic life to undergo aerobic cellular respiration and the evaporation of different bodies of water.

The oxygen cycle is not an isolated system; rather, it has intimate links with many other geological and biological cycles, such as the carbon cycle and the hydrologic cycle. Additionally, other smaller cycling systems, such as the nitrogen and sulfur cycles, require oxygen from the atmosphere, living organisms, or the ground to make their vital nutrients available for uptake and binding to useful substrates. For example, the oxidation of sulfur creates sulfur dioxide, which may then react with water vapor to form sulfuric acid, which can delivered to, and taken up by, plant roots; the sulfur can be used to make cysteine, an important structural amino acid.

Current scientific theories and opinions indicate that the oxygen cycle itself has not always been native to the Earth. In the far geological past, when the Earth was first cooling and forming, the atmosphere contained virtually no free oxygen and was primarily composed of hydrogen and helium gas. As conditions changed, a second type of atmosphere formed, composed of volcanic emissions, still largely devoid of diatomic oxygen gas. While life first developed on Earth, oxygen was released as a waste product from the most ancient forms of life, cyanobacteria. The oxygen cycle, thus, could not have been native to the Earth and must have developed as the Earth matured, because oxygen seemingly was not present. An interesting side note is that if the regeneration of free atmospheric oxygen stopped by cessation of photosynthesis and other oxygen cycle reactions, current estimates indicate that at current rates of oxygen consumption, it would take approximately 5,000 years for the Earth to deplete the atmosphere.

SEE ALSO: Atmospheric Boundary Layer; Atmospheric Component of Models; Atmospheric Composition.

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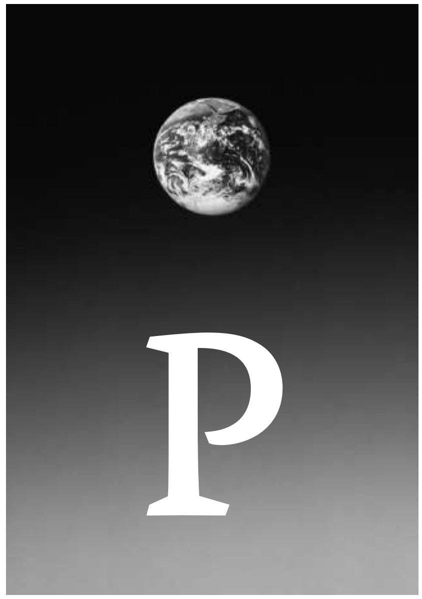


Pacific Ocean

THE PACIFIC OCEAN—named the "peaceful sea" by Ferdinand Magellan, a Portuguese explorer leading a Spanish expedition—is the largest ocean in the world, covering 65.3 million sq. mi. (169.2 million sq. km.), encompassing 32 percent of the total surface of the Earth, and holding 46 percent of the Earth's water. Altogether, there are 25,000 islands in the Pacific, the vast majority south of the equator, which bisects the ocean.

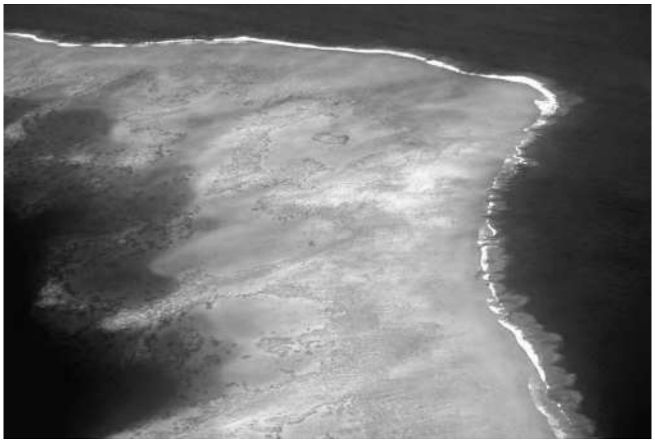
RISING SEA LEVELS

Global warming and climate change pose many real threats to the Pacific Ocean. The major focus of much attention around the world has been on the rising water levels, which is likely to inundate many of the low-lying Pacific Islands. Independent countries such as Fiji, Kiribati, the Federated States of Micronesia, Nauru, Palau, Samoa, and Tuvalu risk losing the vast majority of their land if the rising world temperature continues to raise the water level of the ocean. Atolls in French Polynesia and in Wallis and Futuna are also under threat. In addition to those places, all the countries in the Pacific have an increased risk of flooding, which could lead to permanent soil loss, as well as an increased risk of the prevalence of insect-borne diseases such as malaria and dengue fever as mosquitoes find further breeding grounds. The rising sea levels also threaten mangrove swamps in many areas, including off the northeastern coast of Australia, and in many Pacific Islands, with 13 percent of the world's mangrove swamps at risk of being lost.

For this reason, many of the countries in the Pacific have been at the forefront of urging countries around the word to embrace the Kyoto Protocol and limit carbon dioxide emissions. The Republic of Nauru, the country with the highest per capita rate of carbon dioxide emissions in the Pacific, went as far as adding a long addenda to the Kyoto Protocol, arguing that it did not feel that the protocol went far enough. Two U.S. territories in the Pacific, Guam and American Samoa, have considerable carbon dioxide emissions. The Solomon Islands, Papua New Guinea, and Vanuatu have, respectively, the lowest rates of carbon dioxide emissions in the Pacific, at rates similar to that of many African countries.

CHANGES TO MARINE LIFE

Other problems in the Pacific Ocean regarding global warming focus on the marine flora and fauna. The area most dramatically affected has been the bleaching of coral reefs around the Pacific, with studies by the International Ocean Institute of the University



Reefs in Fiji, in the Pacific Ocean. Global warming and climate change many cause a rise in sea level.

of the South Pacific in Fiji conducting surveys of coral reefs in the southwest Pacific as part of the International Coral Reef Initiative. In many cases, the damage to coral reefs has come from overpopulation, and through overexploitation through tourism, but even many reefs located in remote parts of the Pacific have experienced bleaching, showing that the damage can be ascribed as much to global warming as to other problems.

As well as coral reefs, there have been significant changes to the marine life, especially the fish in the Pacific. The most dramatic changes have been the reduction in the diversity of fish shoals, as well as the decline in the number of fish, the latter probably as much from overfishing as from global warming. However, there still remain large numbers of tuna fish and also some cluepoids in the central part of the Pacific Ocean, as well as sardines and jack mackerel along the coast of Chile, anchovy off the coast of Ecuador and Peru, mackerel and Saury off the Pacific coasts of Mexico and the United States, and sardine and salmon off the Pacific coast of Canada.

Some 4 percent of the ozone in the Earth's stratosphere is lost each decade, and a hole has appeared over Antarctica, leading to a higher risk of skin cancer from ultraviolet light in places such as Australia, New Zealand, Chile, and southern Argentina. Although there has been a great focus on their effects on humans, the ultraviolet rays have also been linked to the reduction in the plankton population in the southern part of the Pacific Ocean. The removal of much of the plankton has major effects on the food chain throughout the Pacific, especially on the whale population, which has been growing following a moratorium on commercial whaling in 1986, although Japan continues whaling for ostensibly "scientific" reasons.

One last major area of problems in the Pacific Ocean through global warming and climate change has been changes in the ocean currents, which have been caused by the rise in the temperature of the water. Although few Polynesians travel long distances in traditional canoes, as they did about 1,000 years ago during the populating of many of the islands, the currents are very important, not just for shipping, but also for the movement of marine life such as shoals of fish. The warmer temperature and changes in the current seem to have had major effects on the spawning process of some fish species, and this may be responsible for a decline in the population of certain fish.

Although there is a serious worry about global warming and its effects on the Pacific Ocean, one report in 1997 by scientists from the Lamont-Doherty Earth Observatory at Columbia University claims that the vast size of the Pacific Ocean has led to the dissipation of many of the effects of global warming and climate change, and might account for the fact that the world's temperature has only risen half the level of that in some projections.

SEE ALSO: Alliance of Small Island States (AOIS); Floods; Marine Mammals; Oceanic Changes; Sea Level, Rising.

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Pakistan

PAKISTAN, IN SOUTHERN Asia, is situated on the Arabian Sea. Pakistan shares borders with Afghanistan (to the north and northwest), Jammu and Kashmir (to the northeast), India (to the east and southeast) (796,095 sq. km.) and Iran (to the west). Pakistan has an area of 307,374 sq. mi., and supports a population of approximately 150 million. Pakistan's topography is varied, with mountains to the north and west, and includes four regions: northern plateau, Baluchistan plateau, southeast desert, and Indus plain. The Indus River, the major river in Pakistan, divides the southern part. Only 5 percent of Pakistan's land has forests, although trees are an essential resource for rural communities and wildlife. Extensive logging in northern areas has resulted in slope instability with the potential for soil erosion and water pollution. Overgrazing results in desertification and soil salinity.

Pakistan's climate is mostly dry, with extremes in elevation and temperature. In the mountain regions of the north and west, temperatures fall below freezing during winter; in the Indus Valley area, temperatures range between about 90–120 degrees F (32–49 degrees C) in summer. Precipitation (often in July and August) is scarce in most of the country, ranging from more than 20 in. annually in the Punjab region, to less than five in. in the arid southeast and southwest.

Pakistan already faces complex environmental problems of air, water, and soil pollution, as well as overuse of natural resources causing deforestation, desertification, and energy and water shortages. Ten percent of households lack access to improved water supply, and 38 percent lack improved sanitation. Air pollution and water shortages are common in the south, with increasing health problems. Warmer temperatures could increase the incidence of heat-related illnesses, lead to higher concentrations of ground-level ozone pollution causing respiratory illnesses (diminished lung function, asthma and respiratory inflammation especially in those persons already susceptible), and increase the risk of contracting certain infectious diseases from water contamination or disease-carrying vectors. Rising sea levels associated with global warming will cause problems on the Indus delta and coastal plains with the loss of land, displaced coastal villages, and population displacement. Flooding and storm surges associated with sea-level rise could increase the incidence of water-borne diseases.

Pakistan's environment minister, speaking at the United Nations, voiced concern for climate change impacts on the environment, the economy, and humans. Some problems already experienced include decreased agricultural productivity (arid land and decreasing water supply) and melting glaciers in the Himalayas in the northern part of Pakistan. The minister indicated Pakistan's major goals include water management, improving energy production, changing agricultural practices, tree planting for carbon sequestration, and establishing a committee for research, advising, and action. Like all preparedness measures, financial resources are necessary for development and implementation. While the future is a concern for Pakistan, solutions for current water quality and energy deficiencies are taking priority.

The University of Peshawar is home to the Department of Environmental Sciences (DES), formed by the university in collaboration with the Pakistan government's Environment and Urban Affairs Division in 1987. DES educates at the graduate level and postgraduate level in Environmental Sciences, Public Health Safety, Natural and Occupational Hazards, Applications of Remote Sensing to Environmental Monitoring and Hazard Mapping. The University of Peshawar uses geographic information systems for planning and natural resources management, performs research, and informs government policymakers in sustainable industrial growth, resource conservation, and environmental preservation.

SEE ALSO: Carbon Sequestration; Desertification; Salinity.

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Palau

THE REPUBLIC OF Palau, formerly known as Caroline Islands, is a group of 200 islands located in the Pacific. In total, they have a land area of 177 sq.

mi. (459 sq. km.), with a population of 20,000 (2006 est.), and a population density of 111 people per sq. mi. (43 people per sq. km.). Because of the prosperity of Palau, it has one of the highest rates of per capita carbon dioxide emissions in the world, and is the country with the 15th largest rate of emissions. It was 15.3 metric tons per person in 1990, but was steadily reduced to 12.3 metric tons per person by 2003. Much of this comes from heavy use of electricity in air conditioning, and also, in spite of the size of the islands, relatively heavy use of private automobiles.

Palau is expected to suffer from rising water levels. This will probably lead to the permanent loss of some of the low-lying islands, with the others at risk from flooding. With the country's public water system badly contaminated and posing a serious health risk in January 2002, flooding could overwhelm the water supply for the country, and could cause the spread of insect-borne diseases such as malaria.

The government of Palau took part in the UN Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, and it accepted the Kyoto Protocol to the UN Framework Convention on Climate Change on December 10, 1999, with it entering into force on February 16, 2005.

SEE ALSO: Alliance of Small Island States (AOIS); Floods; Salinity.

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Paleoclimates

PALEOCLIMATES ARE, LITERALLY, past climates. The term "paleo" is, however, normally reserved for those time periods that are prehistorical, although usage of the term to describe climate in the first millennium C.E. and earlier is not uncommon. Like reading a historical text, paleoclimates give glimpses into the varied past of Earth's climate system, and understanding of paleoclimates may well be critical to understanding how Earth's climate will change in the future.

Unfortunately, understanding of this critical climate history does not come easily. Unlike present climate that is carefully recorded and catalogued by various observational and physical measurements, paleoclimate records must be extracted from Earth's geological history; in particular, the archives of sedimentary rocks and large ice sheets. These geological archives do not contain precise measurements of climatic variables such as temperature and precipitation, but rather record environmental responses to ambient climate conditions. As such, the climate indicators extracted from the geological record are known as proxy data.

PROXY DATA

An example of the use of proxy data would be conducting a North American winter snow survey by searching North American garages for snow shovels in the summer. In regions where snow shovels are common in garages, a researcher might reasonably interpret cold winter temperatures and the presence of snow. The shovels, though not actually snow, are a proxy for the occurrence of winter snow. In regions without snow shovels, winter temperatures are either warmer with no snow, or snow is removed in a different way. Because proxy data may be definitive in one sense, but ambiguous in another, using them to decipher the nature of

The Petrified Forest, in northeastern Arizona, has one of the best fossilized records of the Late Triassic period in the world.

paleoclimates requires a suite of data types, or a multi-proxy approach. Fortunately, paleoclimatologists have proven extremely innovative in their development of climate proxies, which range from preserved vegetation in ancient pack rat middens (nests) to the relative abundances of different stable oxygen isotopes (notably ^{16}O and ^{18}O) in the shells of small, ocean-dwelling plankton known as foraminifera.

Some of the oldest proxy data are those related to preserved vegetation. That vegetation may be actual fossils (permineralized plant material or traces of plant material) or simply desiccated (mummified) plant remains, some of which can be tens of millions of years old in cold climates. Vegetation is used as a climate indicator in two primary ways. The first is based on the observation that certain types of plants inhabit certain types of climates. Alders, for example, prefer wetter climates, while Ponderosa Pines thrive in drier conditions. As such, if a plant fossil is found in a given location and there is reasonable certainty that the plant actually grew there, climate in that location can be interpreted based on the known preferences of the identified vegetation.

This is relatively straightforward when the preserved plant material is from a known, living species such as an Alder or Ponderosa Pine. It becomes increasingly difficult further back in geological time when many plants are unknown. In these instances, the climate tolerances of the extinct plant's nearest living relative are used to interpret climate. The other common use of preserved vegetation as a climate indicator is through a statistical process known as leaf margin analysis. Statistical studies of large, modern data sets have indicated that the shape of a leaf's margin (smooth or toothed, elongated or rounded) has some correlation to the climatic conditions that the plant prefers. By performing the same analyses on ancient leaves, scientists can compare ancient leaf samples to the modern climate interpretation and make some assessment of paleoclimatic conditions.

While analyses of preserved vegetation continue to provide significant insight into paleoclimates, more recently, scientists have developed a suite of chemically based climate proxies that make use of the lengthy climate records stored in the sediments of the ocean floor. The most common of these chemical proxies is based on the stable isotopes of oxygen (in particular ^{16}O and ^{18}O, which are the most abundant). Because different isotopes of a given element have different masses, they are relatively easier or harder to evaporate and, inversely, relatively harder or easier to precipitate. This means that water vapor will always have more ^{16}O than the liquid it evaporated from and is, therefore, lighter. Liquid precipitation will always have more ^{18}O than the vapor it condensed from and is, therefore, heavier. These processes can be used to decipher past climate.

For icehouse climates with large, continent-spanning ice sheets, the relative volume of water stored in large glaciers largely influences the oxygen isotopic concentration of global seawater. Because lighter isotopes evaporate preferentially, precipitation is almost always lighter than the global ocean. If precipitation falls as snow and is then trapped as glacial ice, the overall ocean isotopic composition will get heavier as more and more of the light isotope is locked up in growing ice sheets. If climate warms and ice sheets begin to melt, the lighter isotopes are returned to the ocean and the ocean isotopic composition becomes lighter. Thus, changes in the oxygen isotopic composition of ocean water can be tied to growing and shrinking ice sheets and, by extension, cooling and warming climate.

The primary source of information on past oceanic oxygen isotopic composition is the shells of ocean dwelling microorganisms, in particular, foraminifera. Foraminifera create their shells out of calcium carbonate ($CaCO_3$). The oxygen incorporated into the foraminifera shells comes from the ocean water and, therefore, reflects the ocean's oxygen isotopic composition. The exact isotopic ratio of the shell, however, is also influenced by the ambient temperature and, to a lesser and largely negligible extent, salinity, as well as the organic processes of the foraminifera. Empirically derived equations relate the oxygen isotopic composition of calcium carbonate shells to the ocean temperature and oxygen isotopic composition. If any two of those values are known, the third can be calculated. While the isotopic composition of ancient foraminifera shells can be measured in the laboratory, the overall oceanic oxygen isotopic composition and temperature in the past must either be estimated or derived from other proxies.

CLIMATE EXTREMES

This panoply of proxy climate indicators records a startling array of paleoclimates in Earth's history.

Climatic conditions on Earth have ranged from extreme icehouse conditions with, potentially, the entire planet covered in glaciers (a paleoclimate known as Snowball Earth) to extreme hothouse conditions, with atmospheric carbon dioxide concentrations as much as 20 times higher than those at present, and tropical forests extending nearly pole to pole. Earth's climate has also apparently resided everywhere in between these extremes and at times moved rapidly from one to another.

Whether it is because the current climate falls relatively in the middle of the climate spectrum, or because extremes are more likely to be preserved in the geological record, or because understanding of extremes may provide the greatest insight into the climate system as a whole, the extreme paleoclimate events are the most studied. In the realm of extreme warmth, there were the hothouse climates of the Cenomanian/Turonian boundary (90 million years ago) and the Early Eocene Climatic Optimum (52 million years ago), or nearer-term warm climates like the Miocene Climatic Optimum (14 million years ago), the mid-Pliocene warm period (3.5 million years ago) or the Altithermal of the middle Holocene (5,000 years ago).

At the other end of the spectrum lie the extreme cooling of Snowball Earth (630 million years ago), the rapid inception of large Antarctic ice sheets (35 million years ago), or the peak glaciation of the last glacial maximum (18,000 years ago). Equally fascinating, though even more difficult to quantify, are transient or abrupt climate changes such as Pleistocene Heinrich and Dansgaard-Oeschger events where circum North Atlantic temperature changed by as much as 9 degrees F (5 degrees C) in 30 or 40 years or the Initial Eocene Thermal Maximum, when temperatures in the Arctic Ocean reached 73 degrees F (23 degrees C) for 50,000 to 100,000 years. Climate extremes such as these in Earth's history, and incomplete explanations for them, help show that the current climate samples a very finite portion of Earth's climatic possibilities, and if scientists wish to have a solid understanding of what the climate of the future may hold, paleoclimates must first be understood.

SEE ALSO: Cenozoic Era; CLIMAP Project; Climatic Data, Proxy Records; Earth's Climate History; Ice Ages; Mesozoic Era; Paleozoic Era; Snowball Earth.

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Paleozoic Era

THE PALEOZOIC ERA is the earliest of three geologic eras of the Phanerozoic eon. This era spanned from roughly 542 million years ago to roughly 251 million years ago. The Paleozoic era is subdivided into six geologic periods: the Cambrian, Ordovician, Silurian, Devonian, Carboniferous, and Permian. The Paleozoic covers the time from the first appearance of abundant, hard-shelled fossils to the time when the continents were beginning to be dominated by large reptiles and modern plants. The oldest geological period was classically set at the first appearance of creatures known as trilobites and archeocyathids. The youngest geological period marks a major extinction event 300 million years ago, known as the Permian extinction.

At the start of the era, all life was confined to bacteria, algae, sponges, and a variety of enigmatic forms known collectively as the Ediacaran fauna. The Cambrian Explosion resulted in an exponential increase of life-forms. There is some evidence that simple life may already have invaded the land at the start of the Paleozoic, but substantial plants and animals did not take to the land until the Silurian and did not thrive until the Devonian. Although primitive vertebrates are known near the start of the Paleozoic, invertebrates were the dominant life-forms until the mid-Paleozoic. Fish populations exploded in the Devonian. During the late Paleozoic, great forests of primitive plants thrived on land forming the great coal beds of Europe and eastern North America. By the end of the era, the first large, sophisticated reptiles and the first modern plants had developed.

The Paleozoic era began shortly after the breakup of a supercontinent called Pannotia and at the end of a global ice age. During the early Paleozoic, the Earth's landmass was broken up into a number of relatively small continents. Toward the end of the era, the continents gathered together into a supercontinent called Pangaea, which included most of the Earth's land area.

The Early Cambrian climate was probably moderate at first, becoming warmer over the course of the Cambrian, as the second-greatest sustained sea level rise in the Phanerozoic got underway. Gondwana moved south with considerable speed. By the Ordovician period, most of West Gondwana (Africa and South America) lay directly over the South Pole. The Early Paleozoic climate was also strongly zonal. The climate became warmer, but the continental shelf marine environment became steadily colder. The Early Paleozoic ended, rather abruptly, with the short, but apparently severe, Late Ordovician Ice Age. This cold spell caused the second-greatest mass extinction of Phanerozoic time. The Middle Paleozoic was a time of considerable stability. Sea levels had dropped coincident with the Ice Age, but slowly recovered over the course of the Silurian and Devonian.

The slow merger of Baltica and Laurentia and the northward movement of bits and pieces of Gondwana created numerous new regions of relatively warm, shallow seafloor. The far southern continental margins of Antarctica and West Gondwana became increasingly less barren. The Devonian period (410 to 360 million years ago) resulted in diversifiaction of life on the land, including the first terrestrial vertebrates, the amphibians, and the first forests of trees. In the waters fish continued their diversification with the rise of the lobe-finned and ray-finned fish. The Devonian ended with a series of turnover pulses which killed off much of Middle Paleozoic vertebrate life, without noticeably reducing species diversity overall. Global cooling tied to Gondwanan glaciation has been proposed as the cause of the Devonian extinction, as it was also suspected of causing the terminal Ordovician extinction. Rocks in parts of Gondwana suggest a glacial event. The forms of marine life most affected by the extinction were the warm-water to tropical ones.

The Late Paleozoic consisted of the Carboniferous period (360 to 286 million years ago), also known as the Mississippian period. The period began with a spike in atmospheric oxygen, while carbon dioxide plummeted. This destabilized the climate and led to multiple ice age events during the Carboniferous. The supercontinent of Pangaea was assembled during this time, causing the uplift of seafloor as continental land masses collided to build the Appalachian and other mountains. This created huge arid inland areas subject to temperature extremes. The Permian period spanned the time interval from 286 to 245 million years ago. During the Permian the assembly of Pangaea was completed and a whole host of new groups of organisms evolved.

The Permian ended in the greatest of the mass extinctions, where over 90 percent of all species were extinguished. With the assembly of Pangaea and resulting mountain building, many of the shallow seas retreated from the continents. The Permian saw the spread of conifers and cycads, two groups that would dominate the floras of the world until the Cretaceous period with the rise of the flowering plants. The end of the Permian, also the end of the Paleozoic era, was marked by the greatest extinction of the Phanerozoic eon. During the Permian extinction event over 95 percent of marine species went extinct, while 70 percent of terrestrial taxonomic families suffered the same fate. The fusulinid foraminiferans went completely extinct, as did the trilobites. The majority of extinctions seem to have occurred at low paleolatitudes, possibly suggesting some event involving the ocean. The exact cause of the terminal Permian extinction remains unknown; however, many theories have been hypothesized. Regardless, this event proved to be a massive and severe crisis for life. Many groups of organisms went extinct at that time. Surviving groups diversified during the Triassic period and gradually a more modern world developed.

SEE ALSO: Climatic Data, Proxy Records; Earth's Climate History; Ice Ages.

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Panama

LOCATED IN CENTRAL America, the Republic of Panama has a land area of 29,157 sq. mi. (78,200 sq. km.), with a population of 3,343,000 (2006 est.), and a population density of 111 people per sq. mi. (43 people per sq. km.). Only 7 percent of the land in the country is arable, the second lowest percentage in Central America, with 20 percent used for meadows and pasture, and 44 percent of the land forested. The level of carbon dioxide emissions in Panama was 1.3 metric tons per capita in 1990, rising to 2.3 metric tons per person in 2001, and then falling slightly to 1.9 metric tons per person by 2003. Most of this comes from liquid fuels, which make up 89 percent of all carbon dioxide emissions from the country, with cement manufacturing contributing 6 percent, and solid fuels (coal and charcoal) contributing another 3 percent.

The Caribbean coast of Panama has long had problems with hurricanes, but the rising water temperature in both the Caribbean Sea and the Pacific Ocean have led to increased worry over flooding, and has caused some bleaching of coral reefs in the Archipelago de Bocas del Toro off the northwest coast of the country. Although some 30 percent of the country has been set aside for conservation, the deforestation of many areas used for pasture has led to soil erosion, which has also helped contribute to the destruction of the mangrove swamps. There have also been effects on the wildlife in the pristine cloud forest on the Quetzal Trail around the Parque Nacional Volcán Barú, and worries about flooding, which in turn could lead to a spread of insect-borne diseases such as malaria and dengue fever.

The Panamanian government of Guillermo Endara took part in the UN Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, and that of Ernesto Pérez Balladares signed the Kyoto Protocol to the UN Framework Convention on Climate Change on June 8, 1998. The Kyoto Protocol to the UN Framework Convention on Climate Change was ratified on March 5, 1999, and came into force on February 16, 2005.

SEE ALSO: Diseases; Floods; Hurricanes and Typhoons.

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Papua New Guinea

LOCATED IN THE Pacific, on the eastern half of the island of New Guinea, Papua New Guinea has a land area of 178,703 sq. mi. (462,840 sq. km.), with a population of 6,331,000 (2006 est.), and a population density of 34 people per sq. mi. (13 people per sq. km.). In spite of having a tropical monsoon climate, only 0.1 percent of the land is arable, with 82 percent of the country forested. Conservationists and environmentalists condemn the rate of the timber logging industry as unsustainable.

Some 55 percent of the electricity in the country comes from fossil fuels, mainly liquid fuels, which account for 93 percent of Papua New Guinea's carbon dioxide emissions. The remainder of the electricity in the country comes from hydropower. Plans to harness the power of the Purari in the early 1970s were shelved, with the Ramu River used to generate hydropower from the 1980s.

The effect of climate change and global warming in Papua New Guinea has been significant. A rise in temperature has led to the bleaching of some coral reefs off the south coast of the country, which has exacerbated the problems from logging and the crown-of-thorns starfish. There has also been a decline in the fish stocks, both in diversity and numbers. In addition, some parts of the country have experienced flooding, which has led to an increase in the prevalence of insect-borne diseases such as malaria and dengue fever.

The Papua New Guinea government took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992. It signed the Kyoto Protocol to the UN Framework Convention on Climate Change on March 2, 1999, and ratified it on March 28, 2002, with it entering into force on February 16, 2005.

SEE ALSO: Deforestation; Floods; Forests.

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Paraguay

THIS LANDLOCKED SOUTH American country has land borders with Argentina, Bolivia, and Brazil, and covers an area of 157,047 sq. mi. (406,752 sq. km.). It has a total population of 6,036,900 (2003 est.), with a population density of 38.4 people per sq. mi. (14.5 people per sq. km). However, the real population density for much of the country is higher, as the country is bisected by the Rio Paraguay (Paraguay River), and the vast majority of the population lives in the eastern half of Paraguay. Only 6 percent of the land is arable, although 55 percent of it is used for grazing animals.

The main environmental problem in the country is the lack of arable land. This has resulted in deforestation to create more farmland, although officially 35 percent of Paraguay remains forested. The western half of the country, the Chaco Desert, has extremely poor soil and is used for cattle grazing and ranching, but the cattle industry has faced many problems. Even in the more fertile eastern half of Paraguay, the soil is poor, and much of the land is also used for grazing cattle, for which there are 9,400 head per 1,000 people in the country.

The underdeveloped economy and the low standard of living have helped reduce the effect of the country on global warming, with Paraguay ranking 157th in the world for carbon dioxide emissions per capita of 0.5 metric tons of carbon dioxide per capita in 1990, rising to a peak of 0.9 per capita in 1998, and then falling back to 0.7 in 2000–03. Much of this was because of the low use of electricity by the poor in rural areas and in shantytowns, and the relatively low use of cars.

There has been a sharp increase in car usage in recent years that has coincided with a marked decline in public transport. The railway network that covered parts of eastern Paraguay closed down in the 1970s, and only operates a tourist train, leading to an increase in road haulage, and the tram system in Asunción, the capital, was closed for general use in 1995. There have also been few environmental controls in the country. However, Paraguay has been active at the international level, as a member of the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in 1992, and as one of the early countries to sign the Kyoto Protocol to the UN Framework Convention on Climate Change, which was done on August 25, 1998. Paraguay was the 13th country to ratify the Kyoto Protocol, which took place on August 27, 1999.

One of Paraguay's main contributions to reducing the threat of global warming was the construction of the Itaipu Dam, which started generating power in 1982. By 2000, it was supplying hydroelectric power to much of the country, making 93 percent of all electricity generation in Paraguay; and providing 20 percent of the electricity used by Brazil, generating significant income for the Paraguayan economy. Subsequently, work has begun on the Yacyretá Dam, located on the Paraguayan-Argentine border, which will provide electrical power for sale to Argentina.

SEE ALSO: Agriculture; Deforestation; Transportation.

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Penguins

FROM THE TROPICS to Antarctica, penguins depend on predictable regions of high ocean productivity where their prey aggregate. There are between 16 and 19 species of penguins, all generally restricted to the southern hemisphere, with the greatest species diversity found in New Zealand. Changes in precipitation, sea ice, ocean temperature and productivity, and prey distributions associated with

Changes in precipitation, sea ice, and ocean temperature associated with global warming are affecting penguins.

global climate warming are affecting penguins and changing their distribution and abundance. BirdLife International includes climate change among the threats for seven of 10 species of penguin listed as endangered or vulnerable.

The global climate signal is strongest in the Antarctic Peninsula, where air temperature has increased, glaciers have retreated, and ice shelves have collapsed. Adélie and Emperor penguins, the most ice-associated and southerly of the penguin species, are suffering more reproductive failures because of increases in rain and snow, early breakup of ice, and blocking of colony access by icebergs. Gentoo and Chinstap penguins, more northerly and less ice-tolerant, have extended their ranges farther south, but suffer more failures because of increased precipitation. Snow covers nest sites and rain soaks the down of chicks, which then freeze. King penguins, the second largest species, harvested during the whaling era for their oil, have increased and expanded their range northward.

Many of the temperate species of penguins are in decline because of human perturbations including harvest, accidental capture by fisheries, petroleum pollution, breeding habitat destruction, and climate variation that changes the distribution and abundance of their prey. Temperate penguins also suffer from increases in rainfall or air temperatures, as young chicks cannot regulate their body temperatures when their down is wet. Increased frequency of El Niño events associated with global warming reduced Galapagos penguins to about half of what they were in the 1970s. During El Niño, the water warms, ocean productivity declines, and penguins quit breeding, and under the strongest and longest events, penguins die. Peruvian penguins declined after the 1972 El Niño and have never recovered, in large part because the anchovy fishery, the second largest fishery in the world after Alaskan Pollack, harvests much of their prey to make fishmeal.

Patagonian penguins, the most common of the temperate penguins, have declined by 22 percent since 1987 at their largest breeding colony, in Argentina. They swim farther north during incubation than they did a decade ago, likely a reflection of shifts in their prey in response to climate change and reductions in prey abundance due to commercial fishing. African penguins are only 10–20 percent of their previous number, because humans are harvesting more of the ocean's produce than in the 1950s. African penguins are also shifting their breeding locations because of changes in prey distributions linked to climate. Breeding colonies in protected reserves are no longer near sources of food. Ocean productivity will likely continue to decline as climate warms, which is a problem for penguins, as they need areas of high productivity to survive. As global sentinels, penguins are showing that global climate change is creating new challenges for their populations.

SEE ALSO: Benguela Current; Detection of Climate Changes; El Niño and La Niña; Oceanic Changes; Sea Ice.

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Penn State University

PENNSYLVANIA STATE UNIVERSITY (also known as Penn State) is a large public multicampus university with its main campus located in University Park, Pennsylvania. The University has 24 campuses located throughout the U.S. state of Pennsylvania, including a virtual World Campus. The enrollment at Penn State is over 84,000 students, placing it among the 10 largest public universities in the United States. Penn State offers more than 160 majors. Pennsylvania State University ranks in the top five in the world in total number of citations in the area of global warming research. Penn State Institutes of Energy and the Environment is the central coordinating structure for energy and environmental research at Pennsylvania State University.

The concept of the Penn State Institutes of the Environment arose from intense interactions between Penn State's administration and faculty and remains a novel partnership between the two. It is organized under the Office of the Vice President for Research (OVPR) and is designed to position the environmental faculty to compete vigorously in this new interdisciplinary environmental science and engineering prototype. It facilitates environmental research, teaching, and outreach across eight colleges, including the University Park colleges of Agricultural Sciences, Earth and Mineral Sciences, Engineering, Health and Human Development, and the Liberal Arts, plus the Hershey College of Medicine and Harrisburg Capital College. The PSIEE promotes Penn State's interdisciplinary environmental enterprise through a wide variety of activities.

The PSIEE has been instrumental in assisting faculty and departments in the creation of world-class programs such as climate change, and hydrogen energy, as well as other areas.

Courses offered at Pennsylvania State University that focus on global warming and climate change include:

EARTH 103: EARTH IN THE FUTURE: PREDICTING CLIMATE CHANGE AND ITS IMPACTS OVER THE NEXT CENTURY.

The United States is actively working on national assessment of the impacts of the climate change predicted to occur over the next century. The U.S. National Assessment has developed three major documents: an overview written for Congress, a foundation document giving the sources of information and their interpretation, and a series of regional and sector (water, health, agriculture, forests, and coastlines) reports. These reports present an exceptional opportunity to connect advances in the natural sciences to society. The course has four major objectives: (1) to gain an understanding of climate science and of the possible scenarios of how climate may change in the future; (2) to analyze the linkages between climate and major human and natural systems (e.g., agriculture, human health, water, coastal ecosystems, and forests), necessary to assess the potential impacts of climate change; (3) to demonstrate that the impacts of climate change, and the way in which society responds, are dependent on factors such as age, economic capability, lifestyle (e.g., urban vs. rural), generational differences, and cultural differences; and (4) to understand the different types of responses that humans may have to climate change, including adaptations to change and possible mechanisms to mitigate the factors that are forcing change to occur.

GEOSC 320: GEOLOGY OF CLIMATE CHANGE

Geologic records provide a critical perspective on climate change, with implications for our behavior. Ice cores, ocean sediments, tree rings, and others reveal that agriculture and industry have arisen during a few thousand years of anomalously stable climate. Natural changes half as large as the entire difference between ice-age and modern conditions have occurred repeatedly in mere years, affecting hemispheric or broader regions. Such climate jumps have been linked to changes in greenhouse gases, but not driven by them. Students in this course will learn how records of recent climate changes are recovered, read, and dated, how the climate system works and has worked, and the causes of ice-age cycles and faster climate jumps.

BIOL 436: POPULATION ECOLOGY AND GLOBAL CLIMATE CHANGE

In this course, students investigate the factors shaping the characteristics of populations and their dynamics in time and space, with emphasis on the responses of populations to climatic fluctuation and global climate change. These concepts include the science of climate change, how temperature trends are estimated, the data used in assessment reports by the Intergovernmental Panel on Climate Change, large-scale climate systems such as the North Atlantic Oscillation and the El Niño Southern Oscillation, the basic characteristics of populations, how population densities are estimated, and the types of population data used in studies of population responses to climate change.

SEE ALSO: El Niño and La Niña; Greenhouse Effect.

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Pennsylvania

BECAUSE OF PENNSYLVANIA'S interior location in the northeast, it is in prime position to experience the many negative effects associated with global warming. By 2100, average summer temperatures in Pennsylvania could increase between 7–9 degrees F (4–5 degrees C). This temperature change could cause extreme cases of precipitation. Some parts of the state could experience up to a 50 percent increase in rainfall, while other areas face drought conditions.

In Philadelphia, by 2050, heat-related deaths during a typical summer could increase by 90 percent, from about 130 deaths per summer to more than 240. Currently, "red alert" air quality days happen about two days every summer in Pittsburgh. By the middle of the century, this number could rise to five days per summer. Also, ozone levels in the city are already above the Environmental Protection Agency's healthy standard at least 10 days out of the year. Global warming could cause this number to increase to 22 days in the near future, meaning more cases of respiratory diseases such as asthma. Loss of wildlife and habitat are also possible threats caused by global warming, which could mean a loss of tourism dollars.

Over the last century, the average temperature in Harrisburg, Pennsylvania, has increased 1.2 degrees F (0.6 degrees C), and precipitation has increased by up to 20 percent in many parts of the state. Over the next century, climate in Pennsylvania is expected to change even more. Precipitation is estimated to increase by about 10 percent in spring, by about 20 percent in winter and summer, and by as much as 50 percent in fall. The amount of precipitation on extreme wet or snowy days is also likely to increase, which would cause an increase in extremely hot days in summer because of the general warming trend. Although it is not clear how severe storms would change, an increase in the frequency and intensity of summer thunderstorms is possible.

Higher temperatures and increased frequency of heat waves may increase the number of heat-related deaths and the incidence of heat-related illnesses. Pennsylvania, with its irregular, intense heat waves, could be especially susceptible. Similar but smaller increases have been projected for Pittsburgh, from about 40 heat-related deaths to 60, or a 50 percent increase. Winter-related deaths could drop from 85 per winter in Philadelphia, to about 35 per winter if temperatures warm.

The complications that global warming could have on the major cities in the future will also be felt by the rural areas that make up a large portion of the state. Pennsylvania's farming and agriculture industries are vital to the state's economy, as well as the outdoor tourism market; both would be greatly debilitated by effects of global warming. In 2001, more than 4.5 million people spent nearly $3 billion on hunting, fishing, and wildlife viewing in Pennsylvania, which in turn supported 56,113 jobs in the state.

HEALTH VARIABLES

Climate change may also increase ground-level ozone levels. For example, high temperatures, strong sunlight, and stable air masses tend to increase urban ozone levels. If a warmed climate causes increased use of air conditioners, air pollutant emissions from power plants also will increase. A preliminary modeling study of the Midwest, which included the area around Pittsburgh, found that a 4 degrees F (2 degrees C) warming, with no other change in weather or emissions, could increase concentrations of ozone, a major component of smog, by as much as 8 percent. Currently, ground-level ozone concentrations exceed national

The Delaware River overflowing in 2005. Pennysylvania has some of the most intense flooding in the United States.

ozone health standards in several areas throughout the state. Ground-level ozone has been shown to heighten respiratory illnesses such as asthma, as well as other complications. In addition, ambient ozone reduces crop yields and is harmful to ecosystems.

Warming and other climate changes may cause an increase in disease-carrying insects, thus the potential for the spread of diseases such as malaria and dengue fever is increased. Mosquitoes flourish in many areas around Pennsylvania. Some can carry malaria, while others can carry encephalitis, which can be lethal or cause neurological damage. Incidents of Lyme disease, which is carried by ticks, have also increased in the northeast. If conditions become warmer and wetter, mosquito and tick populations could increase in Pennsylvania, increasing the risk of these types of diseases.

WATER RESOURCES

Pennsylvania's valuable water resources would also be affected by changes in precipitation, temperature, humidity, wind, and sunshine. Changes in stream flow tend to coincide with changes in precipitation. Water resources in drier climates are more sensitive to climate changes. Because evaporation often increases with the onset of a warmer climate, the result could be lower river flow and lower lake levels, especially in the summer. If this happens, groundwater will consequently be reduced. In addition, a rise in precipitation could lead to increased flooding. Pennsylvania's Susquehanna River drains much of the eastern two-thirds of the state, and the Allegheny and the upper Ohio rivers drain most of the western third. A warmer climate would lead to earlier spring snowmelt, and could result in higher stream flows in winter and spring and lower stream flows in summer and fall. However, changes in rainfall also could have significant effects on stream flow and runoff. This alerts many Pennsylvanians because some of the most intense flooding on record in the United States has occurred in Pennsylvania.

SEE ALSO: Diseases; Floods; Penn State University; Rainfall Patterns.

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Perfluorocarbons

THE PERFLUOROCARBONS ARE a group of chemically related greenhouse gases covered by the Kyoto Protocol. Although emissions of perfluorocarbons are low compared to many other pollutants, they are of great concern because the perfluorocarbons are extremely powerful greenhouse gases with very long atmospheric lifetimes. Furthermore, the release of man-made perfluorocarbons is on the rise, due to increasing aluminum and semiconductor chip manufacture. Annual releases of PFM, the most abundant perfluorocarbon, are the global warming equivalent to about 70 megatons of CO_2, roughly one two-hundredth of the amount of CO_2 released annually.

In the context of climate change, the most important perfluorocarbons are perfluoromethane (PFM) and perfluoroethane (PFE). Also of interest in a wider environmental context are the oxygenated perfluorocarbons, PFOS and PFOA. These latter compounds are highly soluble in water, and they are found in the ocean environment and in living tissues, but rarely in the atmosphere. Since 1980, the atmospheric concentration of PFM has risen by around 30 percent, despite reductions in emissions per ton from the aluminum industry, and is thought to have risen by around 70 percent since 1960. The atmospheric concentration of PFE has doubled from its concentration in 1980, and is believed to be more than 10 times higher than its 1960 value.

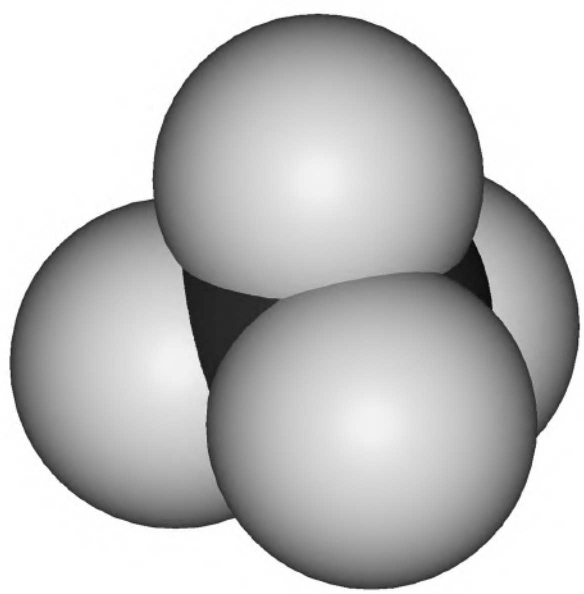
The perfluorocarbon molecules are strong absorbers of infrared radiation, and are therefore powerful greenhouse gases. Although the atmospheric concentration of perfluoromethane is around 100,000 times lower than CO_2, the radiative forcing due to this atmospheric loading of PFM is as much as one five-hundredth of the radiative forcing due to CO_2. (Radiative forcing is a measure of the global warming effect of a chemical at a given atmospheric concentration.) PFM is a much more powerful greenhouse gas than CO_2 as measured by its global warming potential. The global warming potentials of PFM and PFE are 7,390 and 12,200, respectively.

The PFCs are extremely environmentally stable; they are only very slowly destroyed by the action of sunlight and oxygen. The main pathway for removal of PFCs from the environment is via high temperature combustion processes when air is taken into vehicle engines or power station furnaces. This environmental stability arises from the molecules' chemical structure. The PFCs are related to simple hydrocarbons by replacement of all hydrogen atoms by fluorine. For example, the simplest hydrocarbon is methane, CH_4. The corresponding PFC is perfluoromethane, CF_4. The carbon-fluorine chemical bond is tremendously robust with respect to normal mechanisms by which the atmosphere cleans itself. Consequently, the atmospheric lifetimes of PFM and PFE are around 50,000 years and 10,000 years, respectively.

Natural PFM emissions from soils give rise to a background "clean air" concentration of about 40 pptv (parts per trillion by volume). Its concentration has been increasing throughout the latter half of the 20th century, to its current value of about 75 pptv due to industrial activity. Both PFM and PFE are produced as a by-product of the electrochemical extraction of aluminum from its ores. Over the past 20 years, the global aluminum industry has significantly improved its performance: currently, an average of 400 grams of PFM and about 40 grams of PFE are released per ton of aluminum produced, down by almost two-thirds since the 1980s. However, this per-ton emissions reduction has been somewhat offset by increases in aluminum production volumes. The semiconductor chip manufacturing industry is a major source of PFE and a secondary source of PFM. Consequently, the increase in chip manufacture is a major influence on the growing emissions of PFE.

Oxygenated perfluorocarbons, PFOS (perfluorooctane sulfonate) and PFOA (perfluorooctanoic acid) are thought to be harmful to human health. The U.S. Environmental Protection Agency regards PFOA as a "likely carcinogen"; it has been shown carcinogenic in rodents, as well as causing immune and reproductive system damage. PFOA and PFOS are released to the environment from manufacture and use of nonstick materials, fabric protectors, and fire-fighting foams. Due to their high water solubility and extremely long environmental lifetime, they are found in low concentrations in the blood of humans worldwide, and in many animals, including U.S. dolphins, Chinese pandas, and Arctic polar bears.

SEE ALSO: Hydrofluorocarbons; Intergovernmental Panel on Climate Change (IPCC); Kyoto Protocol.



A tetrafluoromethane molecule: The most abundant atmospheric perfluorocarbon is tetrafluoromethane.

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Peru

PERU'S 0.5 PERCENT contribution of greenhouse gases to the world's atmosphere is small, compared to the impact on Peru expected as a result of climate change. Peru is ranked as the fourth country most impacted by climate change. El Niño has regularly affected the 386,102 sq. mi. (one million sq. km.) of Peruvian territory, with droughts in the Andean south, and floods in the northern Pacific coast. These impacts, however, are small compared to the impacts of climate change. The 125 mi. (200 km.)-long White Mountain Range, the world's largest ice-covered tropical range and Peru's main concentration of ice, has been losing volume in the last 50 years. The glaciers are melting, leading to glacier reduction, the formation or increase of glacial lakes, and changes in ecosystem composition. The glaciers of White Range Park have retreated 82 ft. (25 m.) in the last 50 years according to CONIDA, Peru's aerospace agency, and CONAM, the Peruvian environmental agency.

Glacier retreat has implications for downstream river flows. In rivers fed by glaciers, summer flows are supported by glacier melt (with the glacier contribution depending on the size of the glacier relative to basin area, as well as the rate of annual melt). If the glacier is in equilibrium, the amount of precipitation stored in winter is matched by melt during summer. However, as the glacier melts as a result of global warming, flows would be expected to increase during summer—as water is released from long-term storage—which may compensate for a reduction in precipitation. As the glacier gets smaller and the volume of melt reduces, summer flows will no longer be supported and will decline to below present levels. The duration of the period of increased flows will depend on glacier size and the rate at which the glacier melts; the smaller the glacier, the shorter lived the increase in flows and the sooner the onset of the reduction in summer flows. In 18 glaciers in the Peruvian Andes, mass balances since 1968 and satellite images show a reduction of more than 20 percent of the glacial surface, corresponding to 11,300 million cu. m. of ice, according to B. Morales-Arnao and INAGGA-CONAM.

In addition to the White Mountain Range, 19 mountain range glaciers exist in Peru, which according to a study elaborated by the Corporation For the Development of Santa in 1970, occupied 965 sq. mi. (2,500 sq. km.) These mountain ranges lodge 1,500 lagoon glaciers. The White Mountain Range is one of the most sensible thermometers to measure global warming, showing that in the last half-century the Peruvian mountains have lost hundreds of cubic meters of ice. Peru was hit in 1998 with the destruction of the Machu Picchu hydropower station, and rebuilding costs amounted to $160 million, according to RGS Ltd.

Glacial lakes are formed on the glacier terminus due to the climate change–induced glacier retreating processes. The majority of these glacial lakes are dammed by unstable moraines, which were formed by the glaciations of the cooler period of climate within the last millennium. Occasionally, the lake happens to burst and suddenly releases an enormous amount of its stored water, which causes serious floods downstream along the river channel. This phenomenon is known as glacial lake outburst flood (GLOF). Since 1702, more than 25 catastrophic GLOFs have occurred in the White Mountain Range. They come with little or no warning, and are made up of liquid mud that transports rolling stones and blocks of ice with the capacity to destroy cities and lives. The most serious GLOFs destroyed parts of the city of Huaraz in 1725 and 1941, as well as the GLOF from Lake Jancarurish in 1950. Additionally, two other destructive avalanches from the summit of North Huascarán destroyed, in 1962 and 1970, several villages and caused the deaths of more than 25,000 inhabitants.

SEE ALSO: Floods; Glaciers, Retreating; Glaciology; Peruvian Current.

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Peruvian Current

ORIGINATING IN THE frigid waters off the coast of Antarctica, the Peruvian Current moves north along the western coast of South America. When in reaches the continental shelf along South America, the current rises, carrying cold water with it to the surface of the Pacific Ocean. The prevailing winds of the South Pacific and Earth's rotation cause the Peruvian Current to rotate; the Coriolis Force causes the current to rotate clockwise. The Peruvian Current extends 125 mi. (201 km.) west from the coast of South America. As the current moves north through the coasts of Chile, Peru and Ecuador it splits into two masses where Cabo Blanco, Peru, meets the Gulf of Guyanquil. The main current turns west into the Pacific Ocean, while the remnant of the current moves along the coast of Ecuador. At that point, the second branch of the Peruvian Current also moves west, rejoining the main current near the Galapagos Islands.

The Peruvian Current is also known as the Humboldt Current after its discoverer, German scientist Alexander von Humboldt. The Peruvian Current affects Peru year round, and moderates the climate of Chile in spring and summer, when it displaces a subtropical center of high pressure. Ordinarily the coast of Chile would warm in spring and summer, but the onset of the Peruvian Current diminishes temperatures and forestalls any rain. The air that accompanies the current is dry, keeping the coast arid. Some weather stations along the Chilean coast have never recorded rainfall; others areas receive considerably less than 1 in. (2.5 cm.) of rain per year. The northern coast of Peru is dry from May to November, and receives light rain between December and April. Even though some areas of the coast are humid, rain nevertheless does not fall. The arid coastline supports few plants, and so sunlight either is absorbed by the land or radiates back into space. Rainfall along the southern coast of Ecuador totals 12 in. (30 cm.) per year, though in the north, where the Peruvian Current weakens, rainfall increases tenfold. Some regions receive as many as 197 in. (500 cm.) of rain per year.

With Peru located near the equator, one might expect warm temperatures, but the Peruvian Current keeps the coast of Peru at 75 degrees F (24 degrees C). Lima varies from 70 degrees F (21 degrees C) in January and 50 degrees F (10 degrees C) in June. Areas inland from the current often record temperatures of 90 degrees F (32 degrees C). Periodically El Niño disrupts the Peruvian Current, bringing warm water from the tropical Pacific to the western coast of South America. Temperatures along the coast rise and rain falls on some parts of the coast.

As it cools the western coast of South America, the Peruvian Current creates a climate of unremitting dryness. Temperatures are moderate but rainfall is scant. Seabirds inhabit the western coast of South America but humans have only colonized the region in small numbers. The deserts of Chile are especially forbidding. Without rain, the land ceases to sustain plant life. In contrast to the sterility of the desert, life abounds in the ocean. The Peruvian Current carries plankton to the surface of the ocean, and fish feed on it in large numbers. Seabirds in turn feed on the fish. Despite creating an arid climate, the Peruvian Current teems with life.

SEE ALSO: Climate; Coriolis Force.

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Pew Center on Global Climate Change

IN 1998, WITH a grant from the Pew Charitable Trusts, and within the context of increasing concern over the impact of climate change, the Pew Center on Global Climate Change was established. It is a nonprofit, nonpartisan, independent organization. The role of the Pew Center is to build a bank of credible information about climate change and its impacts, and to try to provide solutions to the problems created by climate change. The Pew Center aims to provide an objective forum for research, and development of sensible solutions and policy suggestions.

Underpinning this mission is the commitment by Pew Center staff to educate policymakers and the general community about the causes and consequences of climate change. In so doing, the Pew Center has commissioned many significant reports on the impacts of climate change in various contexts, including domestic and international policy, economic and environmental impacts, and practical solutions. For example, reports have focused on the relationship between developing and developed worlds in relation to climate change policies. Many reports highlight the effects of climate change on marine ecosystems. The Pew reports offer policymakers and the public the opportunity to access and learn about detailed case studies from across the world on this topic. The Pew Center also hosts conferences and workshops on climate-related topics to stimulate engagement and interaction between business, government, and nongovernmental organizations. Staff from the Pew Center also regularly participate and attend key meetings on climate change issues, such as negotiations on the UN Framework Convention on Climate Change (UNFCC).

Within the policy center, staff at the Pew Center for Global Climate Change investigate how policies can be changed and developed within the areas of science and technology, market-based mechanisms, adaptation, international engagement, cross-sector policies, transportation, manufacturing agriculture, and energy production and use policies. Staff members also work within the United States at congressional and state levels to encourage policymakers, and politicians in these areas, to activate plans and legislate on climate change solutions and issues.

UNDERSTANDING CLIMATE CHANGE THROUGH INTERNATIONAL DIALOGUE WITH BUSINESS

The Pew Center's position on climate change is that there is strong scientific consensus that climate change is real, happening now, and is largely the result of human-induced activities. For example, the Pew Center cites the emissions of carbon dioxide and other greenhouse gases produced by industrial processes, fossil fuel combustion, and changes in land use as the primary cause of climate change. The result of these activities is that there will be an additional warming over the 21st century, and that there will be a global increase of 2.5 degrees F (1.4 degrees C) to a global average of 10.4 degrees F (5.7 degrees C). The Pew Center identifies a number of consequences from global warming, including sea-level rise, coastal inundation, beach erosion, flooding from coastal storms, changes in precipitation patterns, increased risk of droughts and floods, threats to biodiversity, and potential public and environmental health problems.

At an international level, the Pew Center is working to develop an international forum for agreement on climate change through the Climate Dialogue at Pocantico, established in 2005. This was a forum convened by the Pew Center on Global Climate Change to give senior policymakers the forum to informally discuss core issues with other policymakers and stakeholders in an international context. These meetings, held between July 2004 and September 2005, resulted in an agreement between the 25 international participants; the dialogue was then presented to the wider community as a platform for initiated change and options for promoting the climate change effort in an international arena. Participating countries and members include Argentina, Australia, Brazil, Canada, China, Germany, Japan, Malta, Mexico, Tuvalu, the United Kingdom, and the United States; senior executives from Alcoa, BP, DuPont, Eskom (South Africa), Exelon, Rio Tinto, and Toyota; and experts from the Pew Center, the Energy and Resources Institute (India), and the World Economic Forum.

The Pew Center has also established the Pew Center's Business Environmental Leadership Council (BELC). Business interests represented include diversified manufacturing, oil and gas, transportation, utilities, and chemicals. The BELC was created when the Pew Center was established, due to the belief that engaging business must be one of the cornerstones for effecting change in relation to addressing climate change impacts. This council is based on the understanding that businesses that are proactive in climate-proofing their business, and minimizing their impact, will have a future competitive advantage. To date, the BELC is the largest consortium of businesses working together to combat climate change, with a membership of 44 members. Together, the membership represents $2.8 trillion in market capitalization and over 3.8 million employees.

These companies are providing leadership by negotiating the establishment of emissions reduction objectives; through investment in new best practice and climate friendly technologies; and by supporting programs designed to achieve cost-effective emissions reductions. For example, 32 of the companies represented within the BELC have greenhouse gas reduction targets. Many of these companies are also implementing strategies in energy supply, energy demand solutions, process improvement, waste management practices, transportation, carbon sequestration and offsets solutions, and emissions trading and offsets.

Overall, the Pew Center advocates that the reduction of emissions of carbon dioxide and other greenhouse gases is the crucial first step to addressing this problem. To do so, it proposes a restructuring of the global economy away from its current reliance on fossil fuels to increased dependence and use of renewable and more efficient energies.

SEE ALSO: Carbon Emissions; Nongovernmental Organizations (NGOs); Policy, International.

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Philippines

THE PHILIPPINES ARE located across 7,107 islands forming an archipelago in southeastern Asia, east of Vietnam. The country lies squarely in the typhoon belt, and is affected by an average of 15 storms (five to six of them direct strikes) annually. Most of the population of 91 million is at risk from landslides, flash flooding, and tsunamis. The Philippines face severe environmental problems, ranging from water pollution, soil degradation, deforestation, and loss of coral habitat, and are expected to suffer from rising sea levels and increased storm intensity.

The Philippines have already been feeling the impact of oscillations in Pacific sea temperatures known as El Niño and La Niña. In El Niño periods, the islands tend to see a decrease in rainfall, leading to droughts. During La Niña periods, rainfall can come in intense bursts, leading to landslides and flash flooding. Supertyphoons are also on the rise, with 2007 bringing a number of category 4 and category 5 cyclones into the Pacific basin.

Deforestation, both in the rainforest and the country's vast mangrove swamps, is another serious environmental issue for the Philippines. After a series of devastating landslides in the 1980s, the government instituted a ban on timber harvesting. Still, the country lost a third of its forest cover to logging 1990–2005. Deforestation has slowed to 2 percent annually, and the government has been more aggressive about pursuing illegal loggers.

With over 36,000 km. of shoreline, a rising sea level will have devastating consequences for the Philippines. Some models show a 100 cm. rise in ocean levels on the Philippine coast by 2080. In the heavily populated capital city of Manila, this rise would potentially displace up to 2.5 million people, and put millions more at risk for flooding from storm surges.

The Philippines is home to southeast Asia's second-largest coral reef system, covering 9,676 sq. mi. (25,060 sq. km.) As temperatures rise, coral bleaching events are expected to become more severe, leading to the eventual death of the reef. The impact will be felt in several ways: it will signal the end of an important habitat; it will destroy the livelihood of more than a million fishermen along the coast; it will reduce an important source of food from the Philippine market; and it will make the coast more vulnerable to storm surge and rising tides, as bleached reefs have been shown to be less of a buffer to sea level rise.

Carbon emissions rose 40 percent between 1990–98, but with CO_2 emissions at 1,000 metric tons per capita in 1998, the Philippines is not a significant contributor to global carbon emission totals. An estimated 73 percent of emissions come from liquid fuels, 18 percent from solid fuels, and 9 percent from cement manufacturing. Climate change has already cost the Philippines billions in lost agricultural production, reduced fish yields, storm damage, and a reduction in tourism. The government is taking steps to educate the public and to institute sustainable policies.

SEE ALSO: Deforestation; El Niño and La Niña; Hurricanes and Typhoons; Sea Level, Rising.

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Phillips, Norman

NORMAN PHILLIPS IS a theoretical meteorologist who pioneered the use of numerical methods for the prediction of weather and climate changes. His influential studies led to the first computer models of weather and climate, as well as to an understanding of the general circulation of the atmosphere, including the transports of heat and moisture that determine the Earth's climate. His 1955 model is generally regarded as a ground-breaking device that helped to win scientific skepticism in reproducing the patterns of wind and pressure of the entire atmosphere within a computer model.

Phillips received his B.S. from the University of Chicago in 1947 and his Ph.D. in 1951. He was the first to show, with a simple general circulation model, that weather prediction with numerical models was possible. The advent of numerical weather predictions in the 1950s also marked the transformation of weather forecasting from a highly individualistic effort to a cooperative task in which teams of experts developed complex computer programs. With the first digital computer in the 1950s, scientists tried to represent the complexity of the atmosphere and its circulation in numerical equations. Nineteenth- and early 20th-century mathematicians such as Vilhelm Bjerknes and Lewis Fry Richardson had failed to come up with adequate mathematical models. Through the 1950s, some leading meteorologists tried to replace Bjerknes and Richardson's numerical approach with methods based on mathematical functions, working with simplified forms of the physics equations that described the entire global atmosphere. They succeeded in getting only partial mathematical models. These reproduced some features of atmospheric layers, but they could not show persuasively the features of the general circulation. Their suggested solutions contained instabilities as they could not account for eddies and other crucial features. Discouraged by such failures, scientists began to think that the real atmosphere was too complex to be described by a few lines of mathematics. The comment of such a leading climatologist as Bert Bolin is revealing of this skepticism. In 1952 Bolin argued that there was very little hope for the possibility of deducing a theory for the general circulation of the atmosphere from the complete hydrodynamic and thermodynamic equations. Yet, computers opened up new possibilities in the field, although the first digital specimens were extremely slow and often broke down.

Jule Charney was the first to devise a two-dimensional weather simulation. Dividing North America into a grid of cells, the computer started with real weather data for a particular day and then solved all the equations, working out how the air should respond to the differences in conditions between each pair of adjacent cells. It then stepped forward using a three-hour step and computed all the cells again. The system was slow to operate and it had imperfections, yet its completion paved the way for more researches to be carried out. It was Norman Phillips who sought to address the problems in Charney's model. The challenge for meteorologists now became the computation of the unchanging average of the weather given a set of unchanging conditions such as the physics of air and sunlight and the geography of mountains and oceans. This was a "boundary problem." A parallel problem that they had to face was that of the "initial value," where the operation of calculating how the system evolves from a particular set of conditions found at one moment becomes less accurate as the prediction moves forward in time.

Phillips was inspired by "dishpan" experiments carried out in Chicago, where patterns resembling weather had been modeled in a rotating pan of water that was heated at the edge. For Phillips this showed that "at least the gross features of the general circulation of the atmosphere can be predicted without having to specify the heating and cooling in great detail."

Phillips argued that if such an elementary laboratory system could effectively model a hemisphere of the atmosphere, a more advanced tool such as a computer should be able to do it as well. Although certainly more advanced than a dishpan, Phillips's computer was still quite primitive. Thus, his model had to be extremely simple. By mid-1955 Phillips had devised improved equations for a two-layer atmosphere. To avoid mathematical difficulties, his grid covered not a hemisphere but a cylinder, 17 cells high and 16 in. in circumference. The calculations allowed the representation of a plausible jet stream and the evolution of a realistic-looking weather disturbance over a period of a month.

This settled an old controversy over what procedures set up the pattern of circulation. The simulation-based approach became the generally accepted method to devise circulation models. For the first time scientists could visualize how giant eddies spinning through the atmosphere played a key role in moving energy from place to place. Phillips's model was quickly hailed as a "classic experiment," the first true general circulation model (GCM). Phillips used only six basic equations (PDEs) which have been since described as the "primitive equations". They are generally conceived of as the physical basis of climatology. These equations represent well-known physics of hydrodynamics. The model was able to reproduce the global flow patterns of the real atmosphere. Phillips was awarded the Benjamin Franklin Award in 2003.

SEE ALSO: Atmospheric General Circulation Models; Bolin, Bert; Computer Models; Richardson, Lewis Fry.

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Phytoplankton

PHYTOPLANKTON ARE A group of free floating microscopic organisms predominantly classified as algae. Over 4,000 species of phytoplankton have been identified and this list is rapidly growing. Phytoplankton are mostly single cellular organisms and all are autotrophic (i.e., they contain photosynthetic pigments). These pigments allow phytoplankton to use the sun's energy to convert CO_2 and inorganic nutrients, through photosynthesis, into biological molecules such as proteins and carbohydrates. This process of creating new biological molecules is called primary production. Phytoplankton are the only primary producers in the open oceans, and thus form the basis of the food chain in over 70 percent of the world's surface area.

Specific aspects of primary production are often considered more carefully and these warrant definition. The Net Primary Production (NPP) refers to the amount of organic carbon available after respiration has been subtracted from the total amount of photosynthesis. It is an important term because this is the amount of carbon that is available to the rest of the foodweb, and is the upper limit on respiration. The Net Community Production (NCP) is the difference between net primary production and heterotrophic respiration. It is measured by gross changes in oxygen or biomass in a specific time. The New Production is the fraction of primary production driven by newly-available nitrogen. This is principally the nitrate and nitrite that becomes available when deep ocean waters are brought up into the euphotic zone, but could include sources from the atmosphere or river inputs.

The global distribution of phytoplankton throughout the world's oceans is not evenly distributed. This distribution is the result of growth being limited by the availability of nutrients. High concentrations of phytoplankton are seen in upwelling areas, such as the Benguela Current off the southwest coast of Africa.

PHYTOPLANKTON AND CLIMATE CHANGE

CO_2 does not limit phytoplankton growth. CO_2 is not thought to limit phytoplankton growth in any region of the ocean. Primary production, in general, is limited by the availability of inorganic nutrients. Therefore it is not expected that increased atmospheric concentrations of CO_2 will have a significant impact on the phytoplankton population in the oceans.

The "Biological Pump" Locks Away CO_2. The "Biological Pump" is the mechanism by which anthropogenic CO_2 is taken from the atmosphere and stored in the deep ocean, which transfers carbon from the surface to the deep ocean, across the barrier of the permanent thermocline. The pump is powered by phytoplankton fixing carbon and sinks to the deep ocean. This removes CO_2 from the surface ocean, causing more CO_2 to be drawn from the air to maintain equilibrium. Carbon is locked away from the atomosphere as a result of being taken below the permanent thermocline. This contrasts to primary productivity on land which builds plants (such as trees) and in turn animals to, locking CO_2 away from the atmosphere.

Although increasing levels of CO_2 do not have a fertilizing effect on the oceans, the longer growing season in temperate and polar regions is expected to lead to an increase in primary productivity.

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Microbiologist Kevin Schrader examines a culture of green algae (Selenastrum capricornutum).

Plants

THE ANCIENT GREEKS were the first to identify a relationship between climate and plants. Following this insight, other naturalists recognized that fossilized plants revealed the climate in prehistory. Plants colonized the land 410 million years ago, shaping the climate as they spread throughout the globe. By absorbing carbon dioxide, plants have the potential to cool the climate. By releasing water vapor into the atmosphere, plants have the potential to warm the climate by trapping heat, or to cool the climate by forming clouds. Rooted to the ground, plants must either adapt to the climate or die. Sudden climate changes threaten some species with extinction, whereas hardier species survive. From equator to pole, climate determines what plants grow at given latitudes.

HISTORY OF THE RELATIONSHIP BETWEEN CLIMATE AND PLANTS

Theophrastus, a pupil of Aristotle and the founder of botany, may have been the first to ponder the relationship between plants and climate. He understood that each species of plant is adapted to a particular climate, and that in a foreign climate a plant will not thrive and may not survive. Plants are thus an indicator of climate. The mangrove, for example, is an indictor of a climate wet enough to form swamps. With the work of Theophrastus, the promising synthesis of botany and the study of climate was in its infancy, but the Romans did not bring this synthesis to maturity. The Romans were a practical people, with no interest in the theoretical relationship between plants and climate. The Middle Ages were no better for the study of the relationship between plants and climate. The emphasis on theology undercut any progress in science.

In 1876, Norwegian botanist Axel Blytt revived Theophrastus's notion that plants are an indicator of climate. Working on prehistoric climates, Blytt identified fossils of trees that no longer grew in Denmark. From this observation, he posited that the climate in Denmark had once been suitable for these species of trees, but was no longer. The climate was not therefore a static, unchanging entity. Rather, the climate has changed over time. Working in a similar vein, Swedish geologist Ernst Von Post identified fossils of *Alnus*, a genus of tree, in the strata of rocks throughout Europe. *Alnus* is adapted to a warm wet climate, and Von Post tracked the tree fossils as they migrated from southern to northern Europe at the end of the Cenozoic Ice Age. As the glaciers retreated, *Alnus* rooted itself in the warm wetlands that followed the ice age.

PLANTS AND CLIMATE CHANGE

Fossilized pollen can likewise pinpoint changes in climate. The evergreen red beech is adapted to warm locales. The abundance of its pollen 8,000 years ago implies that this time correlates with the maximum temperature since the end of the Cenozoic Ice Age. On the other hand, the abundance of pollen from *Phyllocladus*, a shrub that is adapted to the cold, at 26,000 years ago and again at 20,000 years ago, indicates these years as the coldest during the ice age.

Photosynthetic algae evolved in the ocean as early as four billion years ago. From this beginning, the first plants colonized land 410 million years ago, before animals. By 360 million years ago, the beginning of the Carboniferous period, plants had spread throughout the planet, forming lush forests. The temperature and amount of carbon dioxide in the atmosphere were both higher than today. So lush was the growth of plants that when they died, they formed one layer upon another. Under heat and pressure, these many layers of plants formed the vast deposits of coal, natural gas, and petroleum that humans are now exploiting. The immensity of these deposits underscores the massive growth of plants during the Carboniferous period.

The fact that plants absorb carbon dioxide during photosynthesis has an important consequence for the climate. Carbon dioxide correlates with temperature. A high concentration of carbon dioxide correlates with high temperatures, whereas a low concentration of the gas correlates with low temperatures. This relationship holds true, because carbon dioxide is a greenhouse gas: it traps sunlight that reflects from Earth, preventing light, in the form of infrared radiation, from returning to space. In trapping sunlight, carbon dioxide traps heat, thereby increasing the temperature of the atmosphere. Plants lower the concentration of carbon dioxide by absorbing it during photosynthesis. When plants absorb carbon dioxide faster than Earth produces it through volcanism, the concentration of carbon dioxide diminishes, and temperatures decline. In this context, plants may have contributed to the onset of the Ice Ages by absorbing carbon dioxide.

The absorption of carbon dioxide is cyclical. In spring and summer, when plants grow vigorously, they absorb large amounts of carbon dioxide. In autumn, however, plant growth slows and in winter it stops. The decay of dead plants in autumn returns the carbon dioxide that they had absorbed while alive to the atmosphere. The Northern and Southern hemispheres contribute to the carbon dioxide cycle in opposite fashion, for when plants are growing vigorously in the Northern Hemisphere, they are dead and decaying in the Southern Hemisphere, and vice versa.

In another sense, the carbon dioxide cycle spans eons of time. In the Carboniferous period, lush forests absorbed prodigious amounts of carbon dioxide, storing it in their tissues as sugars. Upon the death of plants, their conversion to coal, natural gas, and petroleum locked up these vast amounts of carbon dioxide. Since the Industrial Revolution, humans have burned these fossil fuels for energy, and in the process liberated carbon dioxide, returning to the atmosphere the carbon dioxide that plants had absorbed during the Carboniferous period. The liberation of this carbon dioxide has increased global temperatures. Humans are burning fossil fuels constantly, leading climatologists to predict that humans will, by 2080, double the amount of carbon dioxide in the atmosphere, further increasing temperatures and perhaps leading to the flooding of coastal cities.

Plants absorb carbon dioxide through their stomata, pores on the leaves. At the same time, plants shed water through their stomata. Plants transpire as water vapor more than 90 percent of the water that they absorb through their roots. Through transpiration, plants change the climate, though not in a straightforward way. On the one hand, water vapor is a greenhouse gas, absorbing as heat the sunlight reflected from Earth.

The warmth of the Carboniferous period, a time of abundant plant growth, was due to the greenhouse effect. Along with carbon dioxide, the water vapor transpired by plants contributed to a warm climate. On the other hand, the water vapor that plants transpire forms clouds, which reflect 30 percent of sunlight back into space before it can heat the Earth. In their role in forming clouds, plants cool the climate.

One scientist predicted that a doubling of carbon dioxide concentration might cool, rather than heat Earth, because plants will, in transpiring water vapor, hasten the formation of clouds.

CLIMATE CHANGES AND THE GREENHOUSE EFFECT

The product of a long evolutionary history, plants are adapted to the climate in a way that humans are not. Humans fashion their material culture to suit the climate, or, when climate worsens, they migrate to a more hospitable locale. Plants, rooted to the ground, must adapt or die. Migration is not an option, though seed dispersal is a kind of intergenerational migration. Through dispersal, seeds travel roughly one kilometer per year, a rate too slow to adapt a plant to rapid climate change. As the climate deteriorates, some plant species die out, to be replaced by hardier species. In Neolithic and Bronze Age Denmark, for example, the climate was warmer and wetter than it is today.

The climate was warm and wet enough to sustain the growth of oak trees. In the Iron Age, however, temperatures dropped to current figures. Unable to cope with the decline in temperature and moisture, oak trees died out and were replaced by grasses and heather. In New Hampshire, the tree *Pinus strobus* was for centuries the most numerous tree in the region's deciduous forests. *Pinus* came through the fire of 1665 unscathed, but was unable to cope with climatic catastrophe. In 1921, a tornado, and in 1938 a hurricane, swept through the forests, felling large trees of several species. The catastrophes wiped out *Pinus*, ending centuries of its dominance, and leaving other species to reconstitute the forests.

These sudden changes in climate and flora are dramatic and easy to quantify. No less dramatic has been the effect of hydrofluorocarbons on climate and plants. Humans have released large quantities of hydrofluorocarbons into the atmosphere, where they have thinned the ozone layer. Consequently UV-B radiation, a type of ultraviolet light, penetrates the ozone layer in greater amounts than in the past. UV-B radiation damages half of all plant species. Damaged plants grow small leaves and short shoots and photosynthesize at a slow rate. These effects are magnified by the fact that several crops are among the plants sensitive to UV-B radiation. One study concluded that a 25 percent reduction in the ozone layer would halve soybean yields.

The tropics support lush vegetation, with more than 80 in. of rain per year, temperatures nearly uniform and warm year-round, and abundant sunshine. Trees have thin bark, for they don't need insulation against the cold or protection against water loss. Trees grow in layers, with those in the innermost layers able to survive without exposure to direct sunlight. Because sunlight does not penetrate to the rainforest floor, little vegetation grows along the ground. At higher latitudes north and south of the tropics, rainfall diminishes and temperatures vary year round. These climates have seasons, with vigorous plant growth in spring and summer and dormancy in autumn and winter.

To cope with a diminution in rain, plants in temperate climates have evolved small leaves to minimize the loss of water through transpiration. In areas that have a dry season, trees evolved the shedding of leaves to stop transpiration and, in other species of trees, the growth of needles rather than leaves to minimize transpiration. With their needles, the evergreens and conifers are adapted to short summers because they can carry out photosynthesis as soon as temperatures warm, whereas deciduous trees must regrow their leaves before they can photosynthesize. Evergreens and conifers grow where winter is cold enough to freeze the ground. Once the ground freezes, roots cannot absorb water, making winter a period of drought and favoring trees that can minimize transpiration in response to frost-induced drought.

In contrast to the rainforest, sunlight penetrates to the forest floor in temperate forests, permitting the growth of plants, often grasses, in abundance along the ground. As the dry season lengthens and rainfall diminishes still further, forest gives way to grassland. Grasses need less water than trees. Trees grow alongside grasses on the African savanna, but few trees grow on the Russian steppe. There, grasses are the dominant flora. At high latitudes, temperatures fall below 40 degrees F (4 degrees C) for six to nine months per year. Summers are brief, with temperatures above 50 degrees F (10 degrees C). Rainfall ranges between 10–40 in. (25–102 cm.) per year, with between 15–24 in. (38–61 cm.) typical. This climate favors the growth of coniferous forests. In addition to their needles, conifers have thick bark to retard water loss and to protect against the cold. Temperature separates coniferous forest from tundra. Where summer temperatures exceed

50 degrees F (10 degrees C), conifers predominate, but wherever summer temperatures fall below 50 degrees F (10 degrees C), tundra results. Grasses and sedges are the tundra flora. During the 50 or 60 days of summer, the sun melts a thin strip of ground. Free from the grip of ice and benefiting from the nearly continuous sunlight of summers in high latitudes, plants grow vigorously and then are dormant for the long, bitter winter.

EFFECTS OF CLIMATE CHANGE ON PLANTS

The increase in temperatures that is the likely outcome of the greenhouse effect will affect plants. By one estimate, a two or three degree F increase in temperature will raise crop yields in the temperate zone, though an increase above 3 degrees F (1.7 degrees C) will decrease yields. Any temperature increase will likely reduce yields in the tropics, where crops are already at their maximum heat tolerance.

The climate of the future is sure to affect plants. Despite predictions to the contrary, the increase in carbon dioxide will likely increase temperatures. One study suggests that a doubling of carbon dioxide in the atmosphere will triple the growth rate of plants and trees. Forests will grow more densely and will extend their range to higher latitudes. Plants will grow more vigorously on marginal land. Another study indicates that a doubling of carbon dioxide will shift temperate forests 310 to 621 m. (500 to 1,000 km.) north in the northern hemisphere, and south in the southern hemisphere. The concentration of carbon dioxide is likely to double by 2080, but trees are not likely to migrate so far so fast. Global warming therefore endangers temperate forests. As the climate warms, trees will advance north and south, taking over ground that had been tundra. As temperatures rise, dead plants will decay more rapidly, liberating still more carbon dioxide into the atmosphere.

The cutting down of forests will surely harm the plants that survive. The amount of rainfall will decrease as forests are cut down. With fewer forests, the rate of transpiration will diminish. Whereas forests absorb sunlight, bare ground reflects sunlight back into space. A 15 percent decline in rainfall would replace the forests of South America with grassland. A 30 percent decrease in rainfall would replace the forests of Zaire with grasses. A 70 percent decrease in rainfall would make the Amazon basin a desert.

The climate of the future may imperil many plant species, but as a kingdom, plants are resilient. They have survived the Ice Ages and the predation of herbivores in warm climates. Humans are fortunate that plants are so adaptable, for with their agriculture, humans are dependent on plants. Life would not exist without the diversity of plants. The most numerous form of terrestrial life during the Carboniferous period, plants occupy every biome. Even in deserts, their seeds lie dormant, awaiting the infrequent rains. Plants have adapted to every climate, from the tropics to frigid tundra. Even bodies of water are home to plants. The survival of plants depends on their ability to adapt to the climate of the future. The survival of the rest of the biota depends on the success of plants.

SEE ALSO: Climate; Cretaceous Era; Greenhouse Effect; Greenhouse Gases.

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Pleistocene Era

THE INCREASING FREQUENCY and intensity of glacial-interglacial cycles toward the end of the Pliocene (1.806–5.332 million years ago) set the stage for the Pleistocene epoch (11.8 thousand years ago–1.806 million years ago), which is the final phase of the Quaternary period. Some argue that the lower Pleistocene boundary may be set too late because the general trend toward significant cooling and glaciation had begun in the mid-late Pliocene (2.75 million years ago). Hence, the term Plio-Pleistocene may be used to delineate this transitional phase between the two epochs.

Strong glacial-interglacial phases are the key climatic features that characterize the Pleistocene epoch and have shaped much of the modern landscape. Glacial stages may be referred to as ice ages, and are used to describe a period of extensive ice sheet presence in the polar, high latitude continental, and alpine regions. Glacial phases are synonymous with reduced global temperatures. Quaternary glacial-interglacial cycles occurred with a 41,000-year periodicity, starting in the late Pliocene (2.75 million years ago) to mid-Pleistocene (1.11 million years ago), followed by a 100,000 year cycle in the mid- to late-Pleistocene. The most intensely studied glacial stage during the Pleistocene is the last glacial maximum (21,000 years ago).

Marine fossil material and isotopic proxies were used to simulate sea surface temperatures, sea ice, continental ice sheets, and albedo during the last glacial maximum, with results indicating that high latitudes in the northern hemisphere cooled by 7–11 degrees F (4–6 degrees C), while simulated sea temperatures increased by 2–5 degrees F (1–3 degrees C) in the Pacific and Indian oceans. Most recent evidence suggests that with the exception of Central America and the Indo-Pacific, the climate was much drier than today, due to the combination of reduced evaporation, greater coverage of land surfaces by ice sheets, and wind anomalies.

Glaciation was most extensive in the northern hemisphere, with 2–2.5 mi.- (3–4 km.-) thick ice sheets covering Canada and parts of the northern United States, Greenland, northern Europe, Russia, and perhaps to a lesser extent, the Tibetan Plateau. In the southern hemisphere, the glaciation of Antarctica that began in the Pliocene continued through to the last glacial maximum, the Andes were highly glaciated, the Patagonian Ice Sheet covered much of southern Chile, and small glaciers formed in Africa, the Middle East, and southeast Asia, where simultaneously, deserts were expanding. Sea levels may have been up to 426.5 ft. (130 m.) lower than today. The hydrologic and geological consequences of the last glacial maximum and other glacial stages are still evident, particularly at the higher latitudes of the northern hemisphere, where the abundance of fresh water is effectively the result of glacial retreat and runoff. Remnants of Pleistocene glaciers also remain in high-altitude tropical localities such as on Mount Kilimanjaro and the Peruvian Andes, but these glaciers are quickly retreating.

The causes of the Pliocene-Pleistocene glacial-interglacial cyclicity are largely attributed to climate forcing caused by variations in the Earth's orbital parameters (Milankovitch cycles), but the sequence of events is difficult to establish. However, there is strong evidence that greenhouse gas levels fell at the start of glacials and rose during the interglacial retreat of the ice sheets. So far, eight glacial cycles have been identified from cores in Antarctica dating back to 740,000 years ago, but currently, it is the Vostok ice core dating back to 420,000 years ago that provides the clearest perspective on the link between greenhouse gases and sea surface temperatures over the last four glacial-interglacial cycles. CO_2 concentrations fall between 180–200 ppm during the coldest glacial periods, and 280–300 ppm during full interglacials, while methane concentrations were approximately 350 ppb during glacials, and roughly twice that amount during interglacials. Current thinking is that Pleistocene changes in greenhouse gas levels were probably caused by disturbance to the sources of these gases, of which the oceanic and terrestrial sources were most significant.

During the last glacial maximum, the presence of large ice sheets over the high latitudes of the Northern Hemisphere significantly reduced the amount of exposed vegetation, and combined with low atmospheric CO_2 and other regional climatic changes, created biomes and vegetation assemblages that have no modern analogue. The Laurentide Ice Sheet completely covered Canada and the northern United States, with taiga, desert, and grassland ecotones dominating the mid-latitudes. At this time, woodland and shrub communities were also present, but highly fragmented. An exception to this is the Canadian and Alaskan Pacific coasts, where the continuity of woody flora remains largely unchanged from the last glacial maximum.

Substantial winter cooling reduced the global extent of tropics and subtropics and caused local extinctions, but equable areas may have acted as regional refuges for species that otherwise would have disappeared. The expansion of more arid ecosystems is well documented from pollen data showing that grasslands and shrub ecotones spread into previously tropical areas such as the Amazonian Basin, equatorial Africa and southern Asia. The persistence of rainforests in central North America and Indonesia during the last glacial maximum can be attributed to the consistently high rainfall in these regions. By contrast, over half of central Australia was desert, with tropical grasslands lying in the north, and scrub-woodland vegetation dominating the eastern and western regions.

Substantial evidence exists to support the hypotheses that Pleistocene fauna was dually affected by the climatic oscillations of the early-mid Quaternary, and the hunting activity of ancestral humans. The disappearance of species that had evolved in colder climates, such as the woolly mammoth, woolly rhinoceros, and musk ox, is most consistent with the appearance of humans in North America. By contrast, the Pleistocene extinction of Eurasian megafauna was likely due to climate. The disappearance of African and South American mammals is unresolved, but current evidence points to the arrival of humans as a key factor.

SEE ALSO: Glaciology; Ice Ages; Pliocene Era; Quatenary Era.

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Pliocene Era

THE PLIOCENE EPOCH is the uppermost subdivision of the Tertiary period (65.5 to 2.588 million years ago), and represents a geological stage from about 1.806 to 5.332 million years ago. Although the Pliocene was generally warmer than the present, this epoch is characterized by pronounced climatic oscillations that ultimately led to the characteristic cooling of the late Quaternary glacial-interglacial cycles. Pliocene climate data are inferred from oxygen isotope, dust, microfossil, and in some cases pollen data from cores collected under the flag of the Ocean Drilling Program (ODP), as well as terrestrial deposits. These records have allowed climatologists to refine the absolute chronology of the Pliocene epoch, and provide a continuous climatic record of global ice volume, sea surface temperatures, aridity, and terrestrial vegetation patterns.

The first Pliocene cooling event is documented at 4.5 million years ago, and was followed by variable, but persistent reductions in temperature after 3.6 million years ago. A brief period of warmth followed until 3.5 million years ago, at which time a second cooling event took place. A well-characterized mid-Pliocene warm period dates to approximately 3.3 to 3.15 million years ago, and is followed by the return to progressive cooling that culminated in the arrival of early northern hemisphere glacial-interglacial cycles about 2.75 million years ago. Significant growth of ice sheets did not begin in Greenland and North America until approximately three million years ago, following the formation of the Isthmus of Panama. Many agree that this final Pliocene cooling period set the stage for strongly developed glacial events of the Pleistocene (1.8 million to 11,550 thousand years ago) and thus represents a climatic stage that is most relevant to the climates of late Tertiary and early Quaternary.

The contemporary significance of the mid-Pliocene warm period lies in its utility as a model for future scenarios of global warming. This is because continental distributions and climate-indicative plant taxa are thought to have been very similar to today. Members of the Goddard Institute for Space Studies (GISS) and the PRISM (Pliocene Research, Interpretations and Synoptic Mapping) group have exploited these paleofeatures in their efforts to model global Pliocene climate and vegetation distributions. Average mid-Pliocene global sea levels are modeled at 33 to 82 ft. (10 to 25 m.) higher than today, due to reduced Greenland and Antarctic ice cover, while sea surface temperatures were approximately 6.5 degrees F (3.6 degrees C) warmer than at present day. Mid-Pliocene climate simulations generally indicated increased surface air temperatures, particularly during the winter, and increased annual rainfall, evaporation, and soil moisture. Pollen records from land-based cores are less chronologically accurate, but consistent with a 7–18 degrees F (4–10 degree C) warmer northern hemisphere climate, coupled with higher continental moisture levels. This is especially evident in high latitude regions such as the Arctic.

The PRISM group has used fossil and pollen data to document vegetation patterns across the globe during the mid-Pliocene warm period. Their work indicates extensive conifer and mixed forests in the mid-Pliocene Arctic, and generally more northerly distributions of the mixed deciduous forests of eastern North America. Interior North America was likely to be moister, and warmer than today, with evidence of lakes in southeastern California, Arizona, and Utah. Northern Europe was warmer and wetter, with a greater abundance of swamps and wetland areas. Little information exists about Central and South America, but the limited numbers of pollen studies are consistent with GISS climate models suggesting a warmer, wetter climate, with a greater abundance of steppe and prairie vegetation. The Australian mid-Pliocene warm period is poorly documented, but it is thought to be wetter than today, with broader distributions of forest flora. Regions of Antarctica were significantly warmer than today, so increased exposure of soils supported the presence of mixed beech forests.

The cause of the mid-Pliocene warming is uncertain, but some combination of CO_2 increase and change in ocean heat transport may have been responsible. Carbon isotopic data from deep-sea microfossils, coupled with GISS climate models, support the increased strength of thermohaline circulation during the mid-Pliocene, particularly with respect to North Atlantic deep water production. However, simulations where CO_2 is the single variable show that the proposed, realistic patterns of mid-Pliocene oceanic heat transports would only have been possible at CO_2 levels greater than 1,200 ppm. There is no evidence supporting such elevated CO_2 excursions, but some workers suggest that even the predicted minor increases up to 380 ppm, in combination with altered ocean heat transport, may have been enough to catalyze mid-Pliocene warming.

Early Pliocene fauna was transitional, favoring grazers over browsers, as grasslands and savannas expanded in central North America and Africa, thereby replacing woodlands and their associated fauna. Charismatic Pliocene fauna included mammoths, mastodons, camels, and hippopotamus in the mid-Northern Hemisphere latitudes, while large turtles and marsupials were found in the southern hemisphere. Pliocene high-Arctic fauna was primarily Eurasian, characterized by now extinct species of beavers, badgers, deer, and caniids, the presence of which is consistent with mixed-evergreen forest vegetation. The Pliocene deposits of eastern North America revealed mostly Eurasian fauna, most notably new species red panda.

Pliocene Africa, prior to 2.8 million years ago, was wetter than today, as evidenced by deposits of mangrove swamps and tropical forests, which retreated southward as desertification intensified. The western Sahara desert likely formed after 2.8 million years ago. The Pliocene is a particularly important time for the evolution and diversification of hominids. The aridity-humidity cycles that were related to the late Pliocene glacials-interglacials in the northern hemisphere in the Pliocene climate of Africa may have shaped hominid evolution by creating cyclic opportunities for species extinction and innovation.

SEE ALSO: Global Warming; Pleistocene Era; Quartenary Era; Tertiary Climate.

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Poland

LOCATED IN EASTERN Europe, Poland has a land area of 120,728 sq. mi. (312,679 sq. km.), with a population of 38,125,500 (2006 est.), and a population density of 320 people per sq. mi. (122 people per sq. km.). Some 47 percent of the country is arable, with a further 13 percent used as pastures and meadows, and 29 percent is forested.

Regarding electricity generation in the country, 98.1 percent comes from fossil fuels, mainly coal that is mined in many parts of the country, with 1.5 percent from hydropower. As a result of this, even though Poland is less industrialized than many other European countries, it has a high per capita rate of carbon dioxide emissions—9.1 metric tons in 1990, falling slowly to 8.0 metric tons per person by 2004. Some 57 percent of all carbon dioxide emissions in the country come from the production of electricity, with 17 percent from manufacturing and construction, 11 percent from transportation, and 11 percent for residential purposes. The reliance on coal has meant that 76 percent of Poland's carbon dioxide emissions have been from solid fuels, with 15 percent from liquid fuels, and 7 percent from gaseous fuels.

The rising average temperatures in Poland as a result of global warming and climate change have caused hot summers in Lesser Poland, a region in the south of the country. Poland has been actively involved in various schemes to introduce carbon trading, and has even managed to reduce its own emissions rate, although it is hoping to cut back further. As a result, Poland has tried to follow a project that was developed by the Global Environment Facility, by which Mexico and Norway managed to reduce their power use through widespread introduction of compact fluorescent lamps in two major cities. In the case of Poland, this would also involve the conversion of coal-fired boilers to use gas. The main problem with this has been the political power of the coal-mining areas, which has hindered many attempts to reduce the dependence on coal.

The Polish government took part in the UN Framework Convention on Climate Change signed in Rio de Janeiro in May 1992. It signed the Kyoto Protocol to the UN Framework Convention on Climate Change on July 15, 1998, committing to a 3 percent reduction prior to ratification, which took place on December 13, 2002, with it entering into force on February 16, 2005.

SEE ALSO: Coal; European Union; Global Warming.

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Polar Bears

THE POLAR BEAR (order Carnivora, family Ursidae) is the largest bear species and is thought to have evolved from brown bears, *Ursus arctos*, approximately one million years ago. There are 19 recognized populations, distributed in Canada, the United States (Alaska), Norway (Svalbard Islands), Denmark (Greenland), and Russia. The current estimated worldwide population is 20,000–25,000.

Polar bear territories can cover tens of thousands of sq. km. They live solitarily, but often congregate around food sources. Their diet consists primarily of ringed seals, but includes other seals, walruses, and beluga whales. They get the majority of their nutritional intake in the spring and summer from seal pups, which can be as much as 50 percent fat. Polar bears can swim for 37 mi. (60 km.) without resting, at speeds up to 6.2 mi. per hour (10 km. per hour). They possess several adaptations for a semi-aquatic existence, including partially webbed front paws, eyes adapted to see underwater, and a thick fat layer (eight to 12 cm.) that provides buoyancy and insulation in water.

Polar bears are also highly adapted to the Arctic climate. Arctic temperatures can drop to minus 49 degrees F (minus 45 degrees C) for days or weeks, but polar bears can withstand this due to their thick fat layer, a dense undercoat of fur with longer guard hairs, and black skin (which absorbs heat from sunlight). Other Arctic adaptations include white-seeming fur for camouflage (the hairs are actually colourless and hollow), small ears and tail (which reduce heat loss), large furry feet (which act like snowshoes), and a digestive system very effective at absorbing and storing fat.

Females become sexually mature at four to five years of age. Males may not mate successfully until they are 8 to 10 years old. Mating occurs from April to June and each male may mate with more than one female. The females have induced ovulation, mating multiple times causes the release of an egg. The implantation of the blastula (the fertilized egg after several cell divisions) is delayed until September/October, and in November/December the female excavates a den in the snow. She eventually gives birth in December or January. One to three cubs are born (two-thirds of cubs are twins) and they are nursed in the den until March/April, when they emerge. Cubs are weaned at the age of two or three years. During

A reduction of sea ice would result in the loss of polar bear habitat. It would also affect their access to food and to mates, and disrupt their migration routes. Many drowned polar bears have been reported, the result of larger areas of open water between ice floes.

this period, they learn important hunting skills from their mother. Occasionally, cubs are attacked and killed by males, so mothers are fiercely protective. Females breed after they wean the current cub(s), but will not reproduce at all if conditions are unfavorable. Cub mortality rates are high.

The most common cause of death for subadult bears is starvation, as they do not yet have a territory and must compete with larger bears, pushing many into marginal habitats. In adulthood, mortality drops sharply (to less than 5 percent annually); the most common natural cause of death in adults is attacks by other bears. Human activities and impacts that pose the greatest risk to polar bears include hunting, pollution, industrial development, and climate change.

HUMAN EFFECTS ON POLAR BEARS

Humans kill polar bears for aboriginal subsistence, sport, and defense of human life and property. In some areas, monitoring of polar bear kills is effective (in Norway and the United States), but in other areas there is little reliable information (Russia and Greenland). Concerns have recently been expressed about the threat posed by trophy hunting (currently allowed only in Canada and Greenland). Quotas are often based on poor population data. Approximately 80 trophies are imported into the United States each year from Canada.

Arctic marine mammals can accumulate high concentrations of pollutants in their blubber. As top predators, polar bears accumulate the highest concentrations, and in some areas there is concern about pollution effects on the bears' health. Polar bears with abnormal genitalia and other defects have been recorded, and there have been suggestions that these are caused by exposure to certain contaminants. Development in the Arctic is also an issue. The Arctic is rich in natural resources, especially oil and gas. Exploration for and extraction of these resources involve construction that could potentially reduce habitat, produce pollution, or cause disturbance.

Because of their exclusively Arctic habitat and their charismatic nature, polar bears have become the "poster child" for the impacts of climate change. The primary concern is the loss of sea ice. This would remove essential habitat, for both the bears and their marine mammal prey. Increasing numbers of drowned polar bears have been reported, the result of increasing areas of open water between ice floes, presumably leading to overexertion during swimming. The loss of ice cover could also reduce the ability to access prey and mates, disrupt migration routes, and increase distances animals have to travel to find food (exacting an energetic cost). Many females also construct their birthing dens on ice. In the past 20 years, the proportion of dens located on sea ice has halved.

Habitat loss and prey reduction may force bears closer to human habitation to find food. Sightings of animals near Arctic towns and villages are occurring with greater frequency. This increases the likelihood of negative human/polar bear interactions. In addition, researchers have reported a significant decrease in polar bear body condition over the past 20 years, and such a decline is likely to have impacts on reproduction and survival.

Climate change may also cause chronic overheating in the highly cold-adapted bear. Finally, rising temperatures are likely to cause a shift in the distributions of other bear species; for example, brown bear populations may shift farther north and could compete, or hybridize, with polar bears.

CONSERVATION OF POLAR BEARS

In 1965, the "polar bear" nations met and agreed that each country should take whatever steps were necessary to conserve the species. Cubs, and females accompanied by cubs, should be protected throughout the year; each nation should, to the best of its ability, conduct research on polar bears within its territory; and each nation should exchange information on polar bears freely. This eventually led to the signing of the International Agreement on the Conservation of Polar Bears in May 1973 in Oslo, Norway. This agreement is currently the major international polar bear treaty.

In 1982, largely due to declines resulting from hunting pressure, the World Conservation Union (IUCN) listed the polar bear as Vulnerable. This rating was reduced to Lower Risk in 1996. However, in May 2006, polar bears were relisted as Vulnerable due to a predicted population reduction of more than 30 percent within three generations (45 years), and a decline in area of occupancy, extent of occurrence, and habitat quality resulting from climate change.

In the United States, polar bears are managed by the Fish and Wildlife Service and are protected by the Marine Mammal Protection Act (MMPA), which prohibits harassment, hunting, capture, or killing, or attempts to do any of these. There are exemptions for Alaska Native subsistence hunting, as well as scientific research and "incidental harassment" from activities such as oil and gas exploration. However, a controversial amendment in 1994 permitted the import of sport-hunted polar bear trophies into the United States from some Canadian populations. A legislative attempt is ongoing to repeal this amendment.

In February 2005, the Center for Biological Diversity and Greenpeace USA petitioned the U.S. government to list polar bears as threatened (that is, likely to become endangered within the foreseeable future throughout all or a significant portion of its range) under the U.S. Endangered Species Act. Such a listing would obligate the U.S. government to reduce anthropogenic impacts on polar bears and to devise a plan to aid their recovery. In December 2006, the U.S. Secretary of the Interior announced a proposal to list the polar bear as threatened. The deadline for deciding on the listing was January 2008.

SEE ALSO: Impacts of Global Warming; Marine Mammals; Sea Ice.

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Policy, International

INTERNATIONAL POLICY IS complex because of the necessity to consider the needs of each sovereign nation against economies, global environmental impact, and contributions to human-induced climate change. Much of the work toward international cooperation is done through the United Nations (an international organization with nearly all countries as members). The United Nations facilitates discussion and commitment, though it has limited authority or power. Members agree that something most be done about climate change and the environment; however, getting member nations to agree on solutions is harder. Conflicts and disagreements usually include protection of national interests by not turning authority over to the United Nations, wording of agreements that appears to not protect the interest of private industry or national interest, and economic differences between developing and developed countries.

CURRENT INTERNATIONAL POLICY

The UN Environment Programme (UNEP) was formed in 1972 with the specific purpose of encouraging collaboration on conservation and development. In 1977, the international community adopted a Plan of Action to Combat Desertification due to impacts on economy, society, and environment. In 1991, the UNEP concluded that even with some successes, land degradation due to desertification had increased, and at a 1992 conference proposed sustainable development and for the UN General Assembly to establish an Intergovernmental Negotiating Committee (INCD) to prepare a Convention to Combat Desertification, which was adopted in 1994, with entry into force on December 26, 1996. Over 179 countries were parties to the convention as of March 2002.

The Montreal Protocol on Substances that Deplete the Ozone Layer was agreed on September 16, 1987, and entered into force on January 1, 1989, and has been ratified by 191 countries. In meetings for the Montreal Protocol, the parties established adjustments and reductions of production and consumption of the controlled substances.

At the 1992 UN Conference on Environment and Development, member nations agreed to work together to formulate solutions. The Convention on Biological Diversity (CBD) was adopted at the conference for commitments to maintaining ecology balanced with economic development, though the United States disagreed with some document wording as not protecting biotechnology firms.

The Intergovernmental Panel on Climate Change (IPCC) was formed in 1988 by partnership with the World Meteorological Organization (WMO) and the UN Environment Programme to assess the risk of human-induced climate change, possible impacts of climate change, and provide options to deal with climate change. The First IPCC Assessment Report completed in 1990 provided the impetus for the formation of the UN Framework Convention on Climate Change (UNFCCC) by the UN General Assembly.

The UNFCCC is an international treaty joined by most countries and adopted in 1992, and entering into force in 1994. The UNFCCC provides the overall policy framework for addressing climate change and for coping with the impacts from inevitable temperature increases. From initial discussions, the idea came about of incorporating policy-based commitments into the international climate negotiations. The variety of options considered by the Intergovernmental Negotiating Committee was a system incorporating national assessment, along with implementation strategies and programs for reducing greenhouse gas emissions by considering their country's needs and responsibilities within the scope of international, regional, and local circumstances to determine what agenda items would be a priority and for the setting of objectives.

Developed countries committed under the initial negotiations to take the majority of responsibility for creating policy and actions to mitigate climate change and limit/reduce their output of emissions of greenhouse gases to 1990 levels by the year 2000. In debating further commitments, the participants discussed a variety of options, including policies and measures, as well as quantified emission targets. The 1995 Berlin Mandate, under negotiation, requested more significant quantification of emissions and stricter policy to enforce reduction objectives in a certain period of time. The various participants presented and supported policy approaches including across-the-board standards and taxation as well as options to choose from. Some proposals blended mandatory strict policy standards and taxation, along with a variety of options for reaching those goals.

Proposals from the European Union, the primary proponent of common and coordinated policy, listed specific actions including mandatory commitments, highly recommended commitments, and voluntary commitments. The United States and other participants favored target-based approaches to allow countries complete autonomy in choosing policies and measures.

By the late 1990s, working in voluntary partnerships was leading to reductions in conflict among stakeholders, new ideas on sustainable economic development and poverty alleviation, new thinking about the relationship between conservation areas and the communities in and around them, and more focused application of existing resources. An addition to the UNFCCC treaty is the Kyoto Protocol, drafted in 1997 by 160 nations, calling for the 38 industrialized countries releasing the most greenhouse gases to cut their emissions to levels five percent of 1990 levels by 2012 to achieve a worldwide reduction of greenhouse gases.

THE KYOTO PROTOCOL

The Kyoto Protocol entered into force on February16, 2005, and is legally binding on countries that ratify the agreement. In initial negotiations, the United States voluntarily accepted a more ambitious target, promising to reduce emissions to 7 percent below 1990 levels; the European Union, which had wanted a much tougher treaty, committed to 8 percent; and Japan, to 6 percent. Since the adoption of the Kyoto Protocol, 175 parties have ratified it. The protocol sketched out the basic features of its mechanisms and compliance system, for example, but did not explain the all-important rules of how they would operate. The United States has not ratified the agreement because of wording and exclusions of developing countries from emissions reduction.

Though the United States has not ratified the Kyoto Protocol, the government has established a comprehensive policy to slow the growth of emissions with voluntary and incentive-based programs, strengthen institutional advancement of climate technologies and climate science, and enhance international cooperation. In February 2002, the U.S. government announced a comprehensive strategy to reduce the greenhouse gas intensity of the American economy by 18 percent 2002–12, preventing the release of more than 100 million metric tons of carbon-equivalent emissions to the atmosphere (annually) by 2012 and more than 500 million metric tons (cumulatively) 2002–12.

A core challenge in addressing global climate change is arriving at multilateral arrangements ensuring adequate effort by all major economies to moderate and reduce their greenhouse gas (GHG) emissions. Thus far, the multilateral effort has relied most heavily on a particular form of commitment-economy-wide emission targets. Developed countries agreed to voluntary targets under the UNFCCC, and most later agreed to binding targets under the Kyoto Protocol. Most developing countries, however, view quantified emission limits as a potential cap on their growth and are unlikely to accept binding targets in a post-2012 climate agreement.

At the World Conference on Disaster Reduction, The Hyogo Framework for action signed in January 2005 by 168 countries details steps to reduce the impact of natural hazards on populations. It assesses disaster capabilities and needs and incorporates risk reduction strategies and adaptations associated with existing climate variability and future climate change, including risks from geological hazards such as earthquakes and landslides. The result has been 40 countries adjusting national policies to give priority to disaster risk reduction.

The mission of the Millennium Development Goals is to alleviate poverty by integrating sustainable development into national policies and prevent the loss of natural resources. These goals allow countries to determine their own priorities. One way this is being done is with the creation of model forests to show how sustainability practices can have a positive impact on human life and to reverse environmental degradation with conservation and reforestation.

FUTURE OUTLOOK FOR INTERNATIONAL POLICY

Some international policies retain support over the long term, like the Montreal Protocol on Substances that Deplete the Ozone Layer and the Convention to Combat Desertification. The reduction in greenhouse gas emissions measures agreed to in the Kyoto Protocol end in 2012.

In determining future policy, the success of the target-based approach to reducing greenhouse gas emissions and its enforceability must be examined. The commitment is based on outcome, and coupled with emissions trading, provides economic benefits as well as freedom to apply reduction strategies in the most cost-effective manner. This works for industrialized nations, with already established economies. Developing countries may not accept imposed limits on emissions, because those same limits may limit the potential for growth. Developing countries already have multiple concerns to improve first, including environmental issues like water quality, air quality, poverty, and health issues like access to sanitation, nutritious food, and health services.

Ongoing negotiation and commitment will be needed to continue international cooperation on climate change policy. As discussed at the Climate Dialogue at Pocantico, flexibility seems to be the most important factor in gaining support by perhaps allowing countries to develop national policies in developing countries to reduce emissions on a more individual basis, instead of being limited to strict limits set by an economy-wide emission limit. Within this framework, nations would need to establish quantifiable measurements of emission impacts.

Since the Kyoto Protocol applied emission reduction levels to industrialized nations, gaining agreement to emission standards from developing countries may require some incentive-based policies. Researchers have made a variety of proposals, including the trading of carbon/emission credits as long as emissions can be quantified, control of conventional air pollutants, or improvement of agricultural productivity. Taking measures for limiting the extent of global warming from the greenhouse effect includes preventive measures (reducing emissions, enhancing carbon sequestration) and adaptive measures (construction to protect against the effects of climate change, improving water resources, and improving cultivation practices, or shifting crops to match the plants' ideal weather conditions for maximum production).

Also to be considered is a shift to previously underutilized or unused commodities like carbon taxes on all fossil fuels, such as gas, oil, coal, and the electricity generated from these sources. These taxes would shift the burden of emissions reduction to the consumer by inflating the price of using carbon-based energy and making the use of energy conservation measures and alternative resources more attractive and cost-effective, as well as increasing the demand for alternative sources. The trading of carbon credits (with each nation allocated a certain permissible level of carbon emissions and the ability to sell leftover allocations to nations who have exceeded their allocation limits), subsidizing non-carbon-based fuel providers instead of fossil fuel providers, and research and development expenditures promoting the commercialization of alternative technologies and promoting the transfer of technology to developing nations could also help.

Any measures taken to prevent global climate change will have economic effects, both positive and negative, on the economy, including production, employment, and investment. Continued scientific research on climate and atmosphere, as well as environmental education and continued voluntary dialogue between countries on the future of global environment and economic policies, can help lead to action and global policy development to overcome the limitations of determining economic policies.

Policy must also take into account the damages caused by the impacts of climate change. While climate models vary on temperature increase for each region, depending on the already present climate, potential risks include rising sea levels causing flooding, loss of coastal wetlands, beach erosion, saltwater contamination of drinking water, and damage/decreasing stability of low-lying property and infrastructure; possible increase in frequency and intensity of storms make flooding a possibility in many areas made worse by difficult drainage and causing other damage. Flooding and runoff could contaminate water supplies (with eroded soils and agricultural chemicals containing high concentrations of nitrates, pesticides, and soil nutrients); other damages could include decreased water supplies, population (both human and animal) displacement, changes in agriculture (with benefit to colder climates and loss to warmer climates), forest loss with persistent drought, and loss of trees unsuited to higher temperatures.

Changes within established ecosystems would affect wildlife, including breeding grounds of waterfowl and migratory birds. Human health risks include contracting certain infectious diseases from water contamination or disease-carrying vectors such as mosquitoes, ticks, and rodents. Warmer temperatures would increase the incidence of heat-related illnesses and lead to higher concentrations of ground-level ozone pollution, causing respiratory illnesses (diminished lung function, asthma, and respiratory inflammation). In addition, psychological factors related to higher stress could be prevalent. All of these potential impacts will also have an impact on the economy, and policy, international, national, or local, must take these possibilities into account, as some areas are more vulnerable than others; those with high emissions may not be the ones who suffer from the consequences.

Groundwork for emissions crediting is being demonstrated through the Clean Development Mechanism of the Kyoto Protocol. The projects already approved could generate 870 million tons of emission credits with the current estimated value of between $6 and $9 billion. This monetary value makes carbon crediting a viable source of income, especially for developing countries and those with carbon sequestration in forests and agricultural areas. This type of market enterprise would require independent verification. The limitation to this program might be creating disincentives for industrialized nations to reduce emissions with the option to purchase carbon credits or to not agree to the program at all if they will not be able to benefit from the income produced.

The quantification of standards thus far has been based on present levels and emissions assessments. For developing countries that have not had access to the vast amounts of energy used by industrialized nations, the strategy is not reduction of emissions, but limiting emissions to standards for consumption of energy against the development of renewable energy and improved social structures. The effectiveness of a policy is only as good as the results; other variables may be in action instead of just the policy.

As environmental awareness grows and more individuals choose climate-preserving strategies, those will have a cumulative effect on emissions. Options for telecommuting reduce driving, an economic downturn affects production, and service industries consume less energy than industrial production. Improved agricultural practices remove carbon from the air. In some cases, the effectiveness of the emissions reduction policy will be difficult to determine. The most vital part of international policy is raising awareness of the environment and what can be done to combat climate change and the effects of climate change.

SEE ALSO: Intergovernmental Panel on Climate Change (IPCC); Kyoto Protocol; Preparedness; United Nations Environment Program (UNEP); World Health Organization; World Meteorological Organization.

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Policy, U.S.

U.S. GLOBAL WARMING and climate change policy is a hotly contested issue, one fraught with partisan bickering throughout the course of at least the last three presidential administrations. The official U.S. position has vacillated considerably over the last two decades, swinging from initial global leadership displayed during the very first climate change hearings in the U.S. Congress during summer 1988, to a mixed bag of sorts during the tenures of President George H.W. Bush and President Bill Clinton, to periods of obstruction and outright suppression of scientific studies during the early 21st century under President George W. Bush.

Despite this checkered past, though, a previously politically hamstrung United States is now making considerable advances in climate change policy. Thanks in large part to the federalist model of a national government that shares some power with its individual states, as well as local municipalities, and a fundamental separation of powers among executive, legislative, and judicial branches at the national level, notable changes are underway.

Many analysts now believe that the United States has reached a tipping point in terms of public awareness of climate change. Scientific consensus on both the rising global temperatures and anthropocentric roots of that shift, combined with concerns about energy insecurity and its ties to international terrorism, have pushed climate change discourse to the forefront, particularly in the context of what some now label the post–Hurricane Katrina effect, the growing recognition among Americans that they too are vulnerable to the vagaries of climate change.

No longer is this a problem just for their children or grandchildren to consider, or a problem that threatens primarily the developing world or small island states. According to a survey commissioned by the Yale Center for Environmental Law and Policy in March 2007, 83 percent of Americans believe global warming is a serious problem. Analysts increasingly believe that a reasonable debate about the regulation necessary to reduce greenhouse gas emissions is possible in the United States and that this regulation makes good economic sense, much in the model of the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer.

Yet, when the Kyoto Protocol, the only global treaty with binding measures to address climate change, finally entered into force on February 16, 2005, the United States was one of only two Annex I industrialized countries (Australia being the other) that did not ratify the protocol. In total, 175 states of the world joined together without the world's leading economic engine, and its biggest polluter. United States resistance to the Kyoto Protocol rests firmly on this division between Annex I and Annex II countries, the developed and developing world, and the fact that Kyoto exempted Annex II states from any reductions in greenhouse gas emissions, at least until 2012.

While India is also a concern, American diplomats fear China most. China is the world's largest and most populous country, one that has ranked among the world's fastest-growing economies for two decades. China is also heavily coal-dependent and becoming ever more so, building an average of one new coal-fired plant a week. Its total energy-related carbon emissions have more than doubled since 1980, and it is widely regarded as on pace to pass the United States as the leading greenhouse gas emitter before 2020. Nevertheless, per capita emissions of carbon dioxide in China are still seven times less than that of the United States, according to the Sierra Club. With only 4 percent of the global population, Americans account for roughly 22 percent of the planet's greenhouse gases. Because China was such a late entry into an industrialization process that has created the climate change problem, the ethics of reducing greenhouse gas emission there are spotty. However, the country's economy and greenhouse gas emissions are growing at such a fast pace, reductions seem necessary.

The globalization argument as to dirty industry being able to relocate to China if it continues to be exempt from any global agreement is essentially a red herring. According to the nonpartisan Pew Center on Global Climate Change, the vast majority of U.S. greenhouse gases come from transportation, commercial, residential, and agricultural sectors that cannot leave the country. Only industry itself could potentially do so, which in 2004 accounted for 30 percent of U.S. greenhouse gases.

HISTORY OF CLIMATE CHANGE IN THE U.S.

The United States was an early leader in the field, dating at least to the aforementioned congressional climate change hearings during summer 1988. Experts such as National Aeronautics and Space Administration's (NASA) Jim Hansen first sounded alarms as to the severity of the climate change problem. Four years later, at the 1992 UN Conference on Environment and Development (UNCED) in Rio de Janeiro, Brazil, the United States continued to actively participate in climate deliberations on the international stage. President George H.W. Bush attended what was at the time the largest gathering of world leaders in history, signing the UN Framework Convention on Climate Change (UNFCCC), one of the five major agreements reached at what has since been referred to popularly as the Earth Summit.

But both President Bush's presence and signature were couched within political compromise. Bush feared mandatory limits on greenhouse gas emissions would severely hamper the U.S. economy, and only agreed to attend if the final document would go no further than suggesting voluntary limits by each country. His famous saying was that America's way of life was not up for negotiation. Popular opinion in the United States had yet to grasp the concept of sustainable development, the idea that economic development and environmental resource protection can go hand in hand.

Thus, the great irony of Rio is that a conference that was intended to firmly establish the 1987 Brundtland Report's definition of sustainable development, outlined in their publication *Our Common Future* as development that meets the needs of the present generation without sacrificing the needs of future generations, actually did the exact opposite. An entire cohort of American diplomats handcuffed themselves by bowing to the popular connotation that a tension existed between economic and environmental health. For the next decade and a half, American climate change politics would be shaped primarily by President Bush's language, one that insinuated a trade-off between environmental protection and economic development and completely ignored the underlying foundation of economic health, namely a healthy environment.

The following year, President Bill Clinton, after defeating President Bush in his reelection bid, was faced with precisely this type of obstacle in public sentiment. Despite placing perhaps the most qualified environmental politician of his generation in the number two slot of the Democratic ticket in 1992, President Clinton was unable to generate much political traction when it came to the climate change debate during the eight years in office with Vice President Al Gore, Jr. Two key examples bear out this point. The first is the attempt early in Clinton's first administration to institute a British thermal unit (BTU) tax, one that would raise taxes for a family income of $40,000 by approximately $17 a month and those making under $30,000 by none at all. This proposal failed in short order and reinforced the perception in American politics that the public will not pay to solve a long-forming, distant problem with uncertain consequences. There are simply too many more immediate concerns the average American faces on a day-to-day basis.

The second major example rests squarely upon the foundation of the international climate change debate, the Kyoto Protocol. In the lead-up to the United States signing that international treaty in December 1997, Clinton Administration officials took a central international role. With the preceding April 1995 Berlin Mandate, for instance, the United States was a passionate supporter of the argument for differentiated responsibilities, where the industrialized world would agree to restrict its emissions on the average of 5 percent below its 1990 levels before the developing world would do so, much like the Montreal Protocol had divided the world between developed and developing world.

But well before Vice President Gore left for Kyoto in late 1997 to join the U.S. delegation led by former senator Tim Wirth (D-CO), the U.S. Senate passed the bipartisan Byrd-Hagel Resolution, which stated that body would only support a treaty that included all countries of the world. Touting what would come to be labeled global apartheid, the Byrd-Hagel Resolution demonstrated an overwhelming sentiment, passing by a vote of 95–0. Thus, despite signing Kyoto, Clinton never submitted the treaty for ratification in the Senate, a constitutional requirement that dictates any international treaty must receive two-thirds Senate support before becoming force of law.

THE GEORGE W. BUSH ADMINISTRATION

Such failures pale in comparison to the politicization of climate change during the successor administration of President George W. Bush. Over his two terms, borrowing in large part from the tobacco industry playbook, President Bush has overseen a White House that first vociferously discounted the science of climate change, and then turned to outright suppression of its evidence. Thus, while President Bush has developed a combination of modest bilateral and regional initiatives such as the Asia-Pacific Partnership on Clean Development and Climate, International Partnership for a Hydrogen Economy, and the Carbon Sequestration Leadership Forum, the lasting legacy of President Bush in terms of climate change will be a decidedly negative one.

He has ignored scientific consensus on climate change and its human-induced links in the form of the widely regarded assessments by the Intergovernmental Panel on Climate Change (IPCC). He has withdrawn the United States from Kyoto, citing the familiar refrain on lack of participation by China. And most egregious of all, he has obstructed and even deleted the dissemination of information from his own Environmental Protection Agency (EPA) and other governmental scientists. The most publicized of these was reported by the *New York Times* in its coverage of e-mails obtained by Greenpeace under the Freedom of Information Act, which depict the White House Council on Environmental Quality chief of staff Phil Cooney, a former oil industry lobbyist, as actually doctoring science by editing climate scientist reports to render them innocuous in 2002.

Despite these actions by the Bush Administration, separation of powers in the United States has allowed both the legislative and judicial branches to weigh in regarding climate change. In April 2007, for example, the U.S. Supreme Court, in the landmark 5–4 decision of *Massachusetts et al. v. EPA et al.*, sided with the Commonwealth of Massachusetts in its suit of an EPA that had heretofore ignored whether greenhouse gas emissions cause or contribute to climate change. The Court declared Massachusetts, as well as the supporting states of Connecticut, Illinois, Maine, New Jersey, New Mexico, New York, Rhode Island, Vermont, and California, had every right to request the EPA to regulate greenhouse gases.

Six months prior, the sweeping midterm elections of November 2006 saw a redistribution of party lines in the U.S. Congress, with Democrats gaining advantages in both the House and Senate (with the two Senate independents in Vermont and Connecticut, respectively, agreeing to caucus with the Democrats) for the first time since 1994. While that election was primarily driven by sentiment over the war in Iraq (and climate change debate in Congress is by no means divided solely along partisan lines, with western coal interests and mid-western automobile labor interests often influencing Democrats more than Republicans), the tangible results within congressional committees were nearly immediate, as at least five different greenhouse cap and trade bills began circulating in Congress when it returned to session in January 2007.

Most notably, the newly minted chairwoman of the Senate's Environment and Public Works Committee, Sen. Barbara Boxer (D-CA) replaced James Inhofe (R-OK), who held a grand total of five hearings on climate change in four years as head of that committee, including science-fiction writer Michael Crichton as his star witness. Senator Inhofe was also well known for labeling global warming as the greatest hoax ever perpetrated on the American people. Senator Boxer promptly held five hearings on climate change in her first three months at the helm and proposed what will likely become the centerpiece of a renewed national debate with Sen. Bernie Sanders (I-VT). This bill, formerly known as S-309 but more popularly referred to as the Global Warming Pollution Reduction Act, requires emissions reductions in the United States to the 1990 level by 2020, 27 percent below 1990 by 2030, 53 percent below 1990 by 2040, and 80 percent below 1990 by 2050.

CLIMATE POLICY: STATE AND REGIONAL LEVELS

The most significant advances in U.S. climate policy to date have actually occurred at the state level. It is in these laboratories of democracy where federalism has allowed a number of enlightened governors and their respective legislatures to forge ahead where the federal government has floundered. Where the United States is flexing its muscle most is in California under Republican governor Arnold Schwarzenegger. As the eighth-largest industrial engine on the planet, California's 2006 law targeting a 25 percent cut in carbon dioxide by 2020 is more than mere lip service to climate change.

Furthermore, as the first U.S. law imposing mandatory caps on carbon dioxide, it turned heads all the way up to the Potomac and beyond. This was not California's first foray into the climate change debate. Four years prior, in 2002, the state passed legislation creating vehicle emissions standards that required reductions of 22 percent in tailpipe greenhouse gas emissions from new vehicles by the 2012 model year and 30 percent by the 2016 model year. Governor Schwarzenegger and California are responding to the increasing loss of Sierra mountains snowpack, their primary source of drinking water, and believe they must compensate for a federal government that has dragged its heels on the issue of climate change for far too long. They also believe their economy is large enough to force others to sit up and take notice.

That logic appears to be on target. In February 2007, governors of Arizona, New Mexico, Oregon, and Washington joined California in signing an agreement establishing the Western Regional Climate Action Initiative, a joint effort to tackle climate change by reducing greenhouse gas emissions with a market-based system. This set-up mimics that of the Regional Greenhouse Gas Initiative (RGGI), which became the first mandatory U.S. cap-and-trade program for carbon dioxide in December 2005. Negotiated by the governors of seven northeastern and mid-Atlantic states (Connecticut, Delaware, Maine, New Hampshire, New Jersey, New York, and Vermont) with Maryland joining in April 2007, RGGI sets a cap on emissions of carbon dioxide from power plants at current levels in 2009, and then reducing emissions 10 percent by 2019.

U.S. BUSINESS INTERESTS

Aside from state and regional initiatives, the business community is making perhaps the most significant inroads regarding climate change policy. Echoing the logic and business acumen that drove DuPont Chemical from its position as a stiff opponent of domestic regulation of chlorofluorocarbons (CFCs) in the late 1970s to that of a staunch supporter of the globally-reaching Montreal Protocol in the mid-1980s, an incredibly diverse cross-section of corporations now stands in favor of mandatory limits on carbon dioxide emissions.

A business-NGO alliance, the U.S. Climate Change Action Partnership (USCAP), which touted 33 different members in September 2007, six of which are environmental non-governmental organizations (NGOs) and 27 of which are corporations, is a prime example. These businesses cover a broad spectrum of the economy, including several from the fossil-fuel industry and transportation sector as well as energy and electric power interests, including BP America Inc., Chrysler LLC, ConocoPhillips, Duke Energy, Ford Motor Company, General Electric, General Motors Corp., and Shell.

As Pacific Gas & Electric (PG&E) CEO Peter Darby explained in his congressional testimony in February 2007, these companies worry that a motley collection of different U.S. state regulations will emerge if no national direction is given, making their day-to-day operations much more complicated and expensive than they need to be. And they fear a United States that has abdicated its global leadership in this area risks handicapping their financial interests even further in the global marketplace. This is the driving rationale of USCAP and the reason its January 2007 publication, *A Call for Action*, calls for mandatory, market-driven cap and trade programs in carbon dioxide emissions. In short, USCAP outlines a proposal to first slow, then stop, and ultimately reverse emissions on the order of 60 to 80 percent below the current level by 2050.

CONCLUSION

Thus, on numerous levels, from both the governmental to the business sector, climate change policy in the United States has enjoyed a rebirth of late. The IPCC first noted a discernible human impact on climate change in 1995. In the 2005 aftermath of a devastating Hurricane Katrina and its utter destruction of the truly unique American city of New Orleans, Americans finally concurred. And according to NASA's chief climatologist Jim Hansen, this public opinion tipping point is about to encounter its scientific brethren. Hansen believes there are only 10 more years to act before it is too late, before the phenomenon of irreversibility enters the complex climate models. Others hope the time horizon to be a bit longer, but concur that we are talking about only a two degree C rise before the threat of irreversibility arises.

It is here that a third sector of democratic policymaking, that of civil society, becomes all the more relevant. Since the Frenchman Alexis de Tocqueville first visited the United States in the 1830s, democracy scholars have singled out the United States as a unique bastion of civil society. De Tocqueville's *De la démocratie en Amerique* (1835, 1840) found American individualism and its dominant moneymaking ethic supported the unusually high level of civic interactions outside official government structures. This is part of what handicapped the Bush and Clinton administrations in the 1990s and their efforts to face climate change policy seriously: Americans do not like to be told what they can and cannot do, especially when it limits earnings potential. But it is also what explains the burst of grassroots activity now underway regarding climate change. Americans see great financial loss if action is not taken soon.

Al Gore's 2007 Academy Award–winning film *An Inconvenient Truth* is but one piece in the puzzle galvanizing action. Environmental NGOs from the Sierra Club and Environmental Defense to the National Wildlife Federation and Natural Resources Defense Council to The Nature Conservancy and World Resources Center continue to beat their advocacy drums, and are now showing results. American public opinion surveys over the past decade show a decided maturation of understanding that climate change is real, is in large part human-induced, and, perhaps most notably, actually impacts their own lives in the United States.

SEE ALSO: Bush (George W.) Administration; California; Energy; Gore, Albert, Jr.; Hansen, James; Intergovernmental Panel on Climate Change (IPCC); Kyoto Protocol; Oil, Consumption of; Pew Center on Global Climate Change; Policy, International; Precautionary Principle; Public Awareness.

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Pollution, Air

THE ATMOSPHERE IS an important resource for the survival of all species on the planet, as a source of fresh air for breathing and as a protective layer against direct solar radiation. The Earth's atmosphere is composed of 78.084 percent nitrogen, 20.948 percent oxygen, 0.934 percent argon, 0.031 percent carbon dioxide, and 0.003 percent trace gases such as water vapor and air pollutants. The analysis of air bubbles trapped in ice cores provides evidence that the contents of so-called greenhouse gases, such as carbon dioxide, methane, nitrous oxide, ozone, sulfate, and carbonaceous aerosols, have significantly increased over the past 200 years. This historic change of the atmospheric composition is not fully understood, but it has roots in natural processes and human activity. As a result, both roles of the atmosphere are affected. First, the increase of greenhouse gases contributes to the increase in the amount of solar radiative energy trapped at the Earth's boundaries, which directly affects the planetary climate. Second, the composition of atmospheric air, particularly the air pollutants, strongly affects the human and environmental health.

The air pollutants are defined as substances that adversely affect humans, animals, plants and/or damage property. The air pollutant substances are gases, liquids, or solids, which are suspended in the atmosphere and emitted from different stationary or mobile sources. The pollution sources can be located in outdoor or indoor environments, and as a result the pollution levels are location dependent. Typical outdoor pollutants are particulate matter resulting from different combustion processes, including transportation. The gaseous pollutants include nitrogen oxides (NO_X), sulfur oxides (SO_X), and carbon monoxide (CO), also resulting from combustion processes. These primary pollutants can have chemical reactions in the atmosphere and create secondary air pollutants such as chemical substances forming smog. An example of naturally occurring pollutant is radon (Ra), a radioactive gas, which is released from the soil, and can be dangerous when trapped in poorly ventilated building basements. Indoor air quality is also becoming important because symptoms called sick building syndrome were correlated to the high levels of indoor air pollutants such as volatile organic compounds emitted from common building materials.

Many countries have established their regulations and standards for air pollution. The so-called first class standards define the maximum concentration levels of target pollutants, which are then attained through regulations passed by environmental protection agencies. The second-class standards provide the scales that define risk levels associated with outdoor activity, which are provided as advisory information to the public.

SEE ALSO: Coal; Diseases; Industrialization; Nuclear Power; Oil, Consumption of; Oil, Production of; Pollution, Land; Pollution, Water.

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Pollution, Land

LAND POLLUTION IS the degradation of the land surface through misuse of the soil by poor agricultural practices, mineral exploitation, industrial waste dumping, and indiscriminate disposal of urban wastes. It includes visible waste and litter, as well as pollution of the soil. The contamination of land usually results from its commercial and industrial uses or from the spillage and dumping of waste, including landfill. These activities leave behind levels of trace metals, hydrocarbons and other compounds on the land, which have the potential to cause harm to people or the environment. The main human contributors to pollution are landfills. About half of the waste is disposed of in landfills. The gradual decomposition of landfill wastes over several decades also generates new environmental problems in the form of air pollutants. Trace organic gases are emitted from landfills, along with significant amounts of methane and carbon (IV) oxide, both of which are greenhouse gases. Garbage and other forms of waste arising from homes, municipalities, industries, and agricultural practices are the major sources of pollution on the land environment. The indiscriminate discharge of these wastes into the environment creates a filthy environment.

Unlike contaminated air and water, which directly affect human health, pollution of the land from the dumping or burial of solid wastes affects people less directly. The primary environmental concern is that a waste material in the soil may migrate into surface water or groundwater where it can be ingested and harm living organisms. Soil pollution is mainly due to chemicals in pesticides. Soil erosion and degradation are some of the problems facing the state of the land. The causes are losing six hectares of land every year, and losing 24 billion tons of topsoil. Globally, a minimum of 15 million acres of prime agricultural land is lost to overuse and mismanagement every year. Desertification is threatening about one-third of the world's land surface.

TYPES OF WASTE

Litter is waste material dumped in public places such as streets, parks, picnic areas, bus stops, and near shops. The accumulation of waste threatens the health of people in residential areas. Waste decays, encourages household pests, and turns urban areas into unsightly, dirty, and unhealthy places to live in. The following measures can be used to control land pollution. Anti-litter campaigns can educate people against littering, organic waste can be dumped in places far from residential areas, and inorganic materials such as metals, glass, paper, and plastic can be reclaimed and recycled. One of the main factors influencing fast generation of municipal sewage and garbage and agricultural, commercial, and industrial wastes is population growth. The world human population has increased tremendously, and there has been phenomenal urban growth due to the migration of rural-area dwellers to urban areas. The larger the population, the larger the wastes generated and the greater the pollution. Pollution becomes even more pronounced when the population is crowded into a smaller space.

The sources of domestic wastes are garbage, rubbish, and ashes. Municipal wastes emanate from bulky wastes, street refuse, and dead animals. Municipal solid wastes are wastes collected by private or public authorities from domestic, commercial, and industrial sources. No two wastes are the same. The wastes generated within a municipality vary widely depending on the community and its level of commercial venture. The data on waste will depend on the level of sophistication of the waste management operation. Domestic waste from a house will vary from week to week and from season to season. Waste varies from socioeconomic groups and from country to country. In most cases, the number of refuse dumps decreases with increasing distance from the city center. Other factors that influence the distribution of solid waste dumps in cities are distance from main markets, positions of residential houses, commercial and industrial centers, and topographic characteristics of the city that determine accessibility by vehicles.

Commercial wastes are traceable to markets, stores, and shops, while industrial wastes are from factories, power plants, and treatment plants. Commercial, domestic, agricultural, and industrial activities generate vast amount of wastes, which include paper, food, metals, glass, wood, plastics, and dust. Effluents from domestic and industrial sources are also potential land pollutants. Many commercial houses and industries, especially in developing countries, do not have an organized method of disposing of their wastes. They are dumped indiscriminately, thus constituting a menace, and if they are toxic or in any way harmful, they become hazardous to the health of the public. Spillage of oil on land is a source of pollution. Land can also be polluted by the introduction of pesticides. Acid deposition also changes the integrity of the land. Contamination of land gives rise to impairment of the quality of groundwater, and impoverishment of soil to the

Land pollution occurs in many forms. Some of the sources of land pollution are agricultural, commercial, industrial, military, and from the general public. About half of the waste is disposed of in landfills.

extent of not supporting plant and animal life. Land pollution leads to the uptake of pollutants by plants, thereby introducing the pollutant to the food chain.

Garbage or trash is a component of municipal solid waste, which includes all of the wastes commonly generated in residences, commercial buildings, and institutional buildings. Municipal solid wastes consist of such things as paper, packaging, plastics, food wastes, glass, wood, and discarded appliances. Similar kinds of wastes generated by industrial facilities also are part of municipal solid wastes. The additional wastes generated by manufacturing processes, construction activities, mining and drilling operations, agriculture, and electric power production are referred to as industrial wastes. The environmental threats posed by municipal and industrial wastes are varied. Though defined as nonhazardous wastes, many of these wastes are capable of harming human health and the viability of other living species. They contain discarded hazardous wastes like batteries, paints, solvents, and waste motor oil, items that add trace metals and organic compounds to the inventory of potential contaminants in soil.

Environmental pollution by industrial wastes has become a threat to the continued existence of plants, animals, and humans. Industrial pollution contains traces of quantities of raw materials, intermediate products, final products, coproducts, and by-products, and of any ancillary or processing chemicals used. They include detergents, solvents, cyanide, trace metals, mineral and organic acids, nitrogenous substances, fats, salts, bleaching agents, dyes, pigments, phenolic compounds, tanning agents, sulfide, and ammonia. Many of these substances are toxic. Because of the larger volumes of waste materials, landfills are the preferred method of waste disposal. The pollutants arising from a particular industry are different from those arising from another industry. The waste generated differs from industry to industry. The level of pollution arising from the industry depends on the nature and magnitude of its wastes.

Pollution by trace metals occurs largely from industries, trade wastes, agricultural wastes, and automobile exhausts. These wastes are large in magnitude and varied in types. They include large quantities of raw materials, by-products, coproducts, and final products. Mining is a major area where metal pollution occurs. Apart from natural occurrence such as erosion, metal pollution on land is a direct result of anthropogenic activities. The dumping of old or damaged vehicles on land occurs especially in developing countries. Also, the dumping of obsolete or dangerous military wastes on sites is another source of pollution. Apart from trace metals, the wastes contain organic materials, biological and chemical warfare explosives, pesticides, solid objects, and other materials peculiar to military operations. Trace metals in soil also can enter the food chain via uptake by plants and vegetation that are subsequently consumed by animals and humans, with deleterious consequences. Land disposal sites serve as breeding grounds for disease-carrying organisms.

Pollution from agricultural practices is due to animal wastes, materials eroded from farmlands, plant nutrients, vegetation, inorganic salts, and minerals resulting from irrigation and pesticides that farmers use on their farms to increase agricultural yield and fight pests and weeds. Agricultural wastes are made up of unwanted parts of crops during harvesting season. Examples are maize sheaves and cobs, maize stalks of guinea corn, millet and rice and their chaffs, yam vines, cassava stems, and yam and cassava peelings. Studies have shown that groundwater can be contaminated through seepage by leachate arising from solid wastes dumped on the ground. Land application of wastes is the most economical, practical, and environmentally sustainable method for managing agriculture wastes, especially animal wastes. Application of agricultural wastes to the land recycles valuable nutrients and organic matter into the system from which they originated. Land application can also be an effective component of management strategies for other organic wastes like food processing wastes.

Radioactive wastes are peculiar and dangerous. Their harmful effects on living organisms are induced by radiation, rather than by chemical mechanisms. They also remain dangerous for several years. Radioactive wastes are products of usage of nuclear energy. An example is the mining of uranium ore and its processing into nuclear fuel, which is used for electric power production. Power plants may also be radioactive. The environmental impacts of nuclear waste vary with the nature and form of the waste material. The most dangerous of these include the spent fuel from nuclear reactors, as well as the radioactive liquids and solids produced from any reprocessing of spent fuel. This high-level waste is characterized by the intensity of its radioactivity and long half-life. Death from exposure to intense radiation can occur, depending on the intensity and duration of the exposure. Human exposure can occur through inhalation of radioactive substances and ingestion of food containing radioactive materials.

WAYS TO MINIMIZE WASTE

The best way to avoid the environmental problems of solid waste disposal is to desist from generating wastes in the first instance. Pollution prevention programs aimed at this objective have become widespread. Recycling and reuse of materials are ways to avoid waste generation. At the residential level, recycling programs for newspapers, glass, and metal containers have been implemented. However, some municipal programs have been criticized for increasing environmental emissions of air pollutants from the fuel combustion.

The ultimate land disposal methods used for municipal solid wastes are land filling, land farming, and deep well injection. Land filling of solid wastes involves the controlled disposal of solid wastes on or in the upper layer of the Earth's mantle, which has been excavated to a depth of about 13 ft. (4 m.). When solid wastes are placed in sanitary landfills, biological, chemical, and physical processes occur. Biological decay of organic materials occurs by either aerobic or anaerobic processes, resulting in the evolution of gases or liquids. The chemical oxidation of waste materials occurs, dissolving and leaching of organic and inorganic materials by water and leachate moving through the fill also occur.

Land filling in moist climates produces large quantities of leachate that are toxic and of high organic strength and require treatment in wastewater plants. Land filling in dry climates produces localized air pollution problems. There is also movement of dissolved material by concentration gradients and osmosis. Initially, the organic material in the landfill undergoes aerobic decomposition due to some oxygen amount obtained in air trapped in the landfill. Within a few days, the oxygen content is exhausted and long-term decomposition occurs under aerobic conditions. The anaerobic conversion of organic compounds occurs in the transformation of high molecular weight compounds catalyzed by enzymes in soil bacteria into compounds suitable for use as a source. However, landfill sites cause soil and groundwater contamination if not properly operated. Additional environmental problems with landfill are odors, litter, scavengers, and rat infestation.

Solid wastes are those wastes from human and animal activities. In the domestic environment, the solid wastes include paper, plastics, food wastes, and ash. Improper management of solid wastes has direct adverse effects on health. Solid wastes may contain human pathogens, animal pathogens, and soil pathogens. Inadequate storage of such wastes provides a breeding ground for vermin, flies, and cockroaches, which may act as passive vectors in disease transmission. The pathogens that can cause fecal-related diseases are viruses, bacteria, protozoa, and helminths. As proper waste management involves recycling, reuse, transformation, and disposal, it is relevant to know the physical, chemical, energy, and biological properties of wastes. The physical properties that are relevant include density, moisture content, particle size distribution, field capacity, hydraulic conductivity, and shear strength. Chemical analyses required are proximate analysis, ultimate analysis, and energy content analysis. The important elements in waste energy transformation are carbon, hydrogen, oxygen, nitrogen, and sulfur.

Only 2 percent of waste is actually recycled. Solid waste recycling implies recovery of a component of waste for use in a manner different from its initial function. Recycling consists of recovering from waste the matter of which a product was made and reintroducing it into the production cycle for reproduction of the same item. Composting after decomposition by aerobic bacteria mostly readily recycles garbage, grass, and organic matter. Composting may be defined as the decomposition of moist, solid, organic matter by the use of aerobic microorganisms under controlled conditions. The end product of the decomposition is a sanitary, nuisance-free, humus-like material that can be used as soil conditioner and as partial replacement for fertilizer. In a typical operation, the municipal wastes are presorted to remove noncombustible materials and those that might have salvage value such as paper, cardboard, rags, metals, and glass. Refuse is then shredded and stacked in long piles where it degrades to humus much as it would in soil. Usually, the decomposed material contains less than 1 percent of each of the three primary fertilizer nutrients. The final step is grinding and bagging for ultimate sale as soil conditioner.

Plants die because of land pollution. Crops are affected, as they do not mature and grow well. There are three ways that people pollute the land: littering all over the land, improper garbage disposal, and dumping of chemical fluids on the land. It is not uncommon to see people throw the trash on the road while in the car. Every day, people are polluting the land. Because of pollution, people do not only affect the cleanliness of the land, but also destroy the beauty and increase avenues of contracting diseases. These negative tendencies have effects on tourism potentials of nations as tourists are turned off. Tourists won't like to take risks in an unsafe environment because of pollution. Mosquitoes live in littered empty cans. Thus, the threat of mosquito bite is imminent in a polluted land. A greater proportion of land pollution is instigated and carried out by man. Governments of nations should be alive to their responsibilities of providing a safe and secured world environment to its people.

SEE ALSO: Diseases; Nuclear Power; Pollution, Air; Pollution, Water.

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Pollution, Water

WATER POLLUTION USUALLY describes the introduction or presence of harmful or objectionable substance in water in magnitude sufficient to alter the quality indices of natural water. It also connotes the presence of polluting substances in rivers, lakes, bays, seas, streams, underground water, or oceans in levels capable of resulting in measurable degradation of the water quality or usefulness. For example, if water contains too much contamination as a result of certain harmful chemical compounds or microorganisms, it could be rendered unsafe in its existing state for an intended purpose. This could be described as water pollution. In most cases, water pollution may arise from the use to which the water has been put. Although some kind of water pollution can occur through natural processes, it is mostly caused by human activities.

Water pollution has many sources and characteristics. These sources can be categorized into point and nonpoint sources. Point sources of water pollution are direct discharges to a single point, or simply stationary location discharges. Examples include discharges from sewage treatment plants, power plants, factories, ships, injection wells, and some manufacturing or industrial sources. Nonpoint sources of water pollution are more diffused across a broad area and their contamination is traceable to a single discharge point. Examples of nonpoint sources include mining activities and agricultural and urban runoffs. Water pollution arising from nonpoint sources accounts for the majority of contaminants in streams, rivers, bays, underground water, and seas.

A water pollutant is any biological, chemical, or physical substance if when present in water at excessive concentrations has the capability of altering the chemical, physical, biological, and radiological integrity of water, thereby reducing its usefulness to living organisms, including man. Although there are many sources of pollutants in our waters, the primary sources of water-polluting substances come from sewage, agricultural runoffs, oil spills, industrial wastewaters, land drainage, and domestic wastes. The major categories of common water pollutants include heavy metals, pathogens, nutrients, acids, organic chemicals, and radioactivity. Many of these substances are toxic and are capable of interacting additively or synergistically or antagonistically to give varying responses in aquatic ecosystems and in humans. However, the influence of a pollutant in natural waters varies according to the polluting substance, the local environmental conditions, and the organism involved.

MAJOR TYPES OF WATER POLLUTANTS

Heavy metals are toxic and include many metal pollutants that could have potentially harmful effects on human health and aquatic ecosystems. Common examples include cadmium, nickel, arsenic, lead, vanadium, mercury, and selenium. Typical sources of metal pollutants include wastes from domestic, industry, agriculture, urban, and mining drains. Acids are inorganic water pollutants caused by industrial discharges, especially sulfur dioxide from industrial power plants, drainage from mines, wastes from industry, and aerial acid deposition. Acids have the potential of causing harm to aquatic ecosystems via the mobilization of toxic heavy metal pollutants.

Organic chemicals such as insecticides, herbicides, petroleum hydrocarbons, detergents, and a range of volatile organic compounds such as solvents discharged into aquatic ecosystems have the potential of altering the integrity of natural waters. This variety of chemicals regarded as water pollutants arises from agricultural use of pesticides, especially insecticides and herbicides, industrial wastes, marine oil spillage, and domestic wastes. They are potentially harmful to human health and aquatic organisms. Nutrients arising from sewage and agricultural use of fertilizers may cause eutrophication in aquatic ecosystems.

Although nutrients are elements essential for the growth of living organisms, human-caused contaminations can greatly enhance the presence of nutrients (especially nitrogen and phosphorus compounds), leading to anthropogenic or cultural eutrophication. Continuous nutrient loading to aquatic systems could ultimately increase the phytoplankton population, resulting in algal bloom, by providing more food for the algae than is normally available. Nutrients may affect human health. Excessive algal population in water has the potential of unbalancing the food chain, discoloration of water, and reduction in the quantity of light radiation that is available to aquatic life. However, when the algae dies, the rotting algae could produce a strong, unpleasant smell and the remains could be toxic to aquatic fauna and flora. This process could also result in depletion of dissolved oxygen in water.

There are several sources of water pollutants, and these are domestic and industrial wastewaters, agricultural runoff water, and other nonpoint sources. Domestic wastes commonly carry organic matter, microbiological contaminants, and sometimes physical and chemical pollutants. Industrial wastes contain mostly chemical and radioactive pollutants, while agricultural run-off water may carry mainly nutrients, pesticides, and heavy metals. Moreover, water pollution can be broadly classified into different types and these include microbiological, chemical, physical, and thermal water pollution.

Biological hazards associated with water pollution include disease-causing (pathogenic) microorganisms, like parasites, bacteria, and viruses. People exposed to biologically contaminated waters can become sick from drinking, washing, or swimming. Disease-causing pathogens commonly associated with fecal contamination of water include *Shigella dysenteriae, Salmonella typhi, Salmonella paratyphi, Vibrio cholerae, Entamoeba histolytica* and poliomyelitis virus responsible for causing bacterial dysentery, typhoid fever, paratyphoid fever, cholera, amoebic dysentery, and infantile paralysis, respectively. Also, the consumption of microbe-contaminated seafood, especially shellfish, could lead to outbreaks of food poisoning.

CHEMICAL WATER POLLUTION

Chemical form of water pollution includes the presence of a wide range of chemicals from industry, such as lead, arsenic, nitrates, radioactive substances, metals and solvents, and even chemicals which are formed from the breakdown of natural wastes (ammonia, for instance). Effluents from chemical industries and oil pollution from accidental crude spillage are categorized under chemical form of water pollution. In aquatic systems, these chemicals are poisonous to fish and other aquatic life. Chemical pollutants can be generally categorized into persistent (degrade slowly) and nonpersistent (degradable) substances.

Nonpersistent pollutants include domestic wastes, fertilizers, and some classes of industrial wastes. These polluting substances can be broken down into simple nonpolluting molecules or compounds such as carbon dioxide, and nitrogen by chemical or biological processes. Persistent water pollution is the most rapidly growing type of pollution, and includes polluting substances that degrade or do not grade or cannot be broken down at all. These pollutants tend to remain in aquatic environments for a long period of time. Common persistent chemical pollutants include some pesticides (such as dieldrin, heptachlor, and DDT), petroleum products, polychlorinated biphenyls (PCBs), chlorophenols, dioxins, polycyclic aromatic hydrocarbons (PAHs), radionuclides, and heavy metals. Toxic metals discharged in effluent can be accumulated in seafood, especially fish and shellfish such as prawns, cockles, mussels, and oysters, to levels in excess of public health limiting levels, therefore posing serious health concerns to people who eat them.

Pesticides used in agriculture and around the home, especially those used for controlling insects (insecticides) and weeds (herbicides), are another type of toxic chemical. These chemicals are used to kill unwanted animals and plants, and may be collected by rainwater runoff and carried into streams, lakes, bays, rivers, and seas, especially if these substances are applied in excessive quantities. Some of these chemicals are biodegradable and may quickly decay into harmless or less harmful forms, while others are nonbiodegradable and can persist in the environment for a long time. When animals consume plants that have been treated with certain nonbiodegradable toxicants (NBTs), such as dichlorodiphenyltrichloroethane (DDT) and chlordane, these chemicals are absorbed into the tissues or organs of the animals and can accumulate over time. When other animals feed on these contaminated animals, the chemicals are passed up the food chain. Some of these can accumulate in fish and shellfish and poison people, animals, and birds that eat them. Materials like detergents and oils float and spoil the appearance of a water body, as well as being toxic; and many chemical pollutants have unpleasant odors.

PHYSICAL WATER POLLUTION

A common form of physical water pollution is thermal pollution. This includes warm water from cooling towers, floating debris, foam, and garbage. In highly industrialized areas of the world, power plants are used in generating electricity, where warmer water generated in the process is generally released back to the environment. In nuclear plants, water is used in large quantity to cool reactors. The discharge of high-temperature water into a natural body of water can affect the downstream habitats, therefore altering the ecological balance. It can lead to cultural eutrophication, thereby promoting algal bloom. This development has the potential of threatening certain fish species, as well as disturbing the chemistry of the receiving water body.

Heat may also affect man's legitimate use of water for fishing. Another common and widespread type of thermal pollution is the unsafe removal of vegetations that should naturally keep streams and small lakes cool. Natural vegetations, mainly trees and other tall plants, are usually seen around streams and sizable water bodies and they block direct sunlight from heating and thereby increasing the surface temperatures of these waters. People often remove this shading vegetation in order to harvest wood from the trees, to make room for crops, or to construct buildings, roads, and other structures. When these vegetations are removed and the aquatic ecosystems are left uncovered, the water temperature could increase by as much as 18 degrees F (10 degrees C).

Many wastes are biodegradable, that is, they can be broken down and used as food by microorganisms like bacteria. Biodegradable wastes may be preferable to nonbiodegradable ones, because they will be broken down and not remain in the environment for a very long time. However, too much biodegradable material can cause the serious problem of oxygen depletion in receiving waters. Like fish, aerobic bacteria that live in water use oxygen gas, which is dissolved in the water when they feed. Invariably, the oxygen is not very soluble in water. Even when the water is saturated with dissolved oxygen, it contains only about 1/25 the concentration that is present in air. So if there are too many nutrients in the water, the bacteria that are consuming it can easily use up all of the dissolved oxygen, leaving none for the fish, which will die of suffocation. Once the oxygen is depleted, other bacteria that do not need dissolved oxygen take over. But while aerobic microorganisms convert the nitrogen, sulfur, and carbon compounds that are present in the wastewater into odorless, oxygenated forms like nitrates, sulfates, and carbonates, these anaerobic microorganisms produce toxic and smelly ammonia, amines, and sulfides, and flammable methane.

Nutrients are major chemical pollutants and they include nitrates and phosphates found in sewage, fertilizers, and detergents. Although phosphorus and nitrogen are essential elements necessary for plant growth, in excess levels nutrients overstimulate the growth of aquatic plants and algae. When discharged into rivers, streams, lakes, and estuaries, they cause nuisance growth of aquatic weeds, as well as blooms of algae, which are microscopic plants. Excessive growth of these organisms can clog navigable waters, deplete dissolved oxygen as they decompose, and block light from penetrating deeper waters. Weeds can make a lake unsuitable for swimming and boating. Algae and weeds die and become biodegradable material. If the water is used as a drinking-water source, algae can clog filters and impart unpleasant tastes and odors to the finished water. It can also impair respiration by fish and aquatic invertebrates, which could lead to a decrease in animal and plant diversity.

Suspended solids originate from eroded stream banks, construction, and logging sites. They are a form of physical water pollution. These pollutants are also referred to as particulate matter because they contain particles of much larger size which remain suspended in the water column. Although they may be kept in suspension by turbulence, once in the receiving water, they will eventually settle out and form silt or mud at the bottom. As these sediments enter the rivers, lakes, and streams, they tend to decrease the depth of the body of water. If there is a lot of biodegradable organic material in the sediment, it will become anaerobic and contribute to the formation of algal bloom. Toxic materials can also accumulate in the sediment and affect the organisms that live there, and can build up in fish that feed on them, and so be passed up the food chain, causing problems along the food web. Also, some of the particulate matter may be coated with grease, which is lighter than water, and float to the top, creating an aesthetic nuisance.

CONCLUSION

The pollution of water resources can have serious and wide-ranging effects on the environment and human health. The immediate effects of water pollution can be seen in water bodies and the animal and plant life that inhabits them. Pollution poisons and deforms fish and other animals, unbalances ecosystems, and causes a reduction in biodiversity. Ultimately, these effects take their toll on human life. Drinking-water sources become contaminated, causing sickness and disease. Pollutants accumulate in food, making it dangerous or inedible. The presence of these toxic substances in food and water can also lead to reproductive problems and neurological disorders. The effects of water pollution are varied. They include poisonous drinking water, poisonous food animals (due to these organisms having accumulated toxins from the environment over their life spans), unbalanced river and lake ecosystems that can no longer support full biological diversity, deforestation from acid rain, and many other effects. These effects are, of course, specific to the various contaminants.

SEE ALSO: Industrialization; Pollution, Air; Pollution, Land.

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Population

CLIMATIC EVENTS HAVE had an important impact on the geographical distribution of human populations in the past. Nowadays, the growing consensus among the scientific community on the reality of human-induced global warming has raised concern that millions of people could be displaced.

A LONG HISTORY OF LINKAGE BETWEEN CLIMATE AND POPULATIONS

Population geography has acknowledged for many years the role played by climatic factors in explaining the history of population and the emergence of cities. Thus, for mankind, the passage across the Bering Strait to America 13,000 years ago was possible due to the low sea levels of the Ice Age, while the Medieval Climate Optimum which lasted between the 8th and 13th centuries stimulated the population of Polynesia by making navigation relatively easy, thanks to regular winds and clear skies. The desertification of the Sahara and the Arabian Peninsula also played an important part in the densification of the population on the banks of the Nile and consequently contributed to the birth of ancient Egyptian civilization.

More recently, the droughts of the 1930s in the plains of the American Dust Bowl (parts of Kansas, Oklahoma, Texas, New Mexico, and Colorado) forced thousands of migrants toward California, and those that struck the Sahel between 1969 and 1974 displaced millions of African farmers and nomads.

Notwithstanding the present media focus on global warming, the amount of systematic research on climate and populations remains limited. There is much vagueness surrounding the concepts employed, the underlying mechanisms involved, the number of persons affected, and the geographical zones concerned. Climatic factors are rarely the sole cause of migration, and the economic, social, and political situation of the zone under threat can, depending on the case, increase or decrease the flow of migrants.

The use by numerous authors of the term "climate refugee" has also led to confusion, because it evokes the juridical status recognized by the UN Convention of 1951 to political refugees. The High Commissioner for Refugees, aware of a risk of confusion between political and nonpolitical refugees, has always treated with the utmost prudence the idea of including environmental motivations in the international definition of refugees, even if this category of the population is deemed a part of the protective mandate toward displaced persons.

THE CONSEQUENCES OF GLOBAL WARMING

Alarming predictions of greater resource scarcity, desertification, risks of droughts and floods, and rising sea levels that could drive many millions of people to migrate appeared in the review on the economic consequences of global warming delivered to the British government by Sir Nicholas Stern at the end of November 2006. While it is extremely difficult to elaborate scientific predictions by combining climate and migration models, the expected consequences of climate change can be compared to past experiences so as to establish a list of the populations most at risk and the possible resulting emigration flows. Three consequences of climate warming forecast in the latest report of the Intergovernmental Panel on Climate Change (IPCC) for the end of the 21st century appear to be the most threatening potential causes of migrations:

1. The increase in strength of tropical hurricanes and in the frequency of heavy rains and flooding due

to the augmentation of evaporation correlative to temperature increase.
2. The growth in the number of droughts, with evaporation contributing to a decrease in soil humidity, often associated with food shortages.
3. The increase in sea levels resulting from both water expansion and melting ice.

While the first two consequences are the direct result of sudden natural disasters, the third is a long-term process, which has very different possible implications in terms of migrations.

HURRICANES, TORRENTIAL RAINS, AND FLOODS

The consequences of hurricanes and floods on population displacement are among the easiest to identify in that they manifest themselves in a brutal and direct manner. While the number of persons affected by flooding worldwide (106 million yearly between 2000 and 2005 according to the International Disaster Database) and by hurricanes (38 million) is known, the total number of people threatened by an eventual increase of this kind of disaster is, however, very difficult to estimate. No climate model is able to predict with accuracy whether or not the affected zones will be densely populated and whether the damage wrought will have tragic consequences.

Apart from this difficulty of forecasting, the studies carried out after such events tend to relativize their effects in terms of migration in general, and long-term migration in particular. Living mainly in poor countries, the victims have little mobility, and the majority of the displaced return as soon as possible to reconstruct their homes in the disaster zone. The results from numerous researches conducted worldwide on the subject tend to confirm this point with remarkable regularity. On a global level, the general conclusion therefore is that the potential of hurricanes and torrential rains to provoke long-term and long-distance migrations remains limited.

DROUGHT AND DESERTIFICATION

The latest report of the Intergovernmental Panel on Climate Change predicts increased water shortages in Africa (74 to 250 million people affected in 2020) and Asia. Case studies, however, bring to light a contrasting picture of the consequences for migrations of these kinds of evolutions. The effect of a lack of drinking and irrigation water on migration is actually less sudden than that of hurricanes and floods, and it only generates progressive departures. On one hand, there are many well-known cases of mass population departures following droughts, in particular in Africa (Sahel, Ethiopia) with an impressive figure of one million displaced persons during the drought in Niger in 1985, but also in South America (Argentina, Brazil), in the Middle East (Syria, Iran), in central Asia, and in southern Asia.

On the other hand, many researchers strongly relativize the possible direct link existing between drought and emigration by highlighting the fact that the latter, in general, is the last resort when all other survival strategies have been exhausted. For example, during the 1994 drought in Bangladesh, only 0.4 percent of households had to resort to emigration. Other researchers hold views similar to that of Nobel Prize winner for Economics, Amartya Sen, in remarking that famines are, in general, only marginally the direct result of environmental factors, but much rather political ones and add that this also holds for migrations. In certain contexts, the effect can even be inversed. This was the case in Mali during the drought of the mid-1980s: a reduction in international emigration was observed due to the lack of available means to finance the journey. Forecasts of increased migrations linked to drought-related phenomena remain hazardous. Consequently, it would be difficult to put a figure on the magnitude of populations at risk and the eventual migrations arising from global warming–induced droughts.

RISING SEA LEVELS

While the first two climatic hazards mentioned do not foreshadow massive population displacements due to climate change, the potential for migration when linked to an increase in sea level is considerable. Contrary to hurricanes, rain, and drought, this phenomenon is virtually irreversible and manifests itself over a long period of time. This could make migration the only possible option for the population affected. The localization of the consequences of rising sea levels is a relatively easy task because the configuration of coastlines, their altitude, and population are well known and thus easy to map. Hence, it is possible to calculate, on a global scale, the number of persons living in low-elevation coastal zones and threatened by either rising water levels, higher tides, or farther-reaching waves. Low-elevation coastal zones are defined as situated at an altitude of less than 33 ft. (10 m.). Even though these zones account for only 2.2 percent of dry land, they are presently home for 10.5 percent of the world's population, some 600 million people, of whom more than two-thirds live in Asia, and nearly a half in the poorest countries of the world.

It would be an exaggeration, however, to consider that these hundreds of millions of people are all potential migrants in a near future. The latest report of the IPCC evokes, of course, the possible melting of Greenland ice cover and the consequent 23 ft. (7 m.) rise in sea level, but this would occur over several thousand years. Of more concern is the scenario of thermic expansion of the oceans. According to a future CO_2 emission estimate based on continuing economic growth, but with a moderation of fossil fuel use, there would be an increase of 1 to 2.6 ft. (0.3 to 0.8 m.) of the oceans by 2300. On this basis, it seems reasonable to consider populations living at an altitude of less than one meter as being directly vulnerable by the next century. A study commissioned within the framework of the Stern Report gives a considerable figure of 146 million people for this group. Mainly situated in the major rivers' deltas and estuaries, the flood zones are particularly populated in south Asia (Indus and Ganges-Brahmaputra) and east Asia (Mekong, Yangtze, Pearl River). These two regions account for 75 percent of the population at risk. Certain Pacific states such as Tuvalu or Kiribati are, in the shortterm, among the most threatened, as they are situated only centimeters above water. Although far less populated, they nevertheless have inhabitants numbering several thousand persons.

The increase in sea levels is the greatest direct threat for numerous populations. Contrary to hurricanes and droughts, the localization of potential victims is ascertainable. If no measure of moderation is taken and if no effort is made to protect the groups at risk, then they will have no alternative but to emigrate.

CONCLUSION

Climate changes can generate migration flows. Global warming could, in particular, lead to major forced displacements. The latter will result principally from rising sea levels, but will only progressively manifest themselves over the forthcoming centuries, with the exception of the flooding of certain islands. The increase in droughts and meteorological disasters predicted by climatic models will also have impacts in terms of migrations, but these will remain regional and shortterm, and are at present difficult to estimate.

Existing research shows that due to the number of factors involved, no climatic hazards inevitably result in migrations. Many authors note that even if disasters become more frequent in the future, political efforts and measures of protection will be able to lessen the need to emigrate, provided that the necessary financial means are made available. Even rising sea levels could be partially counteracted by the erection of dikes or the filling in of threatened zones. The question of what kind of international system of burden-sharing and protection to put in place to face these challenges remains unanswered, and is all the more important because of the clear responsibility of rich countries for global warming. Bangladesh, for example, contributes only 0.14 percent of global CO_2 emission, but counts hundreds of thousands of people at risk of increased flooding.

SEE ALSO: Alliance of Small Island States (AOIS); Bangladesh; Climate Change, Effects; Desertification; Developing Countries; Drought; Economics, Impact from Climate Change; Floods; Impacts of Global Warming; Refugees, Environmental.

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Portugal

AS REPORTED IN a major collaborative international research project, named SIAM II, Portugal is one of the European countries that are expected to suffer from the most extreme consequences of global warming and climatic change. These consequences are expected to entail three major geological effects in Portugal. First, due to the rise in sea levels, studies predict an increase in the erosion of Portugal's coastal areas. Second, scientists anticipate increased levels of rain precipitation and the concomitant occurrence of floods that will carry high social and economic costs. Finally, in dry areas of the country, studies point to a higher probability for the incidence of forest fires. Studies show that the tendency for increasingly hotter summers in Portugal has accelerated in the past few decades. Research and analysis based on data collected from 1931 to 2000 in Portugal demonstrates that the six hottest summers occurred in the last 12 years.

The Portuguese population is slowly becoming aware of the relationship between global warming and climate change within the borders of their nation, and this awareness is becoming stronger. One of the reasons for increased knowledge concerning the impact of global warming on Portugal has been the occurrence of major forest fires, as well as fluvial floods. In this context, the mass media and government officials have played a crucial role in sensitizing and educating the Portuguese population about the risks associated with global warming. Another reason is the fact that an increasingly large percentage of the Portuguese population is university educated and, in this context too, they are exposed to recent and important national as well as international research concerning the issue.

Due to Portugal's relatively late entry into the European Union in 1986, and its previous situation of economic isolation and considerable underdevelopment in terms of European standards, Portugal is still highly dependent on importing energy derived from nonrenewable sources. According to the Statistical Office of the European Union (Eurostat), Portugal is 99.4 percent dependent on such imported energy. Because of the economic weight that this carries, it is oftentimes difficult for enterprises to develop or invest in alternative and more ecological forms of energy supply. For this reason, it is feared that Portugal may face difficulties in reaching Kyoto established goals.

SEE ALSO: Deforestation; Energy; Floods.

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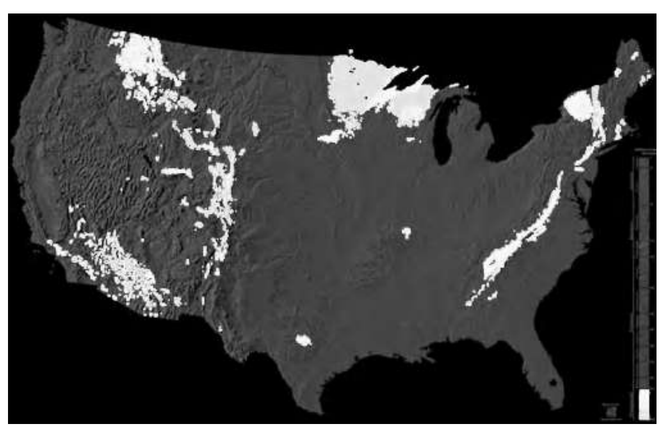
Precambrian Era

THE PRECAMBRIAN ERA, or Supereon, refers to the geological time comprising the eons that came before the Phanerozoic eon. This time spans from the formation of Earth around 4.5 billion years ago to the evolution of abundant macroscopic hard-shelled animals, which marked the beginning of the Cambrian era, the first period of the first era of the Phanerozoic eon. The Precambrian era encompasses 86 percent of the Earth's history, however very little is known about this time period. In fact, the few fossil discoveries from this period were recently made in the late 20th century. Precambrian time can be further divided into three large eons, the Hadean, Archean, and Proterozoic eons.

The Precambrian's oldest eon, the Hadean (4.5 to 3.9 billion years ago), predates most of the geologic record. During the Hadean, the solar system formed out of gas and dust, the sun began to emit light and heat, and Earth took shape. Meteors and other galactic debris showered the planet over the first half-billion years, making it entirely uninhabitable. Planet Earth was very hot during its initial formation. As the earth began to cool and its mass increased, its gravitational field strengthened. This attracted meteorites and other debris, which continued to bombard the planet for at least another 500 million years, producing enough energy and heat to vaporize any water or melt any rock that may be present. Iron continued to sink to form the Earth's core, while silicon, magnesium, and aluminum gradually rose toward the surface. Gases released from magma



Highlighted in light areas are Precambrian rocks. They formed between 560 million years and 2.6 billion years ago.

inside the Earth escaped through cracks in the surface and began to collect in the early atmosphere. The likely presence of methane and ammonia among the gases made for conditions that would be highly toxic to life as we know it. Because there was little to no free oxygen, no protective ozone layers existed and damaging ultraviolet rays showered the Earth at full strength. As the meteorite bombardment finally slowed, Earth was able to cool, and its surface harden as a crust, rocks and continental plates began to form. Water began to condense in the atmosphere, resulting in torrential rainfall. After several hundred million years of falling rain, great oceans were formed. By about 3,900 billion years ago, Earth's environment had been transformed from a highly unstable state into a more hospitable place. This marked the beginning of the Archean eon (3.9 to 2.5 billion years ago). It was early in the Archaean eon that life first appeared on Earth.

The climate of the late Precambrian time, the Proterozoic eon (2.5 billion years ago to 543 million years ago) was typically cold with glaciations spreading over much of the earth. One of the most important events of the Proterozoic was the gathering of oxygen in the Earth's atmosphere. Though oxygen was undoubtedly released by photosynthesis well back in Archean times, it could not build up to any significant degree until chemical sinks unoxidized sulfur and iron had been filled. The first advanced single-celled and multicellular life roughly coincides with the oxygen accumulation. It was also during this period that the first symbiotic relationships between mitochondria and chloroplasts and their hosts evolved. At this time the continents were bunched up in to a single supercontinent known as Rodinia. It broke up starting around 750 million years ago, and as continental fragments reached the North and South poles they likely contributed to the great Ice Ages. In the latest Proterozoic era a new supercontinent called Pannotia came together. A number of glacial periods have been identified going as far back as the Huronian epoch, roughly 2,200 million years ago. The best studied is the Sturtian-Varangian glaciation, around 600 million years ago, which may have brought glacial conditions all the way to the equator, resulting in a "Snowball Earth". This theory states that the continents and oceans were covered in ice approximately 600 million years ago. The Earth may have remained in this frozen form, but it was rescued by the release of volcanic gases. While the Earth was in a deep freeze, chemical cycles were halted; as a result, carbon dioxide accumulated in the atmosphere causing an extreme greenhouse effect. After 10 million years of deep freeze, the Earth thawed in only a few hundred years. These dramatic events may have caused the explosion of lifeforms seen in Cambrian fossils.

At this point, at the start of the Cambrian period, Earth had taken on its current form in the life-filled oceans and oxygenated atmosphere. Coevolution of biosphere and lithosphere over billions of years led to this point. Anaerobes and oxygen-breathers had evolved complementary chemical cycles, and biogenic carbonates entered the plate-tectonic cycle of the crust and upper mantle with new efficiency.

SEE ALSO: Climate Change, Effects; Climate Cycles; Snowball Earth.

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Precautionary Principle

THE UPSHOT OF precaution is that it is better to be safe than sorry when there are severe or irreversible consequences. It has been a very important notion in environmental and public health policy. It has been advocated in several issues ranging from climate change to genetic engineering to phase-out of persistent organic pollutants. The invocation of precaution has been particularly controversial when there are significant business interests at stake. The problem with simply asserting precaution whenever a technology, policy, or action involves possible negative outcomes is that it often poses significant challenges in evaluating the public versus private trade-offs involved.

This use of precaution is often invoked when outcomes are uncertain. The notion of uncertainty is used to characterize how well future events or scientific truths can be predicted or known. It is used in both social and natural science disciplines, from mathematics to philosophy, to risk assessment and public policy. If probability is a measure of likelihood, then uncertainty is a measure of how well the probability is known. Uncertainty can be classified into known and unknown probabilities. Events with known probabilities are referred to as events with statistical uncertainties. Events with unknown probabilities are often called events with true uncertainty.

Uncertainty in the context of the environment mainly refers to scientific uncertainty. Here, science generates truths through the testing of hypotheses. But often, the affirmation of hypotheses involves a certain degree of uncertainty due to the method or research design. Scientists often use the benchmark of 95 percent certainty when deciding whether or not cause and effect have been correctly identified. Scientists often report confidence limits based on research design and sampling error in their studies to account for uncertainty.

The precautionary principle is often invoked under uncertain circumstances, particularly when the consequences are irreversible or permanent. This differs from the choice that scientists make when deciding what to do under conditions of uncertainty. Typically, scientists are interested in avoiding false negatives, because science is epistemologically conservative. Scientists do not want to suggest something as truth when in fact it may not be. In public or environmental policy, however, because the consequences are not epistemological but are ethical, there is desire to avoid false positives and be ethically conservative.

In public and environmental policy, it is important to understand how to make decisions in the absence of perfect information. Knowing the degree of uncertainty is particularly important when questions about risk arise. Risk assessment is a policy approach that deals with uncertainty. Risk assessment is widely used by the Environmental Protection Agency (EPA), but mainly focuses on known probabilities. Because of difficulties with codifying the precautionary principle into policy, the EPA has yet to include true uncertainty in environmental policy.

CLASSES OF SCIENTIFIC UNCERTAINTY

Scientist Schrader-Frechette describes four classes of scientific uncertainty dealt with by scientists and policymakers: framing uncertainty, modeling uncertainty, statistical uncertainty, and decision-theoretic uncertainty. In framing uncertainty, scientists often use a two-value frame to accept or reject a hypothesis. Frechette argues that in public policy, it is more appropriate to adopt a three-value frame that creates a category to deal with situations where significant uncertainty and serious consequences suggest adopting the precautionary principle. Modeling uncertainties involve those involved in the prediction of future scenarios. These are highly speculative, despite claims to be verified and validated models.

In public and environmental policy, statistical uncertainty should be dealt with in such a way that highlights the difference between epistemological consequences and ethical ones. When faced with decision-theoretic uncertainty, scientists are forced to distinguish between using expected value rules and the minimax rule. The former argues that decisions should be based on the expected value, while the latter seeks to prevent the worst-case scenario. More recently, Bayesian statistics has been used to help evaluate data under conditions of uncertainty by updating the probabilities as new data come to view. A Bayesian approach involves the introduction of prior knowledge into statistical models.

There are many environmental policy debates where questions about uncertainty are raised. In debates about global climate change, for example, scientists typically agree that there is significant uncertainty in the projection of future climate change models. Climate change skeptics, to discredit climate change science, often highlight uncertainty. In debates about genetic engineering, uncertainty about the prediction of how transgenic organisms will behave in the environment, or uncertainty about how markets will react to the adoption of transgenic organisms, is cited as a reason to invoke the precautionary principle. In debates about nuclear waste disposal at Yucca Mountain, uncertainty about how the storage facility will perform in the long term is cited as reason to question the suitability of nuclear waste repository.

SEE ALSO: Climatic Data, Nature of the Data; Environmental Protection Agency; Measurement and Assessment.

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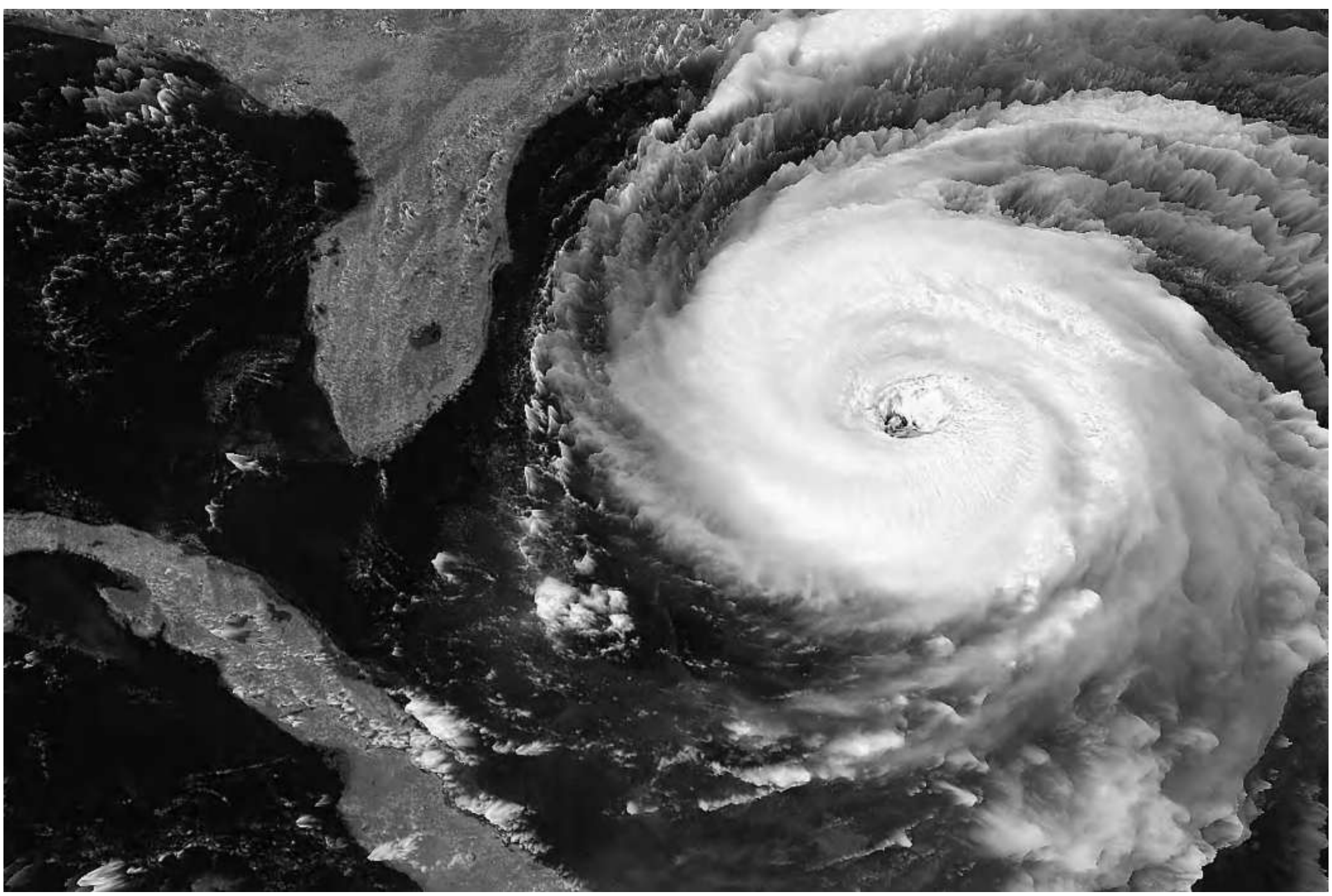
Precipitation

PRECIPITATION IS THE primary factor that controls the hydrologic cycle. It takes different forms, such as rain, snow, hail, sleet, drizzle, dew, and fog. It supplies most of the fresh water on the Earth. Most precipitation starts from space as snow, as the upper space is cooler. If the temperature of the surface closer to the ground is below 32 degrees F (0 degrees C), then the precipitation falls on the ground in the form of snow. If the ground and closer surface temperature is above 32 degrees F (0 degrees C), the precipitation takes the form of rain. When the air at the ground is below freezing, the raindrops can freeze while heating the ground, and that is known as freezing rain. When a dust particle in the atmosphere attracts a moisture drop, hail is formed. Drizzle consists of very small raindrops, 1/1000 of a normal raindrop size. Sleet is a type of precipitation between rain and snow, but very distinct from hail. Dew is another form of precipitation that can be seen in the early morning on colder days. Water vapor in the atmosphere condenses on the surface of exposed objects at a greater rate than that at which it can evaporate, developing dew. Fog as such is not precipitation, but is considered one because of its low-altitude occurrence. This consists of a cloud in contact with the ground, and produces water droplets when intercepted with vegetation or other exposed objects. If the precipitation evaporates before reaching the ground, it is then known as virga.



The 1996 Hurricane Fran, shown in a weather sattelite image, caused about $5 billion in damages in North Carolina alone. Greater precipitation, including hurricanes, typhoons, ocean depressions, and floods, are being experienced globally.

HOW PRECIPITATION OCCURS

Dynamic and adiabatic cooling causes precipitation. Due to this process, condensation of water vapor occurs and then falls to the Earth as rainfall, snowfall, or as other forms of precipitation. Vertical air motion is the leading factor of all rainfall from clouds after condensation. Rising air in the tropics and midlatitudes (40 to 60 degrees N and S latitudes) causes more precipitation and descending air patterns in the subtropics (20 to 30 degrees N and S latitudes) and in the poles causes less. Precipitation is classified into different categories based on the conditions that generate vertical air motion: convective, orographic, and cyclonic.

Convective precipitation is mostly seen in the tropics. Heating up of the air at groundlevel, then moving upward and mixing with the water vapor in the atmosphere, with dynamic cooling in space, causes precipitation to fall on Earth. This is called convective precipitation. Orographic precipitation occurs due to the interception of moisture-laden air or clouds by mountain ranges. Cyclonic precipitation is caused by movement of moist air masses from high-pressure regions to low-pressure regions. In the hydrologic cycle, the total volume of precipitation onto land is measured at 42,471 sq. mi. (110,000 sq. km.), while the total volume of precipitation on the ocean surface is 176,834 sq. mi. (458,000 sq. km).

Precipitation has greater ecological, geographical, and regional impact due to its characteristics, such as relative amount, seasonal timing, and most importantly the size and intensity. Low-intensity and well-distributed seasonal precipitation is good for agriculture. High-intensity, long-duration precipitation creates more problems than good. Precipitation is governed primarily by atmospheric water vapor, but its variation depends upon other climatic factors such as temperature, wind, and atmospheric pressure at different locations and season. The amount of water vapor is very high in the atmosphere closer to water bodies. Therefore, coastal areas always have heavier precipitation (high-intensity, long-duration) than inland areas. Thunderstorms, hurricanes, typhoons, cyclones, blizzards, and hailstorms are high-intensity precipitations with damaging ability.

It is essential to understand the precipitation distribution process and its temporal and spatial variation for water resources planning and management for the betterment of the society. Precipitation distribution mechanisms include interception by vegetation, filling in depression storage, infiltration to soil and ground water, surface detention, and overland or surface flow or runoff. Low-intensity, short-duration storms are good for land and vegetation because most of the water either stays in depression storage or infiltrates to soil and groundwater for groundwater recharge. But high-intensity, long-duration storms are detrimental because most of the precipitation (rainfall) is wasted as runoff. The excessive runoff erodes soil, creates floods, landslides, and other damaging effects. Blizzards are examples of such high-intensity, long-duration precipitation. A heavy amount of snowfall accompanied by high wind creates problems. Many high-intensity, long-duration storms are currently being encountered, believed to be due to global warming.

EFFECTS OF GLOBAL WARMING ON PRECIPITATION

Global warming is the effect of increasing atmospheric concentrations of greenhouse gases. The near surface of the Earth has warmed by nearly 1 degree F (0.6 degrees C) during the 20th century. It may continue in this century, warming the globe further, so that a warmer ocean surface would result. There would be increased evaporation rate and subsequent increase in the other components of the hydrologic cycle, like water vapor in the atmosphere and consequent higher precipitation amounts. Computer simulation models found that a global warming by 7.2 degrees F (4 degrees C) is expected to increase global precipitation by about 10 percent and that rainfall intensity will increase. Scientists using models found that the upper tropospheric water vapor amount will increase by 15 percent with each degree of atmospheric temperature rise. The global water vapor amount will increase by 7 percent with each degree of atmospheric temperature rise.

Another major downside of global warming is less snowfall throughout the world. As the surface temperature is rising, raindrops, in many parts of the Earth, cannot take the shape of snow before reaching the ground. Snow is better for the land than rain because it helps in water conservation. Rainfall becomes runoff to oceans and is a waste if not conserved artificially through dams, earthen embankments, and soil and water conservation structures, whereas snow remains on the ground and melts slowly to release water for agriculture and other consumption. Slow melting of snow also facilitates more accumulation of soil moisture and ground water recharging. Agriculture in the northern United States and southern Canada depends upon soil moisture conserved by snowpack on the agricultural land. With less snowfall, due to increase in surface temperature, there may be less snow deposition on agricultural land, and agriculture would suffer.

The irony of global warming is the occurence of more rain resulting in less water. Due to warmer temperatures in the spring, snowpacks in the mountains are melting unseasonably and at a rapid rate. Many perennial rivers in the world are experiencing shortages of flowing water in summer months and groundwater recharging has lessened. The water from a quick snowmelt cannot be arrested in reservoirs due to lack of space. Therefore, the systems failing to hold the entire season of runoff would face challenges to meet the water demand for agriculture and other purposes. Increased quick melting of snowpacks (due to a rise in surface temperature) in the northwestern United States and India causes spring and summer floods.

It is estimated that there could be a 15 to 30 percent reduction of water available for human consumption from California's Sierra Nevada mountains. Agriculture in the Canadian prairies could be the worst affected, due to spring water runoff. Sufficient water may not be available for subsequent crop seasons. Many rivers in the world will experience water shortages in dry seasons because during dry months, most of the perennial rivers get water from snow and glacier melting. Glacial retreats are clearly visible in the Poles, Greenland, and Antarctica. This occurs due to an insufficient supply of water to glaciers from precipitation as compared to the loss of water from melting and sublimation.

Global warming would cause more precipitation on the Earth, but would create more detrimental effects to agriculture, ecology, and, above all, society. The wetter areas of Earth would become wetter, and the drier areas may become even drier.

SEE ALSO: Climate Change, Effects; Global Warming; Rain; Rainfall Patterns; Weather.

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Preparedness

PREPAREDNESS FOR GLOBAL warming and climate change requires multilevel planning, at the international, national, local, and individual levels to deal with the direct effects of climate changes in temperature, precipitation, wind, storm patterns, sealevel, as well as the indirect strain on world resources leading to migration, famine, and conflicts.

While mitigation strategies like reducing greenhouse gas emissions are a start, they do not take precedence over readiness to respond to natural disaster emergencies associated with the impact of climate change (intense storms, flooding, wildfires, public health, or the necessity to deal with future environmental pressures, the decreasing longevity of infrastructure with roads, bridges, waterworks, buildings, and facilities requiring earlier replacement, repair or modifications to remain safe for use. Adaptive measures in the form of physiological, social, and cultural measures will allow people to live throughout the world.

ASSESSMENT OF IMPACT

In order to prepare for climate change, assessments must be completed and available for decision-making processes. On the international level, the International

Governmental Panel on Climate Change encourages collaboration among scientists, allied professionals, and policymakers, providing a forum for the collection of research material and posing questions to spur planning. The take-away message is evaluation to determine global policy toward a common goal while addressing implications and increasing cooperation between governments.

On the national and local levels, any assessment of the extent of impact climate changes (higher temperatures, rising sea levels, changing weather patterns will have on human health, ecosystem diversity and productivity, agricultural production, water supply, sanitation, infrastructure) must factor in the associated costs and benefits in developing sustainability plans, preparation for emergency situations, and adaptive measures.

Each area is different, with varying susceptibilities, policies, institutions, and social/cultural structures. National and local assessments to be most effective must evaluate the capacity to handle emergency measures associated with natural disasters and identifying susceptible areas of the environment and resources including agriculture, fisheries, forestry, fauna, human health, water supply and sanitation, infrastructure and construction, land use in hazard-prone areas (flood plain, islands), and disaster management.

Challenges to assessment for impact include factors not related to climate change that will impact the areas being considered at risk because of climate change include the dynamics of society and economy (demographic trends, agricultural management, improving and new technologies, cultural preferences, opportunities for employment, availability, and changes in transportation). Complex dynamics in human relationships with the environment, self-reliance, growing population, and increased urbanization may produce very different impacts between urban and rural areas.

IMPACTS TO CONSIDER

When making assessments, a variety of elements need to be considered that cross boundaries of social structures and practices as well as environmental conditions. Severe weather destruction has highlighted areas that lack preparedness. The current global situation for preparedness is still lacking. Severe weather causes great devastation. Even in a highly developed country, as seen in the aftermath of the 2005 Hurricane Katrina hitting New Orleans and other areas on the U.S. Gulf Coast, problems were experienced with infrastructure, the failure of levees to hold back storm surge water, and mobilizing emergency supplies.

Planning for impacts from rising global temperatures must take into account a wide range of factors including the impact on human health, comfort, lifestyle, food production, economic activity, and residential and migration patterns including tourism.

Housing or shelter must be sufficient to meet the needs of an emergency situation or for migration from an area no longer suitable for living or to meet expectations for increased tourism to climates that so far have not been inundated by travelers. In addition, supportive measures must be able to supply water, sanitation, communication, energy, transport, and industry; and social and cultural services including health services, education, police protection, recreational services, parks, and museums for areas with an increased population.

With rising temperatures, weather patterns could alter in frequency and seasonality of precipitation, weather-related events could increase, including droughts, floods, severe tropical storms with associated storm surge flooding and wildfires from increased temperatures and drought conditions. With a rise in evaporation and precipitation rates, water availability and quality could be affected, with lower groundwater levels, decreased surface area and water levels of many lakes or inland waterways, as well as altering natural habitats. Potential impacts range from loss of property, effects on housing and street/road conditions, effects on construction materials, stress on sewage systems and potential overflow from excess storm water and drainage failures.

Rising sea levels could displace residents of delta regions (Nile, Ganges, Yangtze, Mississippi) from homes and livelihoods. Island nations could become uninhabitable. Coastal erosion on gradually sloping coasts by encroaching water could affect densely populated cities (New York, London) and important seaports.

Cooler climates may see an increase in agriculture and warmer climates may see a decrease in agriculture. Feeding the world's population means an inherent dependence on agricultural production, which is highly sensitive to climate change. Land degradation may produce either abandonment of the land or require changes in cultivation practices to improve yields and restoration of soil. Possible changes in fertileness of the land could increase or decrease food production capability for the agricultural country and as an export to other world regions.

Health impacts include temperature stress from either extreme heat or cold, especially among high-risk groups (children, the elderly, and those with already compromised health); air pollution exposure with increased incidence of respiratory disease; chemical pollution; water quality or water shortages from precipitation changes, flooding, or in some areas already a lack of safe water; and vector-borne diseases; lack of physical or economic access to health services or insufficient capacity of health services. In the event of disaster refugees or migration, sanitary facilities and housing could become quickly overburdened, enhancing the spread of communicable diseases.

Climate change could modify supplies and consumption patterns. These impacts would vary by region based on cost of various types of food and fiber. Changing availability of resources might lead to changed diets, production patterns, and employment levels. Major impact could be felt by the energy, transport, and industrial sectors, with increasing need balanced against dwindling supply.

Impact on physical and social environment would also vary by region and could include loss of housing (from wildfires, flooding, mud slides); loss of living resources (water, energy supplies, food, or employment); loss of social and cultural resources (cultural properties, neighborhood or community networks); decline in living standards (conditions caused by mandatory evacuation, contamination of water supply); total loss of livelihood following land degradation (erosion of top-soil, over-cultivation or deforestation); or a major natural disaster like flooding or drought. In some areas, physical and social environments could improve. Communication technologies (cell phones, computers, and fax machines) could have a positive impact including increased potential for decentralization of the population by enabling many professional and technical people to perform work in homes far removed from major metropolitan areas.

POSSIBLE SOLUTIONS

The Hyogo Framework for Action signed in January 2005 by 168 countries details steps to reduce the impact of natural hazards on populations. The result has been 40 countries adjusting national policies to give priority to disaster risk reduction.

Examples of disaster planning paying off in action include Jamaica in 2004. A community disaster response team issued early warning by megaphone, and used risk maps and equipment assembled by the Red Cross for successful evacuation of all area residents. Hurricane awareness is taught in schools in Cuba along with practice drills. The Citizens' Disaster Response Center in the Philippines helps to create disaster management plans and provides emergency response. These examples indicate effectiveness and indicate the need for global, regional, national, and local early warning systems to alert populations of impending disasters.

While the previous examples are for disasters, the same ideas can be used to implement climate change preparedness, of which natural disasters are one element. One caveat for planning is the necessity to include feedback loops to allow for changes as new information becomes available or conditions are modified.

The challenge is the predictive factor (strategies planning far into the future, 10 years, 25 years, 50 years, or 100 years) in the presence of current needs of access to clean water management, production of energy allowing for cost-effectiveness and to allow developing countries to utilize cheap fossil fuels available to them, and supplying enough food for populations with limited agriculture due to already stressed conditions. To meet food supply needs far into the future, research to develop new varieties of wheat, corn, and soybeans for resistance to drought and heat and still produce good yields and strategies for future irrigation sources should begin now, building new wells and reservoirs instead of waiting until water shortages persist. Centralized stockpiles of grain could provide for increases in food needs or to supply areas with crop devastation.

With changing weather patterns, coastal areas should prepare for and be able to demonstrate effective evacuation procedures to deal with rising sea levels and more severe hurricanes, as well as to assess the risks of new construction in low-lying areas. Global, regional, national, and local early warning systems to alert populations of impending disasters should be developed, implemented, and tested.

Water supplies, both in rural areas and in municipal water infrastructure, should be set up for equitable availability and pricing. Some areas have no access to fresh water and must use desalinization systems to make clean water from seawater.

Environmental policy should strengthen institutional and legislative environmental framework at national and regional levels, including environmental authorities, and incorporating new laws, as well as implementing environmental control standards for air quality, including reduced emissions of greenhouse gases, reducing ground level ozone and particulates from stationary and transport sources, and more tightly enforcing pollution and land use regulations.

Emphasis should be placed on nature and biodiversity such as management of protected areas and a national biodiversity strategy and provide for better management of all natural resources, including forests, fishing, soils, water, air, wildlife. Altered habitats will cause animal migration. Barriers standing in their way could be removed by setting up migration corridors to connect natural areas and allow them to migrate safely. In the event these measures aren't enough, wildlife managers may have to capture and move certain species.

Reducing health impacts from climate change can be acted upon early by preventing the onset of disease from environmental disturbances, in an otherwise unaffected population (such as supply bed nets to all members of a population at risk of exposure to encroaching malaria, taking precautions against mosquito bites to prevent West Nile virus, early weather watch warning systems). Surveillance systems could be improved in sensitive geographic areas with the potential for epidemics under certain climatic conditions, including those bordering areas of current distribution of vector-borne diseases (plague from prairie dogs, hanta virus from rats, malaria from mosquitoes). Vaccination programs could be intensified and pesticides used for vector control. Drugs for prophylaxis and treatment could be stockpiled.

In certain areas of the world, irrespective of climate change, breakdowns in public health measures have been responsible for many recent outbreaks of disease. In those areas, climate change would add to the health burden; current and future health problems related to the environment share similar causes of economic factors and access issues. All areas must have sufficient trained staff to handle healthcare issues, as well as technology for diagnosing and treatment and medications or medical interventions required.

Construction practices and advancing technology make possible new building techniques, including floating houses to weather storm surge and flooding in hazard areas. Current building material (including roads) may not be able to withstand future climate change conditions and will require replacement or restoration. Public reconstruction to ensure safe bridges and other infrastructure is necessary. In some areas, drainage improvements will need to be made for water and sewage.

Adaptation refers to actions taken to lessen the impacts of the anticipated changes in climate. The ultimate goal of adaptation interventions is the reduction, with the least cost, of disruptions in living standards, of suffering from diseases, injuries, or disabilities, and of destruction of habitats, ecosystems, and species (both plant and animal).

AWARENESS RAISING

To make any plan for preparedness work, the information collected in assessments must reach all relevant stakeholders in the process of building and reaching a consensus on adaptation strategy. Providing environmental information to the public is essential to any preparedness method; if people don't know what to do in the event of an emergency or steps to take to prevent or adapt to changing conditions, the plan will fail. Awareness campaigns directed at the general public and to those persons who are directly affected should be made available through all forms of media and should be easily understood.

On the individual level, certain precautions can be taken to prepare for natural disasters, and some associated climate change, including extreme heat or winter weather, flooding, hurricanes, landslides and mudslides, tornadoes, tsunamis, and wildfires. Taking preparedness actions helps people deal with disasters in an effective manner. Having emergency supplies of water, food, and first aid prepared and easily available allows an individual or families to either evacuate quickly or shelter in place as appropriate. Having a plan of action for where to go, how to reconnect with family members, and dealing with finances lessens the stress involved with disasters.

SEE ALSO: Intergovernmental Panel on Climate Change (IPCC); Public Awareness; World Health Organization.

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Princeton University

PRINCETON UNIVERSITY IS a private coeducational research university located in Princeton, New Jersey. It is one of eight colleges and universities that belong to the Ivy League.

Originally founded at Elizabeth, New Jersey, in 1746 as the College of New Jersey, it relocated to Princeton in 1756 and was renamed "Princeton University" in 1896. Princeton was the fourth institution of higher education in the United States to conduct classes. Princeton has never had any official religious affiliation, rare among American universities of its age. At one time, it had close ties to the Presbyterian Church, but today it is nonsectarian and makes no religious demands on its students. The university has ties with the Institute for Advanced Study, Princeton Theological Seminary, and the Westminster Choir College of Rider University.

Princeton has traditionally focused on undergraduate education and academic research, though in recent decades it has increased its focus on graduate education and offers a large number of professional master's degrees and Ph.D. programs in a range of subjects. The Princeton University Library holds over six million books. Among many others, areas of research include anthropology, geophysics, entomology, and robotics, while the Forestall Campus has special facilities for the study of plasma physics and meteorology.

The Atmospheric and Oceanic Sciences Program is a unique collaboration between a renowned academic institution, Princeton University, and a world-class climate research laboratory, the Geophysical Fluid Dynamics Laboratory (GFDL) of the National Oceanic and Atmospheric Administration. The program hosts graduate students, postdoctoral researchers, and visiting senior researchers, as well as permanent research staff and faculty. The highly flexible graduate program offers students opportunities for research and courses in a wide variety of disciplines related to climate, including the physics and dynamics of the atmosphere and ocean, atmosphere and ocean chemistry and biological processes, global climate change, and paleoclimate. Through the in Science, Technology, and Environmental Policy (STEP) program at the Woodrow Wilson School of Public and International Affairs students can explore climate- [and air pollution] related policy. Students benefit from an unusually low student-to-faculty ratio and access to GFDL's supercomputing resources.

The Program in Atmospheric and Oceanic Sciences (AOS) offers graduate study under the sponsorship of the Department of Geosciences. An understanding of the complex behavior of the atmosphere and oceans requires a balanced effort in theoretical analysis, numerical modeling, laboratory experiments, and analysis of observations. The AOS program benefits from the research capabilities of the Geophysical Fluid Dynamics Laboratory (GFDL) of the National Oceanic and Atmospheric Administration, which is located on the Forrestal Campus. GFDL has a major in-house supercomputer facility to which students have direct access for their research. Many GFDL scientists are active in the AOS program as lecturers with the rank of assistant through full professor. The geosciences department, with its activities in physical and chemical oceanography, paleoceanography, and paleoclimatology, collaborates with GFDL in providing an academic program of courses and seminars.

The program is internationally recognized for its development of models of atmospheric and oceanic circulation and climate, particularly studies related to global warming. Additionally, it is world renowned for its development of earth system models, specifically as related to the global carbon cycle, and for its training of graduate students and postdocs. The student to postdoc to faculty ratio is typically about 1:1:1, which provides graduate students and postdocs with a highly stimulating environment for learning and carrying out their research.

Courses offered by the department which focus on climate change include:

Introduction to Physical Oceanography: Study of the oceans as a major influence on the atmosphere and the world environment. The theoretical and observational bases of our understanding of ocean circulation and the oceans' properties.

Introduction to Atmospheric Science: Atmospheric composition and thermodynamics including effects of water. Simple radiative transfer, elementary circulation models, phenomenological description of atmospheric motions, structure of the troposphere, stratosphere, mesosphere, and thermosphere, chemistry of ozone, and comparison with atmospheres on other planets.

Atmospheric Radiative Transfer: The structure and composition of terrestrial atmospheres. The fundamental aspects of electromagnetic radiation, absorption and emission by atmospheric gases, optical extinction by particles, the roles of atmospheric species in the Earth's radiative energy balance, the perturbation of climate due to natural and anthropogenic causes, and satellite observations of climate systems are also studied.

Atmospheric Chemistry: Natural gas phase and heterogeneous chemistry in the troposphere and stratosphere, with a focus on elementary chemical kinetics; photolysis processes; oxygen, hydrogen, and nitrogen chemistry; transport of atmospheric trace species; tropospheric hydrocarbon chemistry and stratospheric halogen chemistry; stratospheric ozone destruction; local and regional air pollution; and chemistry-climate interactions are studied.

Atmospheric Thermodynamics and Convection: The thermodynamics of water-air systems. The course gives an overview of atmospheric energy sources and sinks. Planetary boundary layers, closure theories for atmospheric turbulence, cumulus convection, interactions between cumulus convection and large-scale atmospheric flows, cloud-convection-radiation interactions and their role in the climate system, and parameterization of boundary layers and convection in atmospheric general circulation models are also studied.

Introduction to Geophysical Fluid Dynamics: Physical principles fundamental to the theoretical, observational, and experimental study of the atmosphere and oceans; the equations of motion for rotating fluids; hydrostatic and Boussinesq approximations; circulation theorem; and conservation of potential vorticity; scale analysis, geostrophic wind, thermal wind, quasigeostrophic system; and geophysical boundary layers.

Atmospheric and Oceanic Wave Dynamics: Observational evidence of atmospheric and oceanic waves; laboratory simulation; surface and internal gravity waves; dispersion characteristics; kinetic energy spectrum; critical layer; forced resonance; and instabilities.

Physical Oceanography: Response of the ocean to transient and steady winds and buoyancy forcing. A hierarchy of models from simple analytical to realistic numerical models is used to study the role of the waves, convection, instabilities, and other physical processes in the circulation of the oceans.

Numerical Prediction of the Atmosphere and Ocean: Barotropic and multilevel dynamic models; coordinate systems and boundary conditions; finite difference equations and their energetics; spectral methods; water vapor and its condensation processes; orography, cumulus convection, subgrid-scale transfer, and boundary layer processes; meteorological and oceanographic data assimilation; dynamic initialization; verification and predictability; and probabilistic forecasts.

Current Topics in Dynamic Meteorology: An introduction to topics of current interest in the dynamics of large-scale atmospheric flow. Possible topics include wave-mean flow interaction and nonacceleration theorems, critical levels, quasigeostrophic instabilities, topographically and thermally forced stationary waves, theories for stratospheric sudden warmings and the quasi-biennial oscillation of the equatorial stratosphere, and quasi-geostrophic turbulence.

Weather and Climate Dynamics: An examination of various components of the Earth's climate system. Dynamics and physical interpretation of principal tropospheric circulation systems, including stationary and transient phenomena observed in middle and low latitudes. Reviews of phenomena of topical interest, such as El Niño, seasonal climate anomalies, and natural and anthropogenic climate changes.

SEE ALSO: Climate Change, Effects; Global Warming; Oceanography.

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Public Awareness

PUBLIC AWARENESS IN the United States of the issue of global warming increased from about one-third in the early 1980s to near 100 percent 25 years later. By 2007, climate change was featured in the media almost daily. Awareness does not necessarily imply acceptance; although polls indicate that over half of Americans consider climate change to be real, there remains widespread public uncertainty about the degree to which human activities are involved, and to what extent CO_2 emissions need to be curtailed. There also remain widespread misconceptions about the meaning of global warming, and likely effects.

Public acceptance of human-induced climate change as a real phenomenon has lagged well behind the scientific consensus. In the mid-1970s, the popular media widely reported that the Earth was cooling and may be entering the next glacial interval, accelerated by light reflected off atmospheric particulates from pollution. The reports were based on the ideas of several scientists espoused primarily outside peer-reviewed literature. By the late 1970s, scientific consensus emerged from early generation global climate models that the warming influence of greenhouse gases was stronger than the cooling influence of particulates and insolation change. Scientific evidence that the climate was warming first received major coverage in a 1981 front-page article in the *New York Times*. Considerable advances in scientific understanding of current and past climate change occurred in the 1980s; this received enhanced public recognition with the 1988 congressional testimony by climatologists that coincided with a record hot summer.

As calls for government controls to reduce greenhouse gases increased, climate change discussions and media coverage of it grew politicized. In the 1990s, media, in efforts to offer "balanced" reporting, covered a small number of climate change skeptics in roughly equal proportion to the scientific consensus that climate is warming, which had grown to close to 100 percent in peer-reviewed scientific literature. The public was thereby given the impression that a considerable scientific controversy still existed. Debate about U.S. participation in the international Kyoto Accord in late 1997 and again in 2001 further increased politicization of the issue.

Several events in the mid-2000s swung U.S. public opinion from simple awareness of the issue to greater acceptance that global warming was happening. During this time, skeptics also changed stances, from whether climate change was happening to whether humans were causing observed changes. The severe hurricane season of 2005 (in particular, Hurricanes Katrina and Rita) centered U.S. public attention on potential domestic human and financial costs of climate change. Al Gore's 2006 documentary, *An Inconvenient Truth*, one of the most watched documentaries of all time, stimulated a groundswell of activity to further increase awareness, though to some degree maintaining the politicization of the issue. Several very warm years globally during the 2000s also helped give climate change greater reality to a broader geographic segment of U.S. citizens accustomed to hearing about warming in other areas of the world.

FACTORS THAT MAKE PUBLIC UNDERSTANDING OF CLIMATE CHANGE DIFFICULT

Scale: It is difficult for most people to grasp: scales of space the size of the Earth and its atmosphere; scales of time that include analyzing data from thousands of years in the past and up to decades or centuries into the future; and scales of human influence that involve billions of people, each contributing some quantity of CO_2 to the atmosphere.

Complexity: Climate is a complex system that is difficult for any one person, even specialists, to understand in total; in global warming, some places cool, which is why climate change is now the preferred term; spatial and temporal variability in weather systems means that even places that are warming on average may be occasionally unusually cold; in some places climate change is manifested more by precipitation change than temperature change.

Models and uncertainty: Computer models of climate are complex sets of mathematical equations that are "black boxes" for most of the public, and even many scientists; it can be confusing that different results occur for different researchers' models, as is evaluating the probability of events decades in the future, contingent on human actions in the meantime.

Personal reality: In many places climate change may not be readily evident from casual neighborhood observations; changes at the poles may seem personally irrelevant; warming may sound attractive in cooler climates.

Personal beliefs: Spiritual or philosophical beliefs may indicate that the Earth does not change, that humans need not concern themselves with personal influence on the Earth, or that near-term spiritual events on Earth will render changes to the Earth meaningless.

EDUCATION

Many efforts have developed in recent years to go beyond increasing public awareness, to educate the public on the nature of climate change and what can be done about it. The former is especially the purview of science education and the latter of personal and governmental action. Few K-12 school curricula have climate change as a major topic, though building block concepts such as greenhouse warming may be found in Earth and environmental courses at the high school level. Professional development for teachers at the state and national level may be needed in large numbers in the coming decades. Nonformal educational groups such as Scouts and 4-H are alternative settings for introducing climate education to youth. Major research partnerships such as Global Learning and Observations to Benefit the Environment (GLOBE) provide opportunities to collect data for scientific research that is relevant to climate change. Many colleges and universities are developing campus sustainability models and associated student action groups and courses.

Some organizations of informal education, such as museums and science centers, are in a good position to present public climate change education to a wide range of age groups. The International Polar Year (2007–09) provided an opportunity to present outreach associated with research on polar processes, including polar warming. Many grassroots groups have started in towns and cities across the United States to provide information on climate change to local citizens, particularly on how to take action to reduce CO_2 emissions. Among the most influential means of informal education remain radio and television documentaries on the topic.

SEE ALSO: *An Inconvenient Truth*; Education; Gore, Albert, Jr.; Media, Internet; Media, TV; United States.

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Qatar

LOCATED IN THE Persian Gulf, the State of Qatar has a land area of 4,416 sq. mi. (11,437 sq. km.), with a population of 841,000 (2006 est.), and a population density of 192 people per sq. mi. (74 people per sq. km.). With massive prosperity from the petroleum industry and from the production of natural gas, some 90 percent of Qatar's population lives in urban areas. Only one percent of the country is arable, with a further five percent used for meadows and pasture, with the country having no forests or woodland.

Qatar has the highest rate of carbon dioxide emissions per capita, and one of the highest in the world as far back as 1950. In 1990, it was measured at 22.5 metric tons per person, rising dramatically to 37.4 metric tons per person, dramatically increasing to 55.3 metric tons in 1992. It rose steadily, reaching 69.2 percent in 2004, considerably more than the second highest per capita emitter, Kuwait, which reached a peak of 38 metric tons in 2004. This high level comes from the use of natural gas for electricity generation, all electricity coming from the use of fossil fuels. Electricity usage remains high, with heavy use of air conditioning, and also the running of a large desalination plant.

Gaseous fuels account for 80 percent of all carbon dioxide emissions, with liquid fuels making up a further 19 percent. The generation of electricity contributes 28 percent of all carbon dioxide emissions, with other energy industries making up 32 percent, and manufacturing and construction another 32 percent. In spite of its small size, transportation accounts for 8 percent of the emissions, a result of a wealthy economy that has a large private ownership of automobiles, and gasoline is cheap.

The Qatar government took part in the UN Framework Convention on Climate Change signed in Rio de Janeiro in May 1992. They accepted the Kyoto Protocol to the UN Framework Convention on Climate Change on January 11, 2005, with it entering into force on April 11, 2005.

SEE ALSO: Automobiles; Oil, Consumption of; Oil, Production of.

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Quaternary Era

THE QUATERNARY PERIOD, the most recent geologic interval, represents the last 1.8 million years of time. Its most striking feature is that the Earth had cold polar regions, which led to periodic development of continental glaciers. The prolonged Ice Ages, comprising the main part of the Quaternary interval, ended 10,000 years ago, when the continental glaciers had melted. Compared to the many cold periods (glacial intervals) of the Quaternary, the last 10,000 years of the present interglacial has been comparatively warm.

The changes in climate over the past 150 years have shown a varied history. The world endured a historic cool period during the late 1800s (the Little Ice Age), followed by a warm period of the 1930s (the Dust Bowl years), and since about 2000, the climate has been more variable, reaching extremes in warmth at high latitudes. Reports from Vikings show that 1,000 years ago the climate of Greenland and Iceland was warmer than today (the Medieval warming). While these historic shifts in temperature are relatively moderate, much larger changes in temperature on Earth have occurred in the geologic past.

PROXY DATA

Using the changing oxygen isotope ratios from ice cores and marine sediment cores, scientists have discovered global changes, recorded synchronously over a wide range of latitudes. One long climate proxy record was taken in the Antarctic, the Vostok core. From it, the inferred temperature over a long interval is based on the temperature-sensitive ratio of oxygen isotopes, ^{18}O to ^{16}O. In the Vostok core, isotopes of oxygen have been used to develop Earth temperature histories extending over 400,000 years. Trapped gas bubbles record the history of atmospheric CO_2 concentrations for over this period (data from the National Climatic Data Center, Asheville, North Carolina). Because the isotope ^{18}O is heavier than ^{16}O, the proportions of each vary depending on the climate region. In alpine areas such as in the Alps of Switzerland and in the polar regions, ^{18}O is more abundant, while in the lowlands of the middle and low latitudes ^{16}O prevails in the atmosphere. By calibrating these, scientists can use the proportions of oxygen isotopes taken from ancient sediments or ice cores as an index of average annual temperature.

The changing proportions of isotopes can be matched and dated with a geomagnetic signal of polar reversals (the Earth's poles changed in magnetic signals), a known time scale based on isotopically dated magnetic signals that are worldwide. Another source of long climate records are the deep-sea sediment cores from which oxygen isotopes can be extracted from calcareous plankton (foraminifera). These data carry the paleoclimatic records back through more than 60 million years through the Tertiary period and the time of the last dinosaurs.

The Ice Ages, which comprised the main part the last million years, was a globally cold period with increasingly variable swings of climate. The glacial pattern continued over long intervals, with only a few comparatively short warm or interglacial periods. The last major glaciation came in two parts; in the United States, these are called the early Wisconsin (80,000–28,000 years before present, oxygen isotope stage 4) and the Full Glacial or late Wisconsin (23,000–15,000 years ago, oxygen isotope stage 2); between these a somewhat warmer middle Wisconsin period occurred 28,000–23,000 years ago. The maximum of the last major glaciation occurred about 18,000–15,000 years ago (called the Full Glacial). After 15,000 years ago, a global warming began, and continental ice sheets melted by about 10,000 years ago. The period after 10,000 years ago, or postglacial, is called the Holocene or Recent period representing the present interglacial.

The period of the last glaciation (Full Glacial) brought continental ice down to the middle latitudes in both hemispheres. In Europe, ice from the Scandinavian highlands spread southward over the Netherlands and mountain glaciers covered the Alps. Ice stood over parts of northern Siberia, Greenland, and parts of Alaska. Permafrost ice developed underground in Siberia, northern Canada, and Alaska as much as 300 ft. (91 m.) thick. Equivalent ice expansions occurred in the Southern Hemisphere.

As temperatures warmed between 15,000 and 9,000 years ago, the average annual temperatures at mid-latitudes increased by about degrees 11 F (6 degrees C). At Lamont National Observatory, scientists estimated that the difference in solar insolation between the Full Glacial and the mid postglacial was about 8 percent.

An overall trend within the Quaternary is apparent. In the first half, the amount of variance from year to year was fairly low, while in the last half of

A glacier in New Zealand. The prolonged Ice Ages, comprising the main part of the Quaternary interval, ended 10,000 years ago. The continental glaciers melted during a comparatively warm cold period, but some have remained.

the Quaternary, variance became more and more extreme. Looking back over records of the past million years, geologists estimate that there were at least 40 cold or glacial intervals, and these were of varying length and were not regular in occurrence. In the last 400,000 years of the Ice Ages, proxy data indicate that there were four extreme cool periods (glacials) interspersed with five variable warm periods (interglacials). The last major interglacial (spanning the interval of about 80,000–122,000 years before present) was similar in warmth to the present interglacial climate, but the previous interglacials were definitely cooler that the present one.

CAUSES

The main climatic changes of the Quaternary are linked to the orbital position of Earth in relation to the sun. Astronomer Milutin Milankovitch proposed the orbital theory that is established by a variety of evidence, starting with tree ring variation. The precession of the equinox, the obliquity of the Earth's orbit around the sun, and the eccentricity of the Earth's orbit all contribute to the level of insolation received by Earth and are therefore the cause of geologic shifts in climate.

Before the Quaternary was the warm so-called Tertiary period that brought tropical conditions to the mid-latitudes, and extensive temperate forests grew in the Northern Hemisphere. The north and south polar areas were at least 36 degrees F (20 degrees C) warmer than today, perhaps around 41 degrees F (5 degrees C) average annual temperature. Orbital causes for this part of Earth's history have not been specified, but undoubtedly were important factors.

IMPACTS

Global changes in climate forced major changes in plant and animal distributions, especially in the high and mid-latitudes. During the Full Glacial, remains of trees that now grow in the northern boreal forest were found in Tennessee where their fossils were associated with deciduous hardwoods and even cypress-swamp types, creating strange mixtures of genera. Plants and animals that had dispersed to lower latitudes and in areas of southerly environments during glacials dispersed northward again during the postglacial warming. Thus, the Quaternary period records some of the more extreme climate changes known in Earth's history.

SEE ALSO: Ice Ages; Little Ice Age; Milankovitch, Milutin; Orbital Parameters, Eccentricity; Orbital Parameters, Obliquity; Orbital Parameters, Precession.

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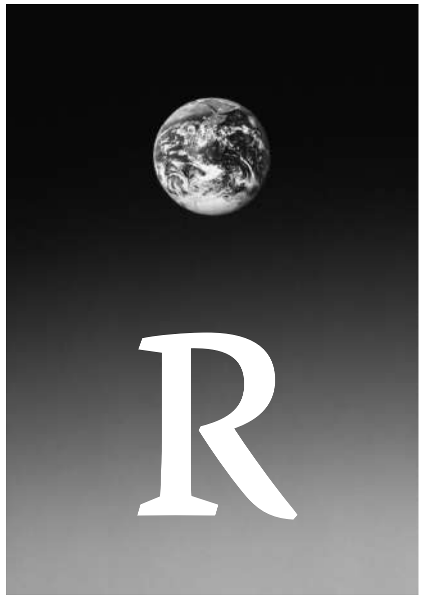


Radiation, Absorption

RADIATION IS ENERGY transmitted by electromagnetic waves. Electromagnetic waves travel at the speed of light (when passing through a vacuum) and have a characteristic wavelength, λ, which is inversely proportional to their frequency, ν, by

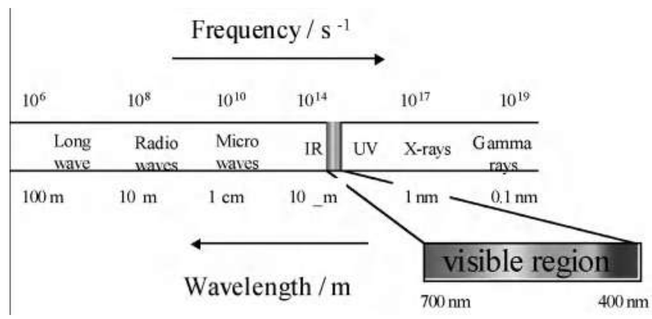
λ (m) = c (m s-1) / ν (s-1),

where c is the speed of light. Electromagnetic radiation is conceptualized in contemporary theory both as a wave and as a stream of particles called photons (this dual approach is referred to as wave-particle duality). The energy of any photon, E, of radiation is inversely proportional to the wavelength by

$E = h\nu$,

where h is Planck's constant. This relationship allows us to order electromagnetic waves from high energy/short wavelength (for example, x-rays), to low energy/long wavelength (for example, radio waves). The resulting progression is referred to as the electromagnetic spectrum (Figure 1). The visible region of the electromagnetic spectrum is bound by infrared (IR) radiation on the lower energy side of the visible region (around

Figure 1: The electromagnetic spectrum



1 µm to 1 mm in wavelength), and by UV radiation (UV) on the higher energy side (from 400 nm to 1 nm). Microwave radiation is slightly lower in energy than IR, with a wavelength of around 1 cm.

All objects both emit and absorb radiation. Although all objects emit radiation at all wavelengths, the frequency of maximum emission, λmax, is proportional to the temperature of the object by Wien's law

$\lambda max = \alpha / T$,

where α is a constant equal to 2897 µm K. This implies that hotter objects emit higher energy radiation, as would be expected from everyday experiences. From Wien's law, the surface temperature of the sun can be calculated based on its emission peak at ~0.5 μm (green light) to be around 5800 K. The average temperature of the Earth's surface is around 18 degrees C (290 K) which corresponds to a peak emission at around 10 μm, in the infrared to microwave region.

There are three basic modes of motion: translational (movement through space), rotational, and vibrational. These are important, because along with electronic energy, they are the ways in which gas molecules can store energy. Quantum theory dictates that energy levels are discrete, not continuous; this implies that molecules will only absorb discrete frequencies of radiation that correspond to the gap between a high and lower energy state. UV radiation corresponds to the gap in energy between electronic energy levels in a molecule. When a molecule absorbs UV radiation, it may be promoted to an electronically excited state. In the general, this will make the bonds holding the atoms together weaker and may help facilitate reactions or the breakup of molecules. For example, the reactions that complete the Chapman mechanism in the stratosphere:

(i) O2 + hν -> O + O (λ < 240 nm)
(ii) O+O2 + M -> O3 + M
(iii) O3 + hν -> O2 + O* (λ < 320 nm)
(iv) O* + M -> O + M

The Chapman mechanism is chemically a null cycle, but it is important in the context of life, as it prevents most of the high-energy radiation from below 320 nm reaching the Earth's surface. IR and microwave radiation, being lower in energy than UV, correspond to the gaps between rotational and vibrational energy levels, respectively. Quantum theory dictates that molecules interact with IR/microwave radiation only when two conditions (selection rules) are met:

1. The energy of the radiation corresponds to the energy gap between two of the discrete energy levels in the molecule and,
2. The resulting motion results in a change in the dipole moment (electron distribution) of the molecule.

This implies that atmospheric components that are symmetrical molecules, such as N_2 and O_2 that have an even electron distribution and cannot be rotated, bent, or stretched in such as way as to create one, do not absorb microwave and IR radiation. Molecules possessing a dipole, which can be altered by bending and stretching, absorb radiation. Atmospheric components that fill this requirement include CO_2, CH_4, H_2O and CFC's, for example, the asymmetric stretch of CO_2. These gases are collectively known as greenhouse gases. Radiation from the sun is received at the Earth's surface, mainly in the UV and visible region, with other frequencies cut out by the atmosphere and electromagnetic field.

SEE ALSO: Chemistry; Radiation, Infrared; Radiation, Long Wave; Radiation, Short Wave; Radiation, Ultraviolet.

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Radiation, Infrared

INFRARED RADIATION IS the part of the electromagnetic spectrum popularly (but not entirely accurately) conceptualized as heat. The IR region covers wavelengths that span nearly three orders of magnitude; it is conventional therefore to break this down into further subgroups (Table 1).

Table 1: Conventional breakdown of IR radiation

Name	Wavelength	Comments
Near-infrared (NIR)	0.75 – 1.4 μm	Absorbed by water and commonly used in fiber-optic technology.
Short Wavelength Infrared (SWIR)	1.4 – 3 μm	Strongly absorbed by water and used in long-range telecommunications.
Mid wavelength Infrared (MWIR)	3-8 μm	Used in heat-seeking missile technology.
Long Wave Infrared / Far IR (LWIR)	8-1000 μm	Not absorbed by water, therefore used for thermal-image sensors.

The main application of IR radiation in relation to climate change is in the fields of meteorology and climatology. Satellite measurements of IR radiation received from the Earth can be used to derive cloud types and heights; these are used for weather forecasting, but knowledge of the number and type of clouds present is useful in calculating the Earth's radiative budget. It is possible to use the IR radiation returned to space from the earth to measure land and sea surface temperature, both of which are important parameters in calculating the Earth's heat budget and in monitoring global climate change. Satellite measurements of IR are also used to determine cloud height and rates of convection.

IR radiation also finds a variety of industrial, military, other scientific, and domestic applications, for example:

1. Night vision—Night vision devices use a photon muliplier to amplify the signal from the available ambient light which is then augmented with the IR radiation.
2. Thermal imaging—non-contact, non-destructive technique that generates a false-color thermal image of a subject finding a wide range of industries.
3. Heating—IR lamps can be used for heating; examples include for frozen aircraft wings and for patio heaters.
4. Spectroscopy—IR spectroscopy (also called rotational spectroscopy) is a technique used by chemists for the identification of molecules and for elution of chemical structure.

SEE ALSO: Radiation, Absorption; Radiation, Microwave.

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Radiation, Long Wave

LONG WAVE (OR longwave) radiation is the part of the electromagnetic spectrum emitted at spectral wavelengths generally greater than one micrometer (μm). Types of long wave radiation include infrared, microwave, and radio waves. Emittance of radiation is a function of temperature, and objects giving off long wave radiation are colder than those radiating at short wavelengths. For example, the sun (approximately 5800 K) radiates primarily in the short wave part of the spectrum (especially visible light from 0.4 to 0.7 micrometers), whereas the Earth (approximately 290 K) emits radiation at much larger wavelengths. Climatologically, long wave radiation generally refers to radiation emitted by the Earth-atmosphere system (also called terrestrial radiation), largely at wavelengths of 5–15 μm. Long wave radiation emitted by the Earth's surface and atmosphere falls primarily within the thermal infrared ("below the red") region of the electromagnetic spectrum. It can be sensed through the sensation of heat.

In the Earth-atmosphere system, short wave radiation from the sun is absorbed and converted to long wave radiation. Various components of the Earth-atmosphere system absorb the incoming short wave radiation; among those are the Earth's surface, gas and dust molecules in the atmosphere, and clouds. Long wave radiation is then reradiated from those components, after which it is referred to as outgoing long wave radiation or counterradiation. Counterradiation may be reabsorbed (and reradiated) by those very same components that initially absorbed short wave radiation. This process is behind the greenhouse effect.

Globally, the Earth's atmosphere is relatively transparent to radiation between 8 and 15 μm. This atmospheric window allows much long wave radiation to be lost to space. However, the window may be closed locally by the presence of large amounts of water vapor or clouds. Additionally, increasing amounts of greenhouse gases can also potentially close this window. Thus, the role of long wave radiation in the greenhouse effect is fundamental. In the absence of an atmosphere containing long wave–absorbing greenhouse gases (for example, water vapor, or carbon dioxide), the Earth's average temperature would be approximately 0 degrees F, (minus 18 degrees C or 255 K). However, due to the efficiency with which greenhouse gases reabsorb counterradiation, the Earth's average temperature is 59 degrees F (15 degrees C, or 288 K).

Water vapor and carbon dioxide are the most abundant greenhouse gases by volume. They are particularly effective at absorbing counterradiation. The amount of water vapor in the atmosphere is a direct response to temperature. Other long wave–absorbing gases can be produced by human activity. Carbon dioxide and certain other trace gases (such as methane, nitrous oxide, and chlorofluorocarbons) can potentially upset the long wave exchanges involved in the Earth's energy balance. Such deviations can lead to changes in the average global temperature. Potential consequences of an escalating amount of these atmospheric gases include a growing proportion of outgoing long wave radiation being "trapped" in the atmosphere, leading to an increase in the Earth's temperature.

Clouds serve as very effective absorbers of outgoing long wave radiation. This, in turn, affects surface and near-surface temperatures. The presence of clouds in a nighttime sky results in warmer temperatures than a cloudless one. In the absence of incoming short wave radiation, only long wave exchanges occur at night. With clouds trapping much of the outgoing long wave, substantial amounts are redirected back toward the surface. This increases the near-surface temperatures. Similarly, the lack of clouds leads to greater amounts of long wave radiation escaping the Earth-atmosphere system to space.

SEE ALSO: Albedo; Radiation, Microwave; Radiation, Short Wave; Radiative Feedbacks.

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Radiation, Microwave

THE EXISTENCE OF microwaves was first postulated by James Clerk Maxwell in 1864 and confirmed by the experiments of Heinrich Hertz some 20 years later. Microwaves are subdivided into categories as listed in Table 1.

Table 1: Microwave frequency bands as defined by the Radio Association of Great Britain

Designation	Wavelength *
L band	15 cm – 30 cm
S band	8 cm – 15 cm
C band	3.75 cm – 8 cm
X band	2.50 cm – 3.76 cm
Ku band	1.7 cm – 2.50 cm
K band	1.1cm – 1.7 cm
Ka band	0.75 cm – 1.1 cm
Q band	0.6 cm – 1 cm
U band	0.5 cm – 0.75 cm
V band	0.4 cm – 0.6 cm
E band	0.33 cm – 0.5 cm
W band	0.3 cm – 0.4 cm
F band	0.2 cm – 0.33 cm
D band	0.27 cm – 0.18 cm

*Note the definition is originally in units of GHz and has been converted here to cm for comparison to the other measurements. This has inevitably led to some rounding.

Microwaves are most well known in popular culture for their role in heating food (in a microwave oven), and for their use in mobile telecommunications such as mobile phones and wireless networking. Microwave ovens work by passing S-band radiation though food, which excites water, sugar, and fat molecules. These molecules in turn reradiate in the infrared to heat the food. With the rapid expansion of mobile phone technology, many studies have been done to look at the effects of microwave radiation on human health. The studies show mixed results however, and the general conclusion is that only doses high enough to heat up tissue are likely to have negative impacts.

SEE ALSO: Radiation, Absorption; Radiation, Ultraviolet; Technology.

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national Conference on Microwave and High-Frequency Heating (Springer-Verlag, 2006).

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Radiation, Short Wave

RADIATION TRAVELING IN waves shorter than one micrometer (µm) is characterized as short wave, and includes gamma rays, x-rays, ultraviolet light, and visible light. Climatologically, short wave radiation commonly refers to the incoming radiation from the sun. There is an inverse relationship between the temperature of an object and the wavelengths at which it primarily emits. Because the sun is a hot object (approximately 5800 K), it emits radiation at short wavelengths. Since shorter wavelengths carry more energy than longer ones, they are more intense. Most of the short wave emitted by the sun is in the visible region of the electromagnetic spectrum, which spans from 0.4 µm (violet) to 0.7 µm (red). The sun's wavelength of maximum emission is found at 0.5 µm.

The amount of emitted solar radiation that reaches the Earth decreases inversely with the square of the distance between the Earth and sun, by the inverse square law. The total of short wave radiation that reaches the top of the Earth-atmosphere system is called the solar constant. Although the amount varies slightly throughout the year, due to the elliptical nature of the Earth's orbit around the sun, the solar constant averages around 1370 W m^{-2}.

Because the eccentricity of the Earth's orbit varies between nearly zero to five percent (with a periodicity of 110,000 years), the amount of short wave received increases or decreases over time from present values. The current orbit is nearly circular, leading to little seasonal variation of incoming short wave radiation. However, a more highly elliptical orbit would render a difference of up to 30 percent between aphelion (maximum Earth-sun distance) and perihelion (minimum Earth-sun distance). Incoming solar radiation can take several avenues once it enters the atmosphere. Over a year, 30 percent of total short wave radiation is reflected back to space, either by gas molecules or other particles in the atmosphere, by clouds, or by the Earth's surface; this is the Earth's albedo (the proportion of radiation that is reflected from a surface). The atmosphere and clouds absorb an additional 20 percent of short wave radiation. Approximately 50 percent strikes the surface, where it is absorbed. These values may vary locally and at shorter time scales.

Some of the short wave radiation reaching the Earth's surface arrives directly, unimpeded by clouds or atmospheric constituents; this is direct radiation. Some is scattered about the atmosphere and arrives at the surface indirectly. This is diffuse radiation. Diffuse radiation is a product of scattering, which occurs when short wave radiation strikes small particles in the atmosphere, including gas molecules. Upon impact, the radiation is scattered omnidirectionally. Some short wave radiation will be scattered toward the surface. Energy received at the Earth's surface is the total amount of direct and diffuse radiation.

The presence and type of clouds in the atmosphere reduces the amount of short wave radiation reaching the Earth's surface. Thin clouds, such as cirrus, have lower albedos than thick ones, such as cumulus. Once short wave solar radiation reaches the surface and is absorbed, it is converted to long wave forms of radiation.

Short wave radiation impacting the Earth also includes ultraviolet light. These wavelengths are shorter than visible radiation, so ultraviolet light carries more energy than visible light. Ultraviolet radiation is classed into three categories: UV-A (0.32–0.40 µm), UV-B (0.29–0.32 µm), and UV-C (0.20–0.29 µm). Excessive exposure to UV-A and UV-B radiation has been linked to skin cancers and skin damage. UV-C radiation is largely absorbed by stratospheric ozone. Absorption of ultraviolet radiation breaks ozone down into atomic and molecular oxygen. The presence of stratospheric ozone helps protect the Earth's surface from the damaging effects of this form of short wave radiation.

SEE ALSO: Radiation, Ultraviolet; Sunlight.

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Radiation, Ultraviolet

ULTRAVIOLET RADIATION WAS discovered as a result of the observation that silver salts darken on exposure to sunlight. In 1801, the German physicist Johann Wilhelm Ritter first observed that invisible electromagnetic radiation was responsible for this darkening. These rays eventually became known collectively as UV, so named as this radiation is immediately beyond violet in the electromagnetic spectrum. This implies that UV is more energetic than the visible light. Conventionally, UV radiation is broken down into further subdivisions as shown in Table 1:

Table 1: Conventional subdivisions of UV radiation

Name	Wavelength	Comments
1. Near	400 nm – 200 nm	Referred to as 'Blacklight'
UV-A	400 nm – 320 nm	Strongly absorbed by O_3
UV-B	320 nm – 280 nm	Strongly absorbed by O_3
UV-C	290 nm – 200 nm	Strongly absorbed by O_2
2. Far	200 nm – 31 nm	Strongly absorbed by O_2
3. Extreme	31 nm – 1 nm	

In humans, UV radiation is important for health. UV-B has health benefits, as it is responsible for the production of vitamin D. A deficiency of vitamin D is thought to lead to a range of cancers and also to osteomalacia (the adult equivalent of rickets), with symptoms ranging from painful bones to brittleness and fractures.

Exposure to UV radiation also causes the skin to release a pigment (melanin), giving the skin a darker color that is regarded as healthy in most Western cultures. Melanin provides some protection again the more harmful effects of UV exposure.

Exposure to UV radiation also has a range of negative health effects. The most widely publicized of these is the link between exposure to UV and skin cancer. UV radiation is strongly absorbed by DNA, the cellular molecule responsibly for the transfer of hereditary information. The absorption of UV radiation causes chemical bonds in the DNA to be broken and reformed in the wrong order. This can lead to mutations and cancerous growths. UV radiation is also harmful to the eyes, leading to short-term uncomfortable conditions such as arc eye or to more serious conditions such as cataracts. There may also be a link between excessive UV exposure and poor immune response. UV radiation also finds a range of industrial and domestic applications; these include:

1. Astronomy: Many hot objects in the universe emit large amounts of UV radiation and are therefore better observed in the UV region. However, as the atmosphere absorbs a lot of this UV, these observations are generally only made from space.
2. Spectrophotometry: A widely used technique in analytical chemistry to determine chemical structure.
3. Analyzing minerals: Many minerals glow characteristic colors under a UV lamp, aiding identification.
4. Sterilization of surface and drinking water: UV radiation is effective at killing pathogens and is used to sterilize critical workspaces (such as biochemistry labs) as an alternative to chlorination. Methods to sterilize water based on using UV from sunlight may provide a carbon neutral solution to domestic water treatment.

SEE ALSO: Chemistry; Geography; Radiation, Absorption; Radiation, Infrared.

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Radiative Feedbacks

WHILE MOST OF the feedbacks at play in the Earth's ecosystem are subject to the closed system of matter, radiative feedbacks are those that deal with the open system in which the sun's energy is transferred to the Earth and then absorbed or reflected back, to varying degrees. Because the amount of absorbed or reflected solar energy is the principal component in the planet's temperature (the other factors then determine what happens to that heat, but the solar energy provides the initial quantity), these feedbacks are key to understanding and modeling global climate. Feedbacks are relationships found in complex systems, in which the output (or result) of the system is returned to the input. For instance, as the summers get hotter, people run their air conditioners longer, releasing more chlorofluorocarbons, accelerating global warming, and causing hotter summers. That is a simple example of a positive feedback often used in schools. The radiative feedbacks in question involve principally clouds, ice, and water vapor.

A critical feedback in global warming is the albedo-ice feedback. Though the melting of the polar ice caps is often associated with rising sea levels, it's only one of the important effects, and simply the most vivid to illustrate. The more complicated effect is in the change it enacts on how much solar energy is retained by the Earth. Ice is far more reflective than land or liquid water, and as the polar ice melts, the area of the surface that it occupied is replaced by one of those two things. As a result, more sunlight is absorbed by the surface instead of being reflected, which then warms the poles further, melting more ice.

Clouds are also critical. Clouds act as a sort of imperfect barrier, absorbing a limited amount of heat moving in either direction, heat emanating from the Earth into space, and sunlight shining on the Earth. Models disagree on whether their overall feedback effect on global warming will prove positive or negative. On the one hand, the evaporative feedback in general accelerates global warming: as the temperature increases, the capacity of the air to hold moisture increases exponentially, so as water evaporates into the warm air, it is able to stay there. Since water vapor is a greenhouse gas, as it accumulates, it causes the temperature to get warmer and warmer. On the other hand, sufficiently great cloud cover shields the Earth from solar radiation, and cloudy days aren't as hot. High-enough clouds can reflect sunlight back down on the Earth, however, more than balancing out the sunlight they have blocked. Water vapor also retains heat better than the atmosphere does; a wetter atmosphere loses heat more slowly. As more and more water evaporates, more and more heat from the sun can be retained, which makes for a warmer Earth, and greater evaporation.

It is possible that the effects of positive radiative feedbacks on global warming have been muted until recently by global dimming, the gradual reduction of the Earth's irradiance (emitted radiation, including heat and light) in the second half of the 20th century, which has reversed in the 21st century. Global dimming is probably caused by the coalescing of water vapor around anthropogenic particles in the air, the product of pollution and other industrial activities. The resulting water droplets form a little differently than they would otherwise, and make more highly reflective clouds. The Clean Air Act and other anti-pollution efforts are presumed to be responsible for ending global dimming. The apparent recent increase in global warming may be because that dimming had been reducing global warming's effects by limiting the amount of sunlight entering the system.

SEE ALSO: Albedo; Atmospheric Absorption of Solar Radiation; Biogeochemical Feedbacks; Climate Feedbacks; Cloud Feedback; Dynamical Feedbacks; Evaporation Feedbacks; Ice Albedo Feedback; Radiation, Absorption; Sunlight.

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Rain

RAIN IS COMPOSED of water droplets formed from vapor that has condensed in the Earth's atmosphere. Regular rainfall is vital to the functioning of the biosphere, and even minor fluctuations in the amount of rain can have substantial impact on the ecosystem. Climatologists believe that rainfall patterns are going to change dramatically as the atmosphere heats up in the coming decades, with potentially damaging consequences.

HOW RAIN FORMS

Precipitation forms under three main types of conditions: convective uplift, frontal uplift, and orographic uplift. Convective uplift is common in the equatorial tropics and during the summer months. As the sun heats up the Earth's surface, the humid, warm air rises into the atmosphere, cools, forms tall, unstable cumulonimbus clouds, and then releases its moisture in a quick downpour.

Frontal uplifts are the result of cold and warm fronts colliding. This can take different forms. Fronts are transition zones between air masses of different temperatures. When warm air collides with cooler air along a warm front, the warm air gently rides up over the cooler air. If cold air collides with warm air along a cold front, the colder, denser air pushes up the warm air rapidly. Depending on the particular conditions, rains from frontal events can be a steady, soaking rain that last for several hours, or severe weather events that spawn quick downpours, high winds, and tornadoes. Orographic uplift, sometimes called "relief rain," occurs when a warm air mass meets a geographical barrier (usually a mountain range) that pushes the warm air up into the atmosphere, where it cools and condenses.

No matter what the type, the development of rain requires the presence of extremely small particles called condensation nuclei to form droplets. These particles, trapped in cloud formations, can be composed of anything from dust and soot to sea salt and phytoplankton, and at 0.02 mm. in diameter, are just 1/100th the size of a typical raindrop. Condensation nuclei give water vapor in the clouds something to coalesce around, thus increasing the size of the individual molecules of water vapor into droplets heavy enough to fall out of the clouds.

The speed with which raindrops fall depends primarily on their weight: for example, a 0.5 mm. raindrop would fall at around 6.5 ft. (2 m.) per second, while a five mm. drop would fall at 29.5 ft. (9 m.) per second. The average raindrop is around two mm. in diameter. The largest raindrop ever recorded was 10 mm. in diameter, but those are rare; drops larger than five mm. tend to be unstable, often breaking into smaller droplets as they fall. Raindrops are not shaped like teardrops: rather, they are spherical, or flattened on the top, with larger drops sometimes shaped liked parachutes.

RAINFALL AND GLOBAL WARMING

Rainfall is vital to the creation of food and water on Earth. With less than 1 percent of all the planet's fresh water available for human and animal consumption, the regular recharging of groundwater and reservoirs from rain and snow is critical to keep fresh water sources flowing, and all plant life requires at least some water to grow. Regular, moderate precipitation is critical to the production of most of the 2,000 food crops under cultivation. Because of the importance of rainfall to the environment, climate experts have been trying to determine the possible impact of global warming on rainfall distribution around the world.

In 2007, a group of researchers constructed a computer modeling program drawing on data collected 1925–99, and, taking into account potential future increases in levels of greenhouse gases and solar activities, made projections well into the next century. Their study found the precipitation in areas lying between 40 and 70 degrees N latitude is likely to increase at a rate of 2.44 in. (62 mm.) per decade, and in areas lying between zero and 30 degrees S latitude is likely to increase 3.23 in. (82 mm.) per decade. However, the area lying between zero and 30 degrees N latitude is likely to see precipitation decreases of 3.86 in. (98 mm.) per decade. This means that regions toward the poles, including Europe, Canada, and parts of Latin America, will become wetter, while already parched regions will become much dryer.

This could be catastrophic for the Sahel region in Africa. A 2,400-mi. (3862 km.) long belt stretching from Senegal on the west coast to Eritrea on the east, the Sahel is the boundary line between the Sahara Desert and the more fertile sub-Saharan region to the south. The area is home to an estimated 50 million people, 62 percent

A patch of rain moving through Tobago in the Caribbean. Climate models predict more heavy rain events, separated by prolonged periods of dry weather. In a global warming scenario, the warmer air in the atmosphere holds more water.

of whom live in poverty. Since the 1970s, the Sahel has been struck by longer and more frequent droughts, with overall precipitation decreasing by around 20 percent during the period. Modeling indicates that in the coming century, rainfall averages in this region could drop by another 30 percent. The death toll from previous droughts has numbered in the millions; in the future, the area may become uninhabitable.

Areas where rainfall is expected to increase will likely see new patterns of precipitation as well. The overall amounts of rain may not change dramatically from year to year, but climate models predict more heavy rain events, separated by prolonged periods of dry weather. Much of this will be due to the heating of the atmosphere: warmer air holds more water, raising the potential for a quick release of a large volume of water. Air pollution will also play a role, as more particulates in the atmosphere give this increased amount of water vapor more condensation nuclei around which to coalesce.

Heavy rains are a potential threat to human life and property, raising the probability of events such as flash floods and landslides. Research has also found that frequent heavy rains combined with long dry spells quickly erode the vitality of a region's biomass, and in the long term contribute to a loss of soil quality and overall biodiversity.

Climate experts predict there could be some initial benefits to plant life in areas of increased rainfall. Scientists have seen a rise in the amounts of reactive nitrogen in the atmosphere, which they believe stems from a combination of rising rates of nitrogen oxides from the burning of fossil fuels and ammonia (NH_3) from agricultural sources. This reactive nitrogen is carried to the ground by rain, where it stimulates plant growth, particularly in the forests. Increasing the vitality of the forest will increase the terrestrial carbon sink, as trees and plants absorb harmful carbon dioxide from the atmosphere as a process of photosynthesis. The amount of reactive nitrogen has increased fourfold since the beginning of the Industrial Revolution, and will likely to continue to grow in coming years. Scientists are not sure at what point there is too much of this substance available, when its risks to the environment begin to outweigh its benefits.

SEE ALSO: Floods; Hurricanes and Typhoons; Precipitation; Rainfall Patterns; Thunderstorms.

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Rainfall Patterns

CHANGE IN RAINFALL pattern is a consequence of global warming. The world's agriculture, especially third world agriculture, depends upon the seasonal rainfall pattern. Recent erratic changes in rainfall pattern lead toward low agriculture production, thus creating food insecurity for an ever-increasing world population. Flood, drought, and famine are the consequences of these changing patterns.

Rainfall pattern means the distribution of rain geographically, temporally, and seasonally. The tropics receive more rainfall than deserts. Cooler places like the poles receive no rainfall, as it is converted to snow before it falls to the ground. Rainfall happens more in a particular time of a year, during a rainy season. In other seasons, rainfall is scant. Therefore, agriculture (rain-fed), worldwide, is planned based on rainfall's natural pattern. Water storages, irrigation networks, and urban water supply systems are designed according to the average annual rainfall. If it rains a lot on a continuous basis for a longer time, there is possibility of flood and subsequent disaster to the infrastructure. No rainfall or little rainfall for a longer period (years) in an inhabited area could lead to drought and famine.

Global warming leads to a near-term collapse of the ocean's thermohaline circulation. Thermohaline circulation is a global ocean circulation pattern that distributes water and heat both vertically, through the water column, and horizontally across the globe. Due to this collapse of thermohaline circulation, warm surface waters move from the tropics to the North Atlantic and extra-warm water surfaces in the Pacific Ocean surrounding the equator. Thus, Western Europe, some parts of Asia, and many parts of the Americas get warmer than normal, and some parts of Europe get cooler rapidly. El Niño and La Niña are examples of this. This latest deviant trend generates dramatic weather impacts, such as rapid cooling in some parts of the world, and greatly diminished rainfall in agricultural and urban areas. UNESCO and other studies found that changes in rainfall pattern could be attributed to the shifts in global wind pattern. These shifts are due to the changes in the ocean surface temperature. Effect of human activity on the surface vegetation is also causing rainfall pattern variation. Widespread deforestation in parts of Africa and Asia is causing scarce rainfall and subsequent drought.

The world's scientific community commonly accepts that global warming has affected rainfall patterns. More precipitation is happening in northern Europe, Canada, and northern Russia, but less in swaths of sub-Saharan Africa, southern India, and southeast Asia. A Canadian research team found with 75 years (1925–99) of rainfall data analyzed through 14 powerful computer models that the Northern Hemisphere's midlatitude (a region of 40 to 70 degrees N) received increased precipitation over the years. It corroborates with the change in thermohaline circulation. The models also showed that in contrast, the Northern Hemisphere's tropics and subtropics (a region between the equator and 30 degrees N) became drier, while the Southern Hemisphere's similar region became wetter. This study was conducted for rainfall patterns over land.

Researchers claim that a natural pattern of rainfall is good for plant growth, as variable rainfall patterns lead to lower amounts of water in the subsurface level of the soil (in the upper 30 cm.). Variable rainfall patterns also cause plant diversity in a particular land. That means that weeds grow rapidly with variable rainfall. The significance of these changes is evident from recent large-scale failure of the crops, rangelands, and water-supply systems in the world. Mass starvation in Sahelian Africa is the stark proof of this.

Some might argue that changes in rainfall patterns are unfounded due to lack of instrumental records for a large time period. However, studies using indirect methods have proved that global warming, in fact, is causing serious rainfall pattern variability. Tree-ring analysis for predicting rainfall amounts in previous years (hundreds of years back) is one study, which proved that rainfall pattern variability is extensive in recent years.

If this trend continues, environmental managers need to make new decisions about the management of water and land. They need to accurately understand the interannual variability of rainfall and a possibility of runs of dry and wet years, which may cause important changes in runoff, sedimentation, soil erosion, or changes in communities of vegetation and animals, and of the viability of large water resource developments. Rainfall pattern variability would certainly cause mass human migration.

SEE ALSO: Rain; Thermohaline Circulation; Thunderstorms.

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Refugees, Environmental

IN THE LAST 10 years, the issue of environmental refugees has emerged as a pressing issue. Most refugees are fleeing from natural disasters such as the Asian tsunami in 2004, or as a result of the impacts of global climate change, such as sea level rise. As the executive director of the United Nations Environment Programme (UNEP) noted in 1989, "as many as 50 million people could become environmental refugees if the world does not support sustainable development." Since then, many studies have considered this topic, with Norman Myers (one of the leading thinkers in this field) estimating that environmental refugees will soon become the largest group of involuntary migrants.

One of the difficulties in managing the issue of environmental refugees is their classification. The 1951 Convention relating to the Status of Refugees classifies a refugee as a person who, "owing to a well-founded fear of being persecuted for reasons of race, religion, nationality, membership of a particular social group, or political opinion, is outside the country of his nationality, and is unable to or, owing to such fear, is unwilling to avail himself of the protection of that country." Refugees who are outside their country for environmental reasons do not strictly speaking fit within this category. The first definition of environmental refugees came from UNEP researcher Essam El-Hinnawi in 1985: "environmental refugees are those people who have been forced to leave their traditional habitat, temporarily or permanently, because of a marked environmental disruption (natural and/or triggered by people) that jeopardized their existence and/or seriously affected the quality of their life [sic]. By 'environmental disruption' in this definition is meant any physical, chemical, and/or biological changes in the ecosystem (or resource base) that render it,

Many are still living as refugees from the 2002 eruption of the Mount Nyiragongo volcano in the Congo.

temporarily or permanently, unsuitable to support human life." Environmental refugees are different from environmental migrants, in that they do not have any choice about their situation.

Today, there are at least 25 million environmental refugees. There are 22 million people in the world that classify as refugees under the traditional definition. Environmental refugees number one person to every 225 worldwide. A further 900 million people may also become environmental refugees because they live in marginal environments, or are driven into marginal environments for political, economic, social, cultural, legal, and institutional reasons.

EXAMPLES OF ENVIRONMENTAL REFUGEES

There are a number of reasons to become an environmental refugee. First, it may happen as a result of a natural disaster. Natural disasters include floods, cyclones, earthquakes, tsunamis, or any other major event that will make the lived environment temporarily or permanently inhabitable. One example is the eruptions of the Soufriere Hills Volcano on the Caribbean Island of Montserrat in 1995–98. As a result of these eruptions, 7,000 residents were forced to evacuate. Second, individuals or whole groups of people might become environmental refugees due to the appropriation of habitat or land by external parties, hence dispossessing and permanently displacing people.

For example, the building of the Three Gorges Dam in China has displaced up to 850,000 people and overall has the potential to displace up to 1.3 million people by 2009. Third, people may become environmental refugees as a result of an ongoing deterioration of their land and seas. Desertification is a good example as is sea level rise of the type of activity that ultimately creates environmental refugees of people in their own homelands. Movement from one area to another occurs as families and settlements find it harder to sustain livelihoods. This is the group that most often finds it hard to get support, as it is hardest for this group to be recognized as having refugee status.

There are many examples of this situation across the world due to climate change. For example, water shortages caused by climate change will cause huge reductions in agriculture and people's way of life. Tropical forests are estimated to lose another 40 to 50 percent of their cover due to climate change, and in turn this will dispossess many millions of people living within and dependent upon it for survival. Up to 500 million people could experience absolute shortages in fuel wood supply as a result of climate change impacts. Other (preliminary) estimates highlight that the total of people at risk of sea level rise in Bangladesh could be 26 million, in Egypt 12 million, in China 73 million, in India 20 million, and elsewhere 31 million, making an aggregate total of 162 million. At least another 50 million people are at risk through increased droughts, desertification, and related climate disruptions.

RESPONSES

One response to the problem is to ensure that environmental refugees have a formal classification within the 1951 Convention relating to the Status of Refugees. Another is to address the root causes of the environmental problems motivating relocation of people across the world. Promoting policies of and achieving sustainable development programs is a good first step to help achieve this goal. Nations must also develop policy to address what support structures and frameworks they are going to put in place to deal with and acknowledge environmental refugees in their countries. Implementing specific projects in countries most affected is another pathway nations could take to support each other on this issue, including the relief of foreign debt and the granting of foreign aid that will help ameliorate this problem. For policymakers and governments, while the issue of how to deal with refugees is politically contentious, the plight of environmental refugees merits special attention because, due to climate change, any country may be vulnerable and need support in the future.

SEE ALSO: Climate Change, Effects; China; Cyclones; Floods; Policy, International; Policy, U.S.; Preparedness; Risk; Tsunamis; United Nations Environment Programme (UNEP); Volcanism.

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Regulation

IN THE CONTEXT of law, the United Nations Framework Convention on Climate Change (UNFCCC) and the complementary agreement of the Montreal Protocol on Substances That Deplete the Ozone Layer are legal regulatory instruments. The UNFCCC Article 4 section 1 governs scientific, technological, technical, socioeconomic initiatives in the research, observation, and development of data on anthropogenic emissions into the atmosphere. To effect the desired regulation of the amount of greenhouse gases released into the atmosphere requires both a legal rule of what is or is not permitted, and the inclusion of regulatory features in equipment and processes or activity to control the emissions of the relevant substances into the atmosphere.

The atmosphere and other planetary features operate according to laws that have been articulated in scientific terms. These scientific laws are anthropocentric in their perspective and can be used to describe the conditions under which human life continues on this planet. The dominant conditions of the laws according to which the planet dictates or regulates human life and activity are related to but distinct from the regulatory operations of neoclassical human law. Anthropocentric law is the law made by persons for persons and their property. It is the actions of persons and their property that have consequences for global warming and climate change. Alternatively, global warming and climate change occur at the intersection of the laws of the planet usually perceived in the context of scientific laws and the anthropocentric laws of human behavior.

LEGAL REGULATION

In a neoclassical utilitarian framework, the regulator is typically a natural or legal person or an entity with the power to regulate within its domain. The difficulty in the context of global issues such as planetary warming and climate change is the absence of a single regulator with the jurisdiction for the global atmosphere or the climate and hence no one with authority to regulate the global commons. Since local climate is not independent or separable from global atmosphere and does not observe legal jurisdictions, regulating local climate change or warming locally without some provision for the larger global dimensions would be an exercise in futility. Further, in the dominant utilitarian approach, the global physical features such as the atmosphere and the climate are a common resource beyond human or state jurisdiction and available for use by all who have access to it.

Within the context of law or legal systems, regulation can refer either to a regulatory regime being a set of laws about some action, or a subset of detailed technical rules that are to be applied in particular physical contexts. In the latter sense, regulations are a set of physical specifications that are to be applied to particular products or processes. Regulatory regimes as part of legal systems in particular jurisdictions differ in the international and the domestic national contexts. Details are particular to the applicable legal system, and may not have comparable features in other legal systems.

The recognition of national sovereignty results in the distinction between the international and the domestic state jurisdictions. In the international context, states may agree to be bound at their own discretion as sovereign entities and not to be compliant with the regulation of a global regulator. Thus, the climate or the atmosphere can only be legally regulated within the jurisdictions of the various sovereign states' legal systems and by agreement with each other. Agreements such as the UNFCCC and the more specific Kyoto Protocol are indispensable in achieving global action. Such agreements to regulate anthropogenic emissions into the atmosphere must be implemented within the jurisdiction of sovereign states by domestic actions and procedures.

In implementing an international agreement in the domestic realm, a state issues laws and enforces them in order to achieve compliance with the international and domestic objectives. In doing so, the state would typically rely on scientific opinion. For instance, a scientific opinion stating that emissions from automobiles include greenhouse gases that should be regulated could lead to applicable regulations. The legal regulation of vehicles may then include a legal rule or a law or legislation that requires the greenhouse gases in tailpipe emissions of an operating automobile to be within certain parameters. This rule could then be accompanied by related regulations that set out in detail the technical specifications as to how the determination of the emissions is to be made and the concentrations of such gases and other acceptable limits of the emissions and may further specify variations by type and model of automobile. The technology in the vehicle itself may then involve systems such as computers or other mechanical systems that adjust or regulate the operation of the equipment to obtain the desired result of compliance with the legal limits.

For the most part, legal regulations are formulated by taking into account the available technical capabilities as well as society's expectations. The Kyoto Protocol, for example, sets legally binding target limits to the emissions into the atmosphere. Some people find the targets inadequate for achieving the stated objective of the UNFCCC and expect further reductions, and others, citing technical and financial reasons, consider these targets unattainable.

FUTURE INTERESTS

A significant feature of the UNFCCC and the Kyoto Protocol is the attempt to regulate the present human behavior in view of the future. This forward concern contrasts with typical legal regimes that usually codify past practice by referring to existing technology and social expectations based on past experience. In the case of climate change, the legal regulation seeks to operate closely with the mechanical or technological aspects to influence future changes.

For those who prefer the typical legal regime, regulating the future is resisted, as the future is not predictable. For others, the scientific understanding of inertia in the trends of climate changes dictates that setting and meeting targets for the future is essential to prevent foreseeable results. To put it in the negative, waiting for the climate to change before regulating current conduct would be meaningless as it would be too late then to make a difference to the outcome.

In law, predictability and foreseeability are distinct and important, with significant implications in practice. Consider the requirement for safety features in a vehicle. One group may take the view that installing safety features would be an unacceptably expensive proposition to provide for an unpredictable future event such as that a particular vehicle will be involved in a particular collision, which may not occur. Another may prefer to consider that it is foreseeable that a vehicle could be involved in the same particular collision and prefer to install features that will enable the avoidance of that outcome. In the climate change context, for the latter, waiting until climate change is predictable before regulating contributing factors may be compared to installing and using safety features on a vehicle after it is predictably involved in a collision. Since the consequences of climate change have been compared second only to those of global nuclear war, waiting for predictability in outcomes of climate change is waiting for the nuclear weapons to detonate before doing something to stop it.

PROBABILITY AND UNCERTAINTY

Predictability and foreseeability also involve different roles for the concepts of probability and risk in technological and scientific and legal regulation. In formulating laws, scientific probability may be characterized as uncertainty, and without sufficient foundation for concern about the atmospheric conditions. Here, scientific uncertainty leads to an absence of regulation.

On the other hand, science can and does operate on probabilities or risk and in that sense does include scientific uncertainty without diminishing the development of appropriate regulatory regimes. For instance, in economic and business decision-making context, risk management is an established approach in many segments of society. Insurance and investment products in the marketplace are examples of socially valued items that are designed specifically by reference to uncertainty and are foundational features of a market economy and have been legally regulated since the last century.

INFORMATION AND REGULATION

Since regulation is a result of social and political actions based on information in which perception is a key component, changing perceptions correspond to changing behavior and regulatory activities. For instance, there is a perceived shift in the discussion from global warming to a broader concern for climate change as including issues other than increases in temperature. Responding to this shift in perception, the U.S. Environmental Protection Agency (EPA) has renamed its website, which also indicates its self-understanding of its regulatory function.

Changing perceptions involve social and political changes and may also lead more directly to changes in regulatory regimes. In a democratic state, legislation is made by acts of a corresponding legislature and its authorized bodies that together formulate the regulatory regime being the law and its regulations.

MODELS AND REGULATION

The perception of the complexity of the atmosphere and climate change has grown over time. Scientific models used to study these phenomena have evolved with a corresponding increasing rapidity as research continues. Weather has played a strategic role in conflict throughout history. The value of information about the weather was appreciated when it was critical in the success of the Allied Forces D-Day invasion of Europe in 1944. After that, meteorology gained in its value as a matter of strategic interest to security forces. It was the incidental observations of meteorologists that led to the development of climate change as a research topic in its own right.

Since meteorologists observed a correspondence between atmospheric CO_2 levels and mean global temperatures, scientific information has been critical in the modeling and understanding of the interaction between human activities and the climate. That the climate does change has always been observed, as has the impact of human activities on the atmosphere, if only at a local scale. The issue now is that of scale in the question of global human activities and global atmosphere and climate changes. It is the position of the Nobel Peace Prize–winning institution known as the Intergovernmental Panel on Climate Change (IPCC), which provides peer-reviewed scientific information on climate change, that anthropogenic emissions are having an impact on global climate patterns.

Established in 1988 prior to the Toronto Conference, the IPCC provides peer-reviewed scientific information to the public which may be used in formulating policies and regulations. Emerging regulations rely on the acceptance of scientific opinions such as that expressed by the IPCC. The IPCC has concluded that without any change in practices, and based on current models, the current trend of increasing greenhouse gas emissions may increase the mean global temperature by 1.4 to 5.8 degrees C by 2100 compared to the temperature in 1990.

In its 1989 *Report to Congress: The Potential Effects of Global Climate Change on the United States,* the U.S. EPA Office of Policy, Planning and Evaluation notes that its report relies on scenarios that are based on information at a certain point in time, and assumes that carbon dioxide levels will have doubled and the climate will have stopped changing, neither of which are realities. This increasing rate of change has already appeared in the complexity of scientific modeling. The capability of regulating such increasing rates of change in the traditional manner has been limited. At the same time, some debate the desirability of regulating changes.

The variety of chemicals now produced and used and the resulting atmospheric emissions add to the complexity of atmospheric models. Contributors to the greenhouse effect include emissions of atmospheric CO_2, methane, CFC/NO_X, and SO_2. Increasing amounts of these gases and particulate matter in the atmosphere is linked to the warming trend in mean global temperatures. The links are still being researched, as the effect of each of the atmospheric components is different. For instance, CFCs and CO_2 remain in the atmosphere up to 100 years, while methane breaks down in 10 years, and SO_2 in a week. They also occur in different proportions and the chemical reactions they induce are different.

Commercial usage of CFCs has declined, and so has SO_2, which also causes acid rain. Each of these emissions and related products and processes are all susceptible to regulation.

THE UNFCCC AND KYOTO

The UNFCCC and the Kyoto Protocol is the principal international agreement relevant to climate change to which more than 140 countries forming a substantial proportion of the global community have signed on. The consensus expressed in the Kyoto Protocol includes the agreement to legally binding obligations on the signatories. Domestic acceptability of this international agreement is an ongoing concern in some states.

Article 1 of the UNFCCC provides definitions of terms and phrases. These definitions indicate some of the complexity and scope of the discussions and indicate the difficulty of regulating the activities necessary to achieve the objective. For instance, "Climate system" means the totality of the atmosphere, hydrosphere, biosphere, and geosphere and their interactions would include most if not the entire human environment on the planet. "Climate change" is similarly comprehensive in referring to climatic change attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods. "Emissions" means the release of greenhouse gases and/or their precursors into the atmosphere over a specified area and period of time. All of which would require regulatory systems in law as well as in the applicable science, technology, and economics of human activities.

The convention's reference to the climate system as a shared resource indicates the continuing dominance of the utilitarian approach to the planet and recognizes the anthropogenic source of changes to the system. The observation of historically unprecedented anthropogenic changes to the system as a whole then also raises corresponding requirements for unprecedented solutions and strategies. In this endeavor, information and cooperation at the same global scale become critical. The Kyoto Protocol established legally binding levels of greenhouse gas emissions on the signatory nations. In doing so, the protocol's regulatory features advance the stated objective of the UNFCCC.

SOVEREIGNTY AND REGULATION

The format of the UNFCCC as a framework convention with protocols provides a foundation for a diversity of regulatory contexts and a variety of rates of change. This design relies on implementing regulatory regimes in sovereign states. Depending on the form and structure of each nation, the regulatory regime within a country will also vary. For example, in the context of the United States, which is a system of federated states, federal law, state law, and more local jurisdictions, all become pertinent to the implementation of international agreements.

Within each sovereign state, the specific form of the regulatory regime will also vary according to the state's legal system and internal rules. In a federal system, the implementation will require the appropriate jurisdiction to enact relevant laws. In a common law jurisdiction such as Canada, the federal and provincial jurisdictions are a constitutionally defined matter. Within each such jurisdiction, there can be further delegated authority that may need to act. For example, it would not be unusual to establish and authorize municipal authorities and regional organizations to fulfill obligations.

The legal regulatory regimes that are applicable to climate change are as complex and diverse as the human activities that influence climate change. These human activities may be broadly differentiated into social, technological, and economic spheres. The range of these activities was reflected in the development of the Kyoto Protocol, where delegates represented every organization with a vested interest in the outcome of the agreement. These included governmental and nongovernmental entities.

The divergent interests in this type of global agreement make discussions complex and differences more apparent. The motivation to achieve the desired objective and the capability of delivering the commitments vary. The use of a trading system to meet commitments was a significant victory for the United States and the overall effective commitment was to a reduction of greenhouse gas emissions to 5.2 percent below 1990 levels. The scientific consensus in contrast recommends a stabilization of the composition of the atmosphere. To achieve this scientifically recommended stabilization would require a reduction of about 50 percent below 1990 levels and an immediate stop to deforestation.

The emerging understanding of the complexity of the climate system and changing human behavior has led to a corresponding shift in the priority of various issues. For example, previous concern for the stratospheric ozone layer has declined while that for particulate matter has increased. Previously unperceived activities such as contrails from aviation activities have gained attention as possible anthropogenic contributors to the changes.

Complexity also results from the variety in the matters subject to regulation and the capacity of previous legal categories to accommodate emerging issues. For instance, in federal systems of national jurisdiction like Canada, transboundary transport of energy supplies would be federal jurisdiction, with the registration of vehicles and local deployment of the energy within the local jurisdiction. A single issue of the supply and use of energy then spans multiple jurisdictions even within a single sovereign state.

Again, if energy is considered as including electricity or gas and their use in commercial or domestic buildings, the related issue of the energy efficiency of building structures becomes relevant. To achieve the regulation of the buildings then involves the formulation of building codes which may depend on the materials used in construction and thereby involve international supplies, federal, and local jurisdictions, including land use regulations.

Land use provisions also relate to the preservation of habitats, which then determine the continuity of species. Changing species distributions impacts emissions to the atmosphere and human activities and therefore also become relevant to regulating climate change. Regulating the activities impacting on migratory species such as birds, energy transmission, and land use that usually modifies species habitat is all relevant to climate change.

Valuation of species is also related to consumer products and services. Consumer behavior and its modification through regulation and appropriately targeted municipal and private market services become imperative. Taxation systems can and do influence choices and have an effect on anthropogenic emissions. Other means of contributing to the amelioration of the climate change problem would be through actual regulatory measures coupled with market mechanisms. The product design and inventories and other similar information may be critically associated with the development of market mechanisms that include cap and trade systems.

Non-state entities also generate rules that are not typically included in the legal sense of the term regulation, but would be regulatory within the entity. For example, a business may take note of international and state laws or lack thereof in formulating its own internal rules and procedures. Where such entities are multinational, these internal rules may also be applicable in multiple state jurisdictions. Trade or industry groups and other associations can also formulate rules and regulations. Independent industry associations have also formulated rules or standards for environmental management systems along with procedures to certify those that comply with such standards.

The enterprise of modifying the climate changes has been inadvertent until recently, and the shift toward regulating the change intentionally has been growing in strength. Early attempts at regulating the climate involved the use of chemicals such as silver iodide to seed clouds to induce rainfall. For some, the ability to regulate the climate was also conceivably a strategic weapon that could be deployed in conflict.

In the United Kingdom, early air pollution issues arose with the regulation of the alkali industry with the Alkali Act of 1863, 1874, and consolidated in the Alkali Works Regulation Act of 1906. The Alkali Inspectorate later became Her Majesty's Inspectorate of Pollution and now amalgamated into the Environmental Agency. With separate legislation for smoke abatement in 1926 and the Clean Air Act in 1956 enacted following the death of 12,000 people from the London smog, regulating atmospheric gases and particulate emissions is not new. However, it was only in 1974 that a coherent regulatory structure was set up with the Health and Safety at Work Act and the Control of Pollution Act.

In the United States, regulation has proceeded unevenly between the federal and state levels and between states. For instance, California has taken a much more aggressive approach to regulating greenhouse gases than the federal government and some other states. Regional cooperation has also resulted in some cooperative regulatory regimes. The unevenness of the regulations regionally and globally has begun to have impacts also on the economic context with flows of products and processes being modified with differing features and specifications in response to local regulatory circumstances.

With the consumption of energy a dominant feature of human activity that results in the emission of greenhouse gases, the regulation of such usage has gained prominence. The installation of smart meters, which provide detailed information on the usage patterns for electricity consumption, along with the possibility of controlling energy distribution patterns by time of day, geographic location, and land use has begun to appear in places like Toronto, Canada. Thus, climate change-related concerns are beginning to be included in urban and regional planning regulations.

Additionally, the emergence of new viable renewable energy alternatives with reduced atmospheric impacts is also part of the trend to new regulations. In some jurisdictions, it is now possible for locally generated wind and solar power to be sold to the statewide grid operated by the usual utility companies. The tax regimes are also being considered legitimate means of regulating greenhouse gas emissions. From taxing the products that lead to the emissions to industries that directly emit the greenhouse gases, the complexity of the human response to climate change is growing.

CONCLUSION

In the context of climate change, regulation proceeds from an anthropogenic understanding and utilizes sociopolitical actions to implement technological and legal regulations as they occur in the totality of the climate system. From the understanding of the climate system as defined in Article 1 of the UNFCCC, very little human activity is irrelevant to the climate change and regulating the changes in the climate system is critical to the future of this planet.

SEE ALSO: Intergovernmental Panel on Climate Change (IPCC); Kyoto Mechanisms; Kyoto Protocol; Policy, International; Policy, U.S.

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Religion

RELIGION IS A universal and varied phenomenon. While there have been those who have rejected all religion and espouse atheism, they have been for practical purposes a very small minority until recently. The attempts since the Enlightenment in Western Europe in the 1700s to foster a belief in atheism has met with little success, except among educated elites in the more advanced industrialized countries. During the time of Communist domination in the Soviet Union or in Communist China, as well as other Communist countries, the attempts to suppress religion have almost completely failed.

ANCIENT RELIGIONS

For much of humanity, especially among tribal peoples, spirits are viewed as the animating part of nature. There are believed to be spirits in rocks, trees, plants, animals, or the forces of nature. Placating these spirits, which can be deadly, is a part of the acts of worship of many different groups of people. This may involve sacrifices to quiet a volcano, or the sacrifice of young men and women to the water god at the bottom of a well in order to bring the rains. Many of the religions of the Middle East in ancient times were fertility religions. Baal worship was done with cultic sexual practices that were believed to affect nature with fertility.

Among many peoples around the world, shamans, witch doctors, or medicine men have been the chief spiritual leaders. Shamans, who would beat drums and were transformed into a dancing bear or a seal or some other totemic animal, led the Inuit of northern Canada. The shaman, in a transformed and trance-like state, would then go on a spiritual journey where he would meet spirits in the spirit world who would be able to give him (or sometimes her) knowledge of the causes of sickness, the absence of the fish, or the failure of crops among people living in more temperate societies. The shaman might also wrestle with evil spirits that were causing nature to war on humans.

Other ancient religions, such as those of the Greeks, Romans, and Chinese, believed that dramatic events in nature were messages from the gods or spirit ancestors. For the Chinese, natural events could be signs that the ruling dynasty had lost the mandate of heaven. Signs such as droughts, floods, earthquakes, fires, or other natural disasters, especially if accompanied by events such as an unexpected arrival of a comet, were among the signs that said the ruling dynasty should be replaced. Virtually all of the movements that changed dynasties in Chinese history were religiously inspired.

The Chinese philosophy of Daoism (Taoism) founded by Lao Tzu, author of the Tao Te Ching, taught a philosophy of living in accord with nature. The sage, or just the common man who sought wisdom, would live wisely if he or even she went with the flow of nature. There was therefore a rhythm to life that led people to live according to nature.

CONTEMPORARY RELIGIONS

The Europeans who came to North America were farmers and settlers, rather than adventurers or traders, like many of the other Europeans who settled in what became Latin America. Their theology was based upon the Bible, which taught in Genesis that people should multiply and fill the Earth. In addition, they were to subdue the Earth and make a garden of it. Obedience to these commands may have been fulfilled too well. However, the land and water practices of Europeans had developed independently of Christian influences for centuries before their conversion. The Europeans had effectively deforested much of Europe and killed off a variety of species before the arrival of Christianity. What Christianity taught was stewardship.

It was like the stewardship practiced in ancient Israel. The religion of the Israelites included farming land owned by a family that would be handed down to the succeeding generations. This meant that the owners needed to practice careful husbandry that preserved the land and its resources for continued use over the generations. The idea of "development" by commercial developers common in the United States today would have been completely alien. In the modern State of Israel, there has been an ongoing project of afforestation, of identifying ancient practices and using them to make the Negev region, which is very arid, to bloom. The religious beliefs of earlier times have pushed the greening of the land since the beginning of the Zionist movement to return to the land of Israel. Oddly enough, those Christians who are most supportive of the return of the Jews to Israel are often not inclined to conservation.

Those groups that are usually evangelicals and fundamentalists who accept the end of history with the return of Jesus Christ in his Second Coming are those who believe that this divine event will happen very soon. To them, it is important to use Earth's resources before Christ returns, or else they will be wasted. The theological doctrine they commonly subscribe to is premillennialist. This, however, has historically been a minority view. Most Christians have been amillennialists, who believe that the Second Coming will be a complete surprise.

Therefore, the appropriate ethic for the eschaton (the period of waiting or the period of the last days) is to practice good stewardship of the resources of nature. The remaining theological position is postmillennialism. It is a very optimistic teaching about the unfolding of the events of the last days. The belief is that most people will become Christians and that the world will make steady progress until virtually near the end of the age. Most adherents discarded this optimistic view after the two world wars.

Religion has a powerful effect on people in a variety of ways. It can satisfy spiritual needs and organize energies to accomplish grand projects. The building of the pyramids, and other numerous architectural monuments in the ancient and medieval world, were driven by religious faith. Today, most of the peoples of the world belong to one of the major religions of Hinduism, Buddhism, Jainism, Sikhism, Judaism, Islam, or Christianity. Those who still follow Confucianism or Daoism are mostly confined to Taiwan or to other overseas Chinese communities. Among these and many smaller religious groups, there is developing a great concern for the present state of the globe.

Jainism has since its beginnings over 2,500 years ago practiced reverence for life or *ahimsa*. For the Jains, all living things are not to be harmed, because this will add karma to the soul of those who kill other living creatures, such as animals or even insects. This has made merchants of Jains, rather than butchers or farmers. Their ethic is one that requires urban living tolerance of wildlife if it invades the urban area.

For example, there are both Christian ethicists who teach in seminaries and lay people who work with environmental issues who are seeking to develop principles of a Christian environmental ethic. The goal is then to apply the Christian ethical principles to agriculture, to natural resources, and to the environment that go beyond traditional principles of stewardship. Ethical debates about environmental issues such as global warming are about problems that are current or that are likely to arise. The problems are likely to be caused by technological advances that allow for exploitation of resources in ways that are very productive, but also destructive of future utilization. The issues that arise concern agreement over what are the environmental facts, the nature of the problem, and the appropriate solution(s).

At the core of these disagreements are different values and beliefs related to nature itself, and the use and management of nature by people. A growing number of scholars in the humanities, social sciences, and physical and biological sciences are emphasizing that the problems causing environmental issues are fundamentally interrelated with ethical issues.

SEE ALSO: Climate Change, Effects; Conservation; Education; Ethics.

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Renewable Energy Policy Project (REPP)

FOUNDED IN 1995, the Renewable Energy Policy Project (REPP) is based in Washington, D.C. The organization researches strategies to make renewable sources competitive in energy markets and to stabilize carbon emissions. REPP supports reindustrialization through the use of renewable technologies. It demonstrates that solar, wind, biomass, and other renewable sources can provide energy services at or below the cost of nonrenewables when structural barriers are removed. REPP works directly with states and firms to help them develop their renewable portfolio. The organization also provides expert information to consumers to improve energy efficiency and guide their transition to alternative energy options. To promote sales of renewable energy products and services, REPP created a buyer's guide and consumer directory for approximately 5,000 businesses.

REPP was initiated with support from the Energy Foundation and the U.S. Department of Energy. While financial support is determined on an annual or project-by-project basis, major donors have included the Oak Foundation, SURDNA Foundation, Turner Foundation, Bancker-Willimas Foundation, Joyce-Mertz-Gilmore Foundation, National Renewable Energy Lab, and the U.S. Environmental Protection Agency. REPP's board of directors includes leaders from renewable energy businesses, the financial sector, environmental advocacy groups, regulators, government officials, and multilateral development institutions.

A core issue for REPP is assisting the United States to stabilize its carbon emissions using renewable energies. This goal would have a significant impact on the world's carbon balance given that the United States produces approximately two-sevenths of global carbon emissions. Half of this, or one of seven total global wedges, comes from electricity. REPP's use of the wedge concept builds from the work of Stephen Pacala and Robert Socolow. Based on REPP's research, they suggest that mitigation of one wedge can be implemented with the annual production of 18,500 Megawatts of electricity from renewables.

REPP works with the renewable energy–component manufacturing sector to make it more transparent, facilitate entry, improve production, and promote growth. For example, wind energy requires rotors, towers, and generators. All the components for wind turbines can be produced domestically, and 25 states already have firms active in this manufacturing. REPP attempts to refine the supply chain to determine the exact specifications and avoid any potential bottlenecks as the use of wind power rapidly expands. This type of expertise has been underdeveloped and has slowed domestic manufacturing of renewable technologies. REPP also advocates for production tax credits for renewable energy projects.

REPP recently completed a state analysis for California, Michigan, Ohio, Wisconsin, Pennsylvania, Nevada, and Arizona. The REPP state reports provide an explanation of how manufacturing potential is calculated, and offer detailed analysis showing for a state, region, and county the potential for each of the 43 industrial codes (NAICS codes) that comprise the major component parts for the major renewable energy technologies. REPP provides states with a web-based product to present analysis in a graphical manner.

A total of 16 states have created Renewable Portfolio Standards that mandate that they generate a percent of their electricity from renewable sources. REPP analyzes the experience of these states and tracks industries to determine whether costs have declined. In addition to stimulating demand for renewables, REPP state reports identify the specific firms that could benefit from an existing or proposed national program.

REPP has linked social and economic development to ecological concerns. The staff argues that renewables take advantage of resources, such as biomass or wind, that are currently underutilized or wasted. This can provide local economic support, labor benefits, and job creation. As REPP promotes wind energy development in North Carolina, the organization advocates for a variety of direct and indirect benefits to local communities. An important element of REPP's work is promoting public awareness of success stories, such as a Nevada bill in 2003 that provided economic incentive to participants using photovoltaics. The first Solar Energy Systems Demonstration Program resulting from the bill was created in conjunction with the Washoe Tribe. REPP acquired the Center for Renewable Energy and Sustainable Technology (CREST) in 1999. CREST circulates policy briefs, fact sheets, and testimonials from

The Renewable Energy Policy Project researches strategies to make renewable sources competitive in energy markets. Solar, wind, biomass, and other renewable sources can provide energy services at or below the cost of nonrenewable sources.

public officials. It hosts popular renewable energy discussion groups with topics such as green building, stoves, photovoltaic use, and bioenergy.

SEE ALSO: Alternative Energy, Overview; Carbon Emissions; Department of Energy, U.S.

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Resources

A RESOURCE IS any item or substance that is in scarce supply and has some value. Resources are normally considered to be physical items, such as oil and natural gas. However, it is also possible to consider humans resources, since they are finite in number and are perishable under current technological conditions. Resources, when used in the context of computer or virtual environments, meanwhile, are inherently intangible in nature, although the hardware that produces them is not.

It is customary, when considering resources, to distinguish between those that are renewable and those that are nonrenewable. Resources such as oil are consumed in use and are, therefore, nonrenewable. However, in a number of other cases, it is possible to recreate or recycle some resources either in the original form or, at least, some components of the original. Glass and plastic bottles may, to some extent, be recycled into different forms and so value is created from spent resources that appear to be valueless. Considerable effort has been expended in determining which resources may be recycled or recreated in this way and, in some countries, it has led to significant social change as people become accustomed to considering the issues involved and sorting out recyclable household waste. The process is mirrored at the industrial level, too, especially when economic incentives are provided to encourage this behavior.

Improved technology has also provided two other means of increasing the stock of resources, or at least minimizing their depletion. The first is to employ more commonly occurring resources for more rare ones. This substitution may be seen in the prevalence of plastic bags, which are dispensed with alacrity at many retail outlets. More recently, the negative impact of those plastic bags has prompted the search for other materials that would be more environmentally friendly (more biodegradable). The process of beneficiation, on the other hand, is one in which technology enables the gathering or exploitation of resources which were previously considered to be too difficult or expensive to obtain. The search for coal deeper underground or in mines located underwater is an example of this, while the continuing demand for oil and the ability to extract it means that sources previously ignored have become of considerable strategic importance.

For example, water is considered a renewable resource, because once used, it can be returned to the circulatory system that returns it to use via evaporation and precipitation. However, the modern world has seen a growth in populations and demand for water, together with climate change, that has demonstrated the extent to which water resources are in fact insufficient for future use, given current trends for demand. It is possible to characterize the Middle Eastern wars between Israel and neighbors as the result of fighting for scarce water resources, while the conflict in Darfur in Sudan has been characterized as resulting from nomadic movements of people searching for water.

MORAL AUTHORITY TO USE AND DEPLETE RESOURCES

Most human societies have developed with a religious basis that justifies mankind's prerogative to use the resources of the Earth for its own benefit. Christianity, Judaism, and Islam, for example, have similar roots in a tradition that states a divine provenance for the world and the entire universe and the passing of responsibility to shepherding the world to humanity. Certain variations in scripture explain dietary rules for the different religions, and these have led to different uses of the land and the resources of the world. The same is true of those now rare religions that are believed to offer stewardship of the world to one specific group of people. The animism of the Mongols, for example, in common with that of certain other steppe peoples, was used to help justify the destruction of resources, including people, not immediately wanted or needed by khans and other leaders.

Buddhism stresses the endless cycle of birth, rebirth, and suffering in which souls are reincarnated in a variety of forms through the ages. Since souls could inhabit not only animate but inanimate objects, then it benefits people to take care of those items appropriately. They may be used in moderation, but not abused and used excessively. Other religious beliefs also confer upon humanity the right to use natural resources, but with certain limitations. The same is true of some moral creeds that have an environmental basis. Proponents of the Gaia hypothesis, for example, hold the resources of the Earth to be central to the successful existence of nature; consequently, husbanding of those resources is a central part of the successful functioning of society.

Belief systems based on nonreligious bases have not always been so favorable to the environment. Communism, for example, appropriates the resources of the Earth for the betterment of society, and has little to say about conservation of those resources. The impact on the environment by the Russian and Chinese Communist parties has been among the most severe in the world. Similar levels of exploitation of resources, such as pollution and overlogging, for example, are also witnessed when private-sector, free-market interests have been able to gain access to resources. The *Tragedy of the Commons* by William Foster Lloyd framed the potential problem of a laissez-faire approach to the management of nature. The presence of democracy in a country, accompanied by fair and transparent policing of the laws, is one of the best means of ensuring that overexploitation of resources does not take place. The Indian economist Amartya Sen, who observed that no famine had ever occurred in a functioning democracy, originally noted this concept.

THE DIMINUTION OF NATURAL RESOURCES

The history of cod fishing in the Atlantic Ocean is a graphic example of the abundance of resources available in past centuries and the way in which those resources have been enormously diminished within the last century. For hundreds and in some cases thousands of years, the ability of man to harvest resources, renewable resources in any case, was exceeded by the fertility of nature in replacing them. The development of industrialized harvesting techniques succeeded not only in depleting the stocks of the fish, but also seriously damaged the environment, including the ecology, in which the cod thrived. The diminution of this resource, in common with so many others, has been so severe that it is not possible to recreate a satisfactory understanding of the amount of the resource previously available. This makes it extremely difficult to identify means of returning to the status quo before overexploitation and, hence, it is not very likely that such a state could ever be attained. It would take an event as severe in its impact as World War II, which effectively prevented deep sea fishing in the Atlantic Ocean altogether for several years, for fish stocks to be replenished to any meaningful degree.

Overfishing has probably already destroyed ocean ecologies beyond repair, and the same is true of the logging of hardwood trees in the former rainforests of Thailand and Burma. Arguments persist over whether the production of oil and natural gas has yet peaked, or is at its maximum now, but the existing oil is not going to be replenished. Human society must prepare to live in a world in which many of the resources on which it had previously relied are no longer available.

RESOURCE ALLOCATION

Given that resources are, by definition, finite and scarce in nature, then there must be some mechanism to allocate different shares to different sets of people. Allowing everyone who has an interest in resource exploitation to do so as freely as desired will lead to disastrous depletion of the resource. Consequently, the basis of allocation must be determined.

In mature, democratic societies, coalitions of interests will help to set the agenda by which resources are allocated. This can be quite efficient in determining the share that each set of interests will gain, but has proved to be less successful in setting the amount of resource that may be allocated on a sustainable basis. Democratic debate must, consequently, be supplemented with a technical limitation determining overall exploitation in order to be viable. This is a superior approach to those that rely on market power (where resources go to those who can afford them and are denied to the poor), since these suffer from equity issues and, more relevantly, from the stress inflicted by inequality and the high probability that it will lead to social unrest and ultimately rebellion.

Systems that reward the rich at the expense of the poor rely, therefore, on the ability and willingness of the former to mobilize the threat of armed violence against the latter. Even so, social systems of this sort still rely upon the labor of the masses to produce goods and services to facilitate the lifestyle of the rich. Sequestering oxygen or water, therefore, which are essential for life, will provide short and possibly medium-term gains for the rich, but the system is not sustainable over the long term because it will lead to the deaths of so many of the poor. This in itself might not threaten the survival of the system, but the reduction in production capacity will do so.

Irrespective of the means by which resource allocation is managed, it must be supplemented by attempts to determine the presence or creation of substitutes. Resource scarcity inevitably leads to inequality, and this reduces social stability. The promise of suitable substitutes at some stage in the future helps to alleviate the pressures that this builds.

SEE ALSO: Alternative Energy, Overview; Ethics; Oil, Consumption of; Oil, Production of; Religion.

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Resources for the Future (RFF)

RESOURCES FOR THE Future (RFF) is a nonprofit, nonpartisan organization with headquarters in Washington, D.C. Founded in 1952 under the Truman Administration, RFF initially had a domestic focus, but has since shifted to include international affairs. With a variety of outlets for data dissemination, RFF provides intellectual leadership in environmental economics. Research methods are based in the social sciences and quantitative economic analysis, including cost-benefit trade-offs, valuations, and risk assessments. RFF scholars compile core knowledge on a range of environmental topics, with the goal of contributing to scholarship, teaching, debate, and decision making. One major division of research is energy, electricity, and climate change.

RFF was the first think tank in the United States devoted exclusively to environmental issues. The impetus for RFF came from William Paley, who had formerly chaired a presidential commission charged with examining whether the United States was becoming overly dependent on foreign natural resources and commodities. Today, the RFF board of directors consists of members of the business community, former state officials, academics, and leaders of environmental advocacy organizations. It is increasingly inclusive in terms of nationality, race, and gender.

By 2006, RFF had operating revenue of $10.6 million, of which nearly 70 percent came from individual contributions and private foundations, as well as the 25 percent that is generated from government grants. The rest was withdrawn from a reserve fund valued at over $35 million that was created to support the organization's operations.

RFF has approximately 40 staff researchers composed of senior fellows, fellows, resident scholars, research assistants, and associates. In addition, RFF hosts visiting scholars from academia and the policy community. RFF scholars share their findings through seminars and conferences, congressional testimony, and global media. They publish in external peer-reviewed journals and several RFF publications, including discussion papers, reports, issue briefs, and *Resources* magazine. The online *Weathervane* is a guide to global climate policy. *RFF Connection* is an electronic newsletter that provides updates on events, research, and publications. RFF Press offers hundreds of titles on environmental issues written by the organization's staff and outside experts.

The focus of RFF's research has shifted to include global concerns, although U.S. policy innovation and implementation maintain importance. International research topics include environmental governance in the European Union, the UN-based negotiations that produced the UNFCCC and the Kyoto Protocol, and the U.S. proposal for a technology transfer agreement. RFF scholars also examine the related topics of climate stabilization and air pollution control in rapidly developing countries such as China and India.

RFF's Climate and Technology Program analyzes and critiques options for U.S. policy and the role of technology development and deployment in combating carbon emissions. In 2007, RFF scholars authored a series of background reports related to the design of federal climate policy. They provide stakeholders and policymakers with an understanding of policy options, from which effective mandatory federal policy might be crafted. Researchers have estimated the costs of emissions abatement, calculated the benefits of mitigating climate change impacts, assessed the effect of the choice of discount rate for long-term policies, and characterized uncertainty in such analyses.

RFF is certified as a U.S. General Services Administration (GSA) Management, Organizational and Business Improvement Services (MOBIS) contractor for consulting, survey, and facilitation services. MOBIS contractors assist the federal government to respond to new mandates and evolving practices. RFF researchers are also analyzing proposed actions and evaluating current efforts of state and local governments as well as the business sector.

RFF provides ongoing support to many state and nongovernmental organizations, including the Intergovernmental Panel on Climate Change. For decades, the RFF Seminar Series has provided the Washington community with a weekly forum in which scholars, journalists, advocates, and policymakers interact. RFF internships and doctoral and postdoctoral fellowships train and support future leaders and scientists.

SEE ALSO: Policy, International; Policy, U.S.; Sustainability.

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Revelle, Roger (1909–91)

AN EARLY PREDICTOR of global warming, Roger Revelle helped to start the scientific debate on the issue in the late 1950s. He challenged the accepted notion that global warming was countered by the absorption of carbon dioxide from the oceans. Revelle discovered that the particular chemistry of sea water hinders such absorption. Because of the respect that he earned among the scientific community, Revelle was regarded as a spokesperson for science whose advice on as diverse matters as world population, agricultural policies, education, and the preservation of the environment were held in high esteem.

Born in Seattle, Washington, on March 7, 1909, Revelle was raised in Pasadena, California, and soon stood out as a gifted student during his academic career. In 1925, Revelle enrolled at Pomona College with an interest in journalism, but later switched to geology as his major field of study. In 1928, Revelle met Ellen Virginia Clark, a student at the neighboring Scripps College and a grandniece of Scripps College founder Ellen Browning Scripps. The couple married in 1931.

Revelle obtained his bachelor's degree from Pomona in 1929, and then entered the University of California–Berkley to pursue his studies in geology. In 1931, his professor George Davis Louderback recommended him for a research assistantship in oceanography at the Scripps Institute of Oceanography in

Roger Revelle lead navy research in oceanography. His carbon dioxide research led to his predictions of global warming.

La Jolla, California. While at Scripps, Revelle took part in several expeditions on the *Scripps*, the institute's small research vessel. He was also a guest on ships of the U.S. Coast and Geodetic Survey and the U.S. Navy. In 1936, Revelle completed his dissertation, "Marine Bottom Samples Collected in the Pacific Ocean by the *Carnegie* on its Seventh Cruise," and was awarded his Ph.D. He was immediately hired as an oceanography instructor at Scripps, under the directorship of Harald Sverdrup.

During World War II, Revelle served in the U.S. Navy as the commander of the oceanographic section of the Bureau of Ships and became head of their geophysics branch in 1946. His reputation and influence in the navy quickly grew during the war and enabled him to substantially influence the navy research program in oceanography. Revelle received an official commendation for this work from Secretary of the Navy James Forrestal after the war. After the conflict, he returned to Scripps in 1948 and directed it from 1951 to 1964. The scientist was involved in supervision of the first postwar atomic test on Bikini Atoll, Operation Crossroads. He led the oceanographic and geophysical components of the operation. His task was to study the diffusion of radioactive wastes and the environmental effects of the bomb at Bikini.

During his directorship at Scripps, Revelle was also appointed to other prestigious positions such as chairman of the Panel on Oceanography of the U.S. National Committee on the International Geophysical Year (IGY). Scripps, which Revelle was constantly expanding thanks to his administrative skills, was initially designated as a participant in the IGY, but was later promoted to the main center in the Atmospheric Carbon Dioxide Program. As a result, Revelle's interest in the general carbon cycle and the solubility of calcium carbonate grew and he began a systematic research which engaged him for the rest of his life. The result of this interest was a famous 1957 article published in *Tellus*, a European meteorology and oceanography journal, which Revelle coauthored with Hans Suess, one of the founders of radiocarbon dating. The article demonstrated that carbon dioxide had increased in the air as a result of the use of fossil fuels.

Following this discovery, in 1963, Revelle took a leave of absence from Scripps and committed himself to public policy. Revelle was among the first in the scientific community to bring the subject of rising levels of carbon dioxide to the attention of the public as a member of the President's Science Advisory Committee Panel on Environmental Pollution in 1965. The committee, chaired by Revelle, published the first authoritative U.S. government report which officially stated that carbon dioxide from fossil fuels was a potential global threat. Revelle also founded the Center for Population Studies at Harvard University, and spent more than a decade as director. His primary interests were applications of science and technology to world hunger. In 1976, Revelle returned to the University of California–San Diego where he received the title of Professor of Science and Public Policy and joined the Department of Political Science.

As the chair of the National Academy of Sciences Energy and Climate Panel in 1977, Revelle concluded that about 40 percent of the anthropogenic carbon dioxide has remained in the atmosphere. It was produced two-thirds from fossil fuel, and one-third from the clearing of forests. In his role of spokesperson against the dangers of global warming, Revelle influenced public opinion on the carbon dioxide issue thanks to a widely read article published in *Scientific American* in August 1982. His research emphasized the rise in global sea level and the melting of glaciers and ice sheets caused by the thermal increase of the warming surface waters. Through his international scientific contacts, Revelle circulated his research findings and fostered debates about his findings and the threatening environmental and social effects of increased atmospheric carbon dioxide. The scientist was an early advocate of governmental policy and action.

Revelle was a respected member of many academic, scientific, and government committees. He was science adviser to the secretary of the interior, president of the American Association for the Advancement of Science, and a member of the NASA Advisory Council. In November 1990, Roger Revelle received the National Medal of Science from President George Bush.

SEE ALSO: Carbon Cycle; Carbon Dioxide; Carbon Emissions; Global Warming; Navy, U.S.; Scripps Institute of Oceanography; Sea Level, Rising; Sverdrup, Harald Ulrik.

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Rhode Island

RHODE ISLAND HAS an area of 1,545 sq. mi. (4,001 sq. m.) with an average elevation of 200 ft. (61 m.) above sea level. The land is divided into two regions: the coastal lowlands (made up of sandy beaches, rocky cliffs, lagoons, saltwater ponds and low plains) covering more than half of Rhode Island; and the Eastern New England Uplands, a region of small valleys, rolling hills, lakes, reservoirs and ponds.

Rhode Island's humid continental climate is a little milder than in most of New England, with the extremes of winter cold and summer heat moderated by the Atlantic Ocean and Narragansett Bay. Providence's annual average temperature is 51 degrees F (11 degrees C), with January temperatures averaging 29 degrees F (minus 1.5 degrees C), and July temperatures averaging 73 degrees F (23 degrees C), with an annual precipitation of 46 in (117 cm.). Temperatures are moderated by warm winds off Narragansett Bay, but extremes do occur. The highest temperature recorded in the state was 104 degrees F (40 degrees C) on August 2, 1975, and the lowest temperature recorded in the state was minus 23 degrees F (minus 31 degrees C) on January 11, 1942. Rhode Island's soil is fertile, but very rocky, and about 60 percent of Rhode Island's land is covered by forest.

In 1969, massive storm surges from Hurricane Carol raged through the Rhode Island Yacht Club.

IMPACT OF CLIMATE CHANGE

Beaches do not stay put, waves and current move the sand and change the coastline, and this damage will likely increase as sea levels rise and the intensity of storms increases. The average temperature in Providence has risen about 3.3 degrees F (1.8 degrees C) over the last century. Coastal erosion and storm surges have already damaged many of the state's tidal flats and dunes, including those on Block Island and throughout the Rhode Island Refuge Complex. Rhode Island's 400 mi. (644 km.) of coastline is home to the bulk of the state's residents. The beaches along the south shore have already been severely damaged by hurricanes and storm surges. Many of Rhode Island's lakes and waterways are freezing for shorter periods of time, reducing traditional outdoor recreation opportunities such as hockey and ice-skating. Rhode Island's current ozone levels exceed national health standards, and the entire state is rated as having a "serious" problem attaining safe levels. Warmer weather could increase concentrations of ground-level ozone, which is known to aggravate respiratory problems.

Based on energy consumption data from the Energy Information Administration, Rhode Island's total CO_2 emissions from fossil fuel combustion in million metric tons for 2004 was 10.95, made up of contributions by source from commercial, 1.20; industrial, 0.62; residential, 2.80; transportation, 4.38; and electric power, 1.96.

Rhode Island adopted a "renewable portfolio standard" that calls for 16 percent of the state's energy to come from clean, renewable sources like solar and wind by 2020, and a greenhouse gas reduction target is to meet 1990 levels of six greenhouse gases by 2010 and below 1990 levels by 2020. Rhode Island joined the Climate Registry, a voluntary national initiative to track, verify, and report greenhouse gas emissions, with acceptance of data from state agencies, corporations, and educational institutions beginning in January

2008 and joined all the states in New England (as well as others in the mid-Atlantic area) in the Regional Greenhouse Gas Initiative (RGGI), the first multiple-states, market-based mandatory cap-and-trade program to reduce heat-trapping emissions from power plants. The Environmental Council of Rhode Island and more than 70 other state groups and businesses are part of the Rhode Island Climate Coalition, which is working to support the state's climate action plan.

SEE ALSO: Hurricanes and Typhoons; Sea Level, Rising.

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Richardson, Lewis Fry (1881–1953)

LEWIS FRY RICHARDSON was an innovative Britsh mathematician, physicist, and psychologist who first tried to apply mathematical concepts to weather forecast. Although his method for weather forecasting was not entirely successful during his lifetime, it was rediscovered with the advent of computers and formed the basis for computer-based weather forecast. The recorded change over a given distance of temperature and wind (gradient) is named the Richardson number after him.

Lewis Fry Richardson was born into a wealthy Quaker family in Newcastle-Upon-Tyne on October 11, 1881. His mother, Catherine Fry, was the daughter of corn merchants, and his father, David Richardson, came from a family of tanners, a profession that he took up himself. Lewis was the youngest of a large family of seven children. He attended Newcastle Preparatory School where he already showed his predilection for math, particularly the study of Euclid. Then in 1894 he went to Bootham School in York, an elite Quaker institution established in 1823. It was here that Richardson first combined his interest for math with science and meteorology in particular. One of his teachers, Edmund Clark, was in fact an expert in meteorology and greatly influenced Richardson. The institution also reinforced Lewis's pacifism, a value that had been taught to him by his parents and a fundamental tenet of Quakerism which led him to difficult career choices in his maturity. After leaving Bootham in 1898, Richardson spent two years in Newcastle at the Durham College of Science where he studied mathematics, physics, chemistry, botany, and zoology. Richardson completed his education at King's College, Cambridge, from which he graduated with a First Class degree in the Natural Science Tripos in 1903.

After graduation, Richardson was employed at many different posts. He worked in the National Physical Laboratory (1903–04, 1907–09) and the Meteorological Office (1913–16), and he was hired as a university lecturer at University College Aberystwyth (1905–06) and Manchester College of Technology (1912–13). In addition he was a chemist with National Peat Industries (1906–07) and directed the physical and chemical laboratory of the Sunbeam Lamp Company (1909–12). He married Dorothy Garnett in 1909 and although they had no children of their own, they adopted two sons and a daughter.

Richardson was working for the Meteorological Office as superintendent of the Eskdalemuir Observatory at the outbreak of World War I in 1914. Because of his Quaker beliefs, he declared himself a conscientious objector and could not, therefore, be drafted into the military. This choice implied that he would never be able to qualify for university posts. While Richardson was not involved in military operations, from 1916 to 1919 he served in the Friends Ambulance Unit, attached to the 16th French Infantry Division, where his work earned him praise. After the war, Richardson returned to his position in the Meteorological Office, but had to resign from it in 1920 when the Meteorological Office became part of the Air Ministry. His pacifist beliefs could not allow him to continue to work for an institution which was part of the military. Richardson then went back to teaching. From 1920 to 1929 he headed the Physics Department at Westminster Training College, and from 1929 to 1940, he was principal of Paisley College of Technology and School of Art in Scotland. He retired in 1940 at the age of 59 to concentrate on research.

Richardson had a lifelong interest in the application of mathematics to meteorology. He was the first to apply the mathematical method of finite differences to the prediction of the weather in his study *Weather Prediction by Numerical Process* (1922). His method of finite differences was designed to solve differential equations, arising in his work on the flow of water in peat for the National Peat Industries. As these methods allowed him to obtain highly accurate solutions, he decided to apply them to solve the problems of the dynamics of the atmosphere encountered while working for the Meteorological Office. The initial conditions were defined through observations from weather stations, and would then be used to solve the equations. Finally, a prediction of the weather could be made. Richardson's remarkable insight was ahead of its time since the time taken for the necessary hand calculations in a precomputer age took too long. Even with a large group of people working to solve the equations, the solution could not be found in time to be useful to predict the weather. Richardson himself admitted that it would take 60,000 people to have the prediction of tomorrow's weather before the weather actually arrived. In spite of this flaw, Richardson's work pioneered present day weather forecasting.

Throughout his life, Richardson published extensively on the application of mathematics to the weather and contributed to the theory of diffusion, specifically regarding eddy-diffusion in the atmosphere. For his scientific achievements, he was elected to the Royal Society in 1926. His deeply-rooted interest in pacifism led him to apply mathematics to the study of wars and military conflicts. His results were published in three major books: *Generalized Foreign Politics* (1939), *Arms and Insecurity* (1949), and *Statistics of Deadly Quarrels* (1950). Richardson used mathematics to challenge the assumption that war was a rational national policy in the interests of a nation. He gave systems of differential equations governing the interactions between countries. Starting with the armament of two nations, Richardson constructed an idealized system of equations calculating the rate of a nation's military buildup as directly proportional to the amount of arms its rival has and also to the disputes toward the enemy. This rate is, instead, negatively proportional to the amount of arms it already has itself. Richardson died on September 30, 1953, in Kilmun, Argyll, Scotland.

SEE ALSO: Climate Models; Weather.

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Risk

RISK IS A concept that captures the probability and, in some instances, the potential severity of the occurrence of a negative outcome (that is, being exposed to a hazard). There is much discussion surrounding the various risks associated with global warming and climate change, such as those related to the environment, ecosystem, human health, and the world economy. In this regard, various experts have used risk analysis to assess, manage, and communicate these associated risks.

Global warming occurs as a result of the accumulation of greenhouse gases in the atmosphere. These greenhouse gases occur both naturally (such as water vapor, carbon dioxide, methane, and ozone) and as a result of human activity (for example, from the burning of fossil fuels, deforestation, and the use of chlorofluorocarbons and fertilizers). The latter has been the focus of a 2007 report from the Intergovernmental Panel on Climate Change (IPCC). This has led to a great deal of discussion surrounding the various policy implications that lie ahead.

There are several environmental risks associated with global warming and climate change—some of which have been noted by researchers worldwide as already occurring, and others that have been forecast. Climate change affects countries differently depending partly on their geographical location.

The record high temperatures documented over the past two decades have resulted in early ice thaw on rivers and lakes. Furthermore, the rates of sea-level rise are expected to continue to increase as a result of both the thermal expansion of the oceans and the partial melting of mountain glaciers and the Antarctic and Greenland ice caps. It has been reported that increasing temperatures have also been the cause of many extreme weather events such as heat waves, droughts, and wildfires.

Moreover, changes to ocean temperatures and wind patterns have resulted in more frequent and intense rain and ice storms, floods, and some natural disasters such as hurricanes and typhoons. An increase in the frequency and severity of disasters can lead to secondary effects such as massive mudslides—as was the case with Hurricane Mitch in 1998. They can also have far-reaching effects that can result in a loss of livelihood, displacement, as well as local and global migration, particularly for those living in communities in the most vulnerable areas (such as low-lying coastal areas and estuaries, alpine regions, and tropical and subtropical population centers). Additionally, these risks can be exacerbated for marginalized groups as well as those living in more vulnerable communities (for example, regions that are poverty laden or more crowded).

HUMAN HEALTH AND DISEASE RISKS

Extreme weather events can have disastrous effects on physical and mental health as well as environmental health. The occurrence of droughts can lead to problems associated with water availability and quality (for example, people sharing water with livestock). Similarly, heat-related effects such as exhaustion, cramps, heart attacks, stroke, and even death are possible outcomes as a result of heat waves. Furthermore, excessive rainfalls and flooding are associated with the risk of injuries and death (as from drowning), as well as the spread of various water-borne diseases (via fecal-contaminated waterways and drinking supplies), and exposure to toxic pollutants (from nearby industrial sites and municipal sewage—as was the case with the Elbe flood which took place in 2002 in central Europe). The variation of risks associated with the transmission of infectious diseases as a result of extreme weather events have also been documented; however, their relation to global warming and climate change have not yet been conclusively reported in the literature.

The risks associated with the transmission of infectious diseases are dependent upon the kind(s) of weather event(s) that have occurred. As such, the reproduction and survival of disease-carrying vectors such as mosquitoes could be impaired by heavy rainfalls (such as flushing larvae from pooled water) or heightened by changes in climate and rainfall patterns. For instance, changes in climate have allowed vector-borne diseases such as malaria and dengue fever to survive in otherwise inhospitable areas (in higher elevations). Other vector-borne diseases (such as cholera, Ross River virus, and West Nile) and food-borne diseases (like the proliferation of bacteria in contaminated foods) are also at risk of occurring as a result of higher temperatures.

As noted by the Canadian Lung Association, climate change and the effects of it can lead to air quality problems such as those resulting from the increased burning of fossil fuels as a direct result of rising temperatures (for example, increased use of air conditioners, refrigerators, and freezers); increases in forest fires; and increased mold growth as a result of elevated levels of precipitation. Associated health effects such as asthma and allergies as well as other respiratory-related morbidity and mortality are also of concern. The Canadian Lung Association provides a more comprehensive explanation of the connection between climate change, air quality, and respiratory health.

Global warming and climate change can impact both the balance and health of the ecosystem, which in turn puts human health at risk. A report by the UN Environment Programme provides an overview of the relationship between climate change and ultraviolet radiation, ozone depletion, terrestrial and aquatic ecosystems, and biogeochemical cycles. Changes and losses related to biodiversity (disruption in ecosystems and species extinction) are also of concern. In a 2007 article, Frederic Jiguet and colleagues note a number of studies that have shown that habitat degradation is taking place; particular reference is made to research on plants, butterflies, beetles, mammals, bumblebees, birds, coral reefs, and coral-dwelling fishes—however, there are a number of other habitats which may also be at risk. Moreover, based on findings from the first comprehensive assessment of extinction risk, the Natural Resources Defense Council notes, "more than one million species could be committed to extinction by 2050 if global warming pollution is not curtailed."

Diversity in species is important, because it aids in ecosystem services/functions (maintaining soil fertility and pollinating plants and crops); a change in ecosystem services/functions can have far-reaching implications (it can affect agro-ecosystems, marine systems, and fresh water, as well as the transmission of vector-borne diseases). Furthermore, there are also risks associated with nutrition, which is dependent on the state of agricultural output (such as changes in food productivity and associated pests which are involved in the transmission of diseases) as well as other food sources (like fisheries and mammals); this can have consequences on ecosystem and human health in the immediate area(s) and globally.

ECONOMIC RISKS

As far as businesses are concerned, environmental risks are usually understood in terms of costs, managed by regulatory compliance, potential liability, and pollution release mitigation. Supply chain risks might occur, whereby suppliers may eventually pass the costs pertaining to carbon-related and more energy efficient alternatives (technology advancement) to customers. Also, businesses that generate significant carbon emissions could face similar litigation risks (lawsuits) as those experienced by tobacco, asbestos, and pharmaceutical industries that in turn may also put the company's reputation at risk.

Organizations that seek a competitive advantage in light of global warming and climate change may use a Strengths, Weaknesses, Opportunities, and Threats (S.W.O.T.) analysis to examine their organization's strengths and weaknesses in relation to the opportunities and threats posed by the environment in order to transform the various business-related threats into opportunities. For instance, organizations that are able to identify and implement new market opportunities for climate-friendly products and services may fare better than other organizations that are unable to achieve this. Additionally, organizations may want to take measures such as quantifying their carbon footprint (the amount of CO_2 created by business operations) in order to show consumers that they are aware of their role in climate change—and then take measures to correct the identified shortcomings. This could lead to the development of new and profitable products that are also environmentally friendly, as well as an increase in consumer loyalty.

There are other far-reaching economic implications outside the immediate business arena. For instance, the costs associated with insurance (both for the customer and for insurance companies) may affect those living in more vulnerable areas. Moreover, it has been argued that the impacts of climate change are not evenly distributed; for instance, developing countries are not only at a geographical disadvantage (with high rainfall variability), but their economic livelihood is heavily dependent on their agricultural output (which is at risk with climate change). Furthermore, the implementation of more stringent regulations as well as the adoption of better and safer technological alternatives and advancements may not seem like a feasible option economically for developing countries.

There are various types of risks that need to be considered with respect to global warming and climate change. Risk analysis is a process that considers the scientific, social, cultural, economic, and political issues that shape the identification, evaluation, decision making, and policy implementation concerning risk. As such, risk analysis encompasses the assessment, management, and communication of risks, each in turn having their own framework. In the context of environmental health, Annalee Yassi and colleagues have provided a comprehensive list of hazards which arise from both natural and anthropogenic (caused or induced by human activity) sources and explain the processes involved in the assessment and management of these risks—some of the hazards identified are applicable to global warming and climate change.

The risk assessment framework most frequently used in relation to environmental and human health follows the steps first identified by Lawrence, E. McCrae in 1983; these steps include problem formulation, hazard identification, dose-response relationships, exposure assessment, and risk characterization. Once characterized, risks are sometimes ranked by organizations through the use of a risk matrix. Risk matrices are made up of rows and columns that denote the severity or impact of the hazard and the likelihood or probability of its occurrence, where the former is usually more subjective, and the latter is relatively objective.

Accurately predicting (through the use of modeling and other forecasting techniques) and assessing (via the five aforementioned steps) the environmental, ecosystem, and human health risks related to global warming and climate change is challenging because of the level of complexity and uncertainty involved. These factors can result for various reasons; among these are: incomplete, insufficient or inaccurate data; gaps and errors in observation; measurement error(s); lack of knowledge (inadequate or conflicting modeling, or unknowns pertaining to feedback effects); variation in assumptions; unforeseen circumstances; variability in natural conditions, exposures, and human activity; and contributions of natural and human-induced changes.

Both risk assessment and cost-benefit analysis (a tool used to determine whether or not costs outweigh benefits—the applicability of this tool has been a widely debated issue in the face of climate policy) usually drive risk management. As such, risk management is the process through which a regulatory agency decides which action(s) to take and which regulation(s) and policies to implement based on risk assessment estimate(s) and cost-benefit analyses. With respect to global warming and climate change, there are three risk management strategies that are frequently discussed in the literature—these are mitigation, adaptation, and geoengineering.

Mitigation strategies are those that are concerned with taking actions that are aimed at reducing the extent of global warming and climate change. For instance, mitigation strategies might include adopting measures that reduce anthropogenic sources of climate change (for example, limiting greenhouse gas emissions relating to fossil-fuel combustion, or deforestation). On the other hand, adaptation strategies are aimed at decreasing vulnerability to global warming and climate change. Adaptation solutions include insulating buildings (for heat-related illness); installing window screens (for vector-borne diseases); and constructing strong sea walls (for health and extreme weather events). A third strategy is geoengineering; this is essentially when large-scale manipulation of the environment takes place in an attempt to correct climate change. An example of geoengineering would include the (proposed) manipulation of the Earth's global energy balance by blocking a percentage of sunlight (via the use of superfine reflective mesh, or orbiting mirrors) in order to offset the doubling of carbon dioxide. However, approaches such as these carry great risks and are therefore largely debated.

Good risk communication includes the two-way exchange of information, concerns, and preferences between decision makers and the public in a manner where the mutual understanding of risks is achieved. The risks associated with global warming and climate change are numerous and have far-reaching implications; it is therefore imperative that all aspects of risk are carefully considered.

SEE ALSO: Climate Change, Effects; Diseases; Ecosystems; Health; Impacts of Global Warming.

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Romania

LOCATED IN EASTERN Europe, Romania has a land area of 92,043 sq. mi. (238,392 sq. km.), with a population of 21,438,000 (2006 est.), and a population density of 236 people per sq. mi. (93 people per sq. km.). Some 41 percent of the land of Romania is arable, with a further 21 percent used for meadows and pasture, and 28 percent is forested. For the generation of electricity in the country, 53 percent comes from fossil fuels, with 37 percent from hydropower, and 10 percent from nuclear power, with a small amount of electricity exported, and an even smaller part imported. The heavy use of hydropower has resulted in Romania having one of the lowest per capita rates of carbon dioxide emissions: 6.7 metric tons per person in 1990, falling to 3.8 metric tons per person in 1999, and rising slowly to 4.16 metric tons in 2004.

The generation of electricity contributed to 49 percent of the country's carbon dioxide emissions, with

Bucura Lake in the Retezat mountains in Romania. Global warming has increased the risk of flooding.

24 percent from manufacturing and construction, 11 percent from transportation, 8 percent from residential uses, and the remaining 8 percent from nonelectricity energy industries. The source of the emissions comes from gaseous fuels (33 percent), liquid fuels (32 percent), and solid fuels (31 percent), with 4 percent from cement manufacturing.

Global warming has caused increased risks of flooding in parts of the country. It is also thought to be the major reason for the heat wave in the summer of 2007, which resulted in shortages of water in some parts of the country, and the deaths of some people, especially in Bucharest and other urban centers. The highest temperature ever recorded in Romania was, however, in the 1950s, when 45 degrees C was registered at the city of Calafat in the far south of the country. The hot summer of 2007 followed an extremely warm winter, especially in January and February 2007, during which the Romanian Soccer Federation even announced that if the trend of warm winters continued, they would change their calendar, which brought the problem to national attention.

The Romanian government of Ion Iliescu took part in the UN Framework Convention on Climate Change signed in Rio de Janeiro in May 1992. They signed the Kyoto Protocol to the UN Framework Convention on Climate Change on January 5, 1999, and ratified it on March 19, 2001, with it entering into force on February 16, 2005; the government committing itself to a reduction of emissions by 1.2 percent as a stage toward ratification, and by another 8 percent by 2012. The Romanian government has long signaled its interest in emissions trading.

SEE ALSO: Drought; Emissions, Trading; Floods.

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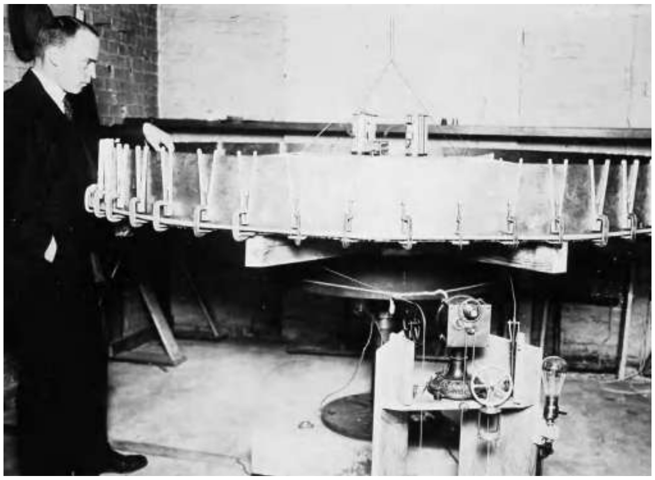
Rossby, Carl-Gustav (1898–1957)

CARL-GUSTAV ROSSBY WAS a Swedish-American meteorologist whose innovations in the study of large-scale air movement and introduction of the equations describing atmospheric motion were largely responsible for the rapid development of meteorology as a science. Rossby explained the large-scale motions of the atmosphere in terms of fluid mechanics and was one of the first scientists to notice the problem of global warming.

Rossby was born on December 28, 1898, in Stockholm, Sweden. When he was 20, he moved to Bergen, Norway, to study under pioneering atmospheric scientist Vilhelm Bjerknes at the Geophysical Institute. At that time, Bjerknes and his so-called Bergen School were making great progress in laying the foundations of meteorology as a science with their breakthroughs in the polar front theory and air mass analysis. The center was the world's leading center of meteorological research. The young Rossby contributed his brilliant ideas to the development of the group's projects. Because of the impact of Bjerknes's guidance, Rossby, who had previously been interested in studying mathematics and astronomy, committed himself to meteorology.

Rossby moved to the United States in 1926, where he worked in Washington, D.C. He was employed as a fellow of the American-Scandinavian Foundation



Carl-Gustav Rossby with a rotating tank used to study atmospheric motion. Rossby explained atmospheric motion.

for Research at the U.S. Weather Bureau to explain the innovations of the polar front theory. While at the Weather Bureau Rossby established the first weather service for civil aviation. The Weather Bureau was not a stimulating context for Rossby, who, in 1928, became professor and head of the first department of meteorology in the United States at the Massachusetts Institute of Technology, Cambridge. At MIT, he made important contributions to the understanding of heat exchange in air masses and atmospheric turbulence. He also investigated oceanography to study the relationships between ocean currents and their effects on the atmosphere.

Rossby was given American citizenship in 1938. The following year, he became assistant chief of the Weather Bureau. In that capacity, Rossby was responsible for research and education and began his studies of the general circulation of the atmosphere. In 1941, he became chairman of the department of meteorology at the University of Chicago. Rossby carried out pioneering work on the upper atmosphere, proving how it affects the long-term weather conditions of the lower air masses. Measurements recorded with instrumented balloons had demonstrated that in high latitudes in the upper atmosphere there is a circumpolar westerly wind, which overlies the system of cyclones and anticyclones lower down. In 1940 Rossby developed the theory of wave movement in the polar jet stream. He demonstrated that long sinusoidal waves of large amplitude, now known as Rossby waves, are generated by perturbations caused in the westerlies by variations in velocity with latitude. Rossby also showed the importance of the strength of the circumpolar westerlies in determining global weather. When these are weak, cold polar air will sweep south, but when they are strong, they cause the normal sequence of cyclones and anticyclones. Rossby worked on mathematical models for weather prediction and introduced the Rossby equations, which, with the introduction of digital computers in the 1950s, were of fundamental importance to forecast the weather. During World War II, Rossby was in charge of training military meteorologists, and, at the end of the war, hired many of them to work in his department at the University of Chicago. Rossby served as president of the American Meteorological Society for 1944 and 1945, and laid the foundations for the Society's first scientific journal, the *Journal of Meteorology*.

Rossby and his Chicago Group were able to compile weather charts over periods of five to 30 days to extract the general features, and tried to analyze these using basic hydrodynamic principles. The group made radical simplifying suppositions, ignoring essential but transitory weather effects like the movements of water vapor and the dissipation of wind energy. Still, they began to conceptualize how large-scale features of the general circulation might arise from simple dynamical principles.

In 1950 Rossby returned to Sweden, but continued to visit the United States. In his home country, he worked with the Institute of Meteorology, which he founded in connection with the University of Stockholm. From 1954 to 1957 he was instrumental in arousing interest in atmospheric chemistry and the interaction of airborne chemicals with the land and the sea. On December 17, 1956, Rossby appeared on the cover of *Time* magazine and was praised for his key role in raising meteorology to the status of science. The piece also referred to a theory that Rossby was developing as a result of his interest in atmospheric chemistry. According to Rossby, the world's climate might be altered by solar heat trapped in the atmosphere due to a buildup of carbon dioxide. This was one of the first insights into the problem of global warming and paved the way for many researches in the field. Rossby was unable to fully develop this insight as he died on August 19, 1957, just nine months after the *Time* article.

The Carl-Gustav Rossby Research Medal is the highest award for atmospheric science presented by the American Meteorological Society for outstanding contributions to the understanding of the structure or behavior of the atmosphere. Rossby himself was the second recipient of this prestigious award when it was still called Award for Extraordinary Scientific Achievement.

SEE ALSO: American Meteorological Society; Global Warming; Waves, Rossby.

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Royal Dutch/Shell Group

THE ROYAL DUTCH/SHELL group is a major contributor to the release of greenhouse gases, and has been among the leading oil companies to publicly embrace the need for sustainable development, including the need to address climate change. It is by most measures the world's second largest oil company, with over 100,000 employees, operations in over 130 countries, 2006 production of nearly 3.5 million barrels of oil equivalent per day, and proven reserves of nearly 8.5 billion barrels of oil equivalent. Shell's 2006 income was $26.3 billion on revenue of $318 billion.

HISTORY

Shell Transport began in 1833 with a British shopkeeper importing oriental shells, leading to an export/import business importing oil. Royal Dutch Petroleum Company began producing petroleum in the Dutch East Indies. A partnership was formed in 1907, expanded rapidly, and was the main fuel supplier to the British in World War I, and the world's leading oil company by 1930. During this period, it also began developing its global network of service stations. Demand for petroleum exploded after World War II. During the 1960s, Shell strengthened its presence in the Middle East, and discovered reserves in the North Sea. The 1973 oil crisis led Shell to diversify into other energy sources such as coal and nuclear power, with little economic success. Shell also acquired 50 percent of an Australian solar energy company, and began producing renewable softwoods that could be used for paper, construction, and fuel. Shell is the world's leading biofuels distributor.

After oil prices collapsed in 1986, Shell invested in research and development that led to huge improvements in drilling techniques, and began some of its most challenging offshore exploration. During the 1990s, high oil prices allowed Shell to further develop biomass technologies. Since 2000, Shell's greatest expansion has been in China. In 2005, the old partnership was dissolved, and one company was created, Royal Dutch Shell.

SUSTAINABLE DEVELOPMENT

The company experienced two major public image setbacks in 1995 related to sustainable development. After the British government approved Shell's plans to decommission the Brent Spar oil storage platform by sinking it in the North Sea, Greenpeace claimed this would create large amounts of pollution. Shell argued this would create the least environmental damage. Greenpeace activists protested, boarding the rig as it was being towed to the disposal area. Widespread media coverage followed, and resulted in huge negative publicity for Shell, spawning boycotts and even a firebombing of a Shell station. Shell eventually reversed its decision and towed the rig to port in Norway for dismantling. Dismantling revealed that claims of a negligible amount of oil in the rig were accurate, and Greenpeace later issued an apology.

That fall, Shell experienced another public relations fiasco. A wholly-owned subsidiary, Shell Nigeria, is the major international oil-producing company in Nigeria, with joint ventures with the Nigerian state-owned oil company and other multinational oil companies. Significant revenues from oil production go to the central government, with little benefit accruing to people in oil producing regions. Author Ken Saro-Wiwa, a member of the Ogoni tribe from the Niger Delta, led protests against the government for not using oil revenues to benefit the Ogoni, many Ogoni leaders for complicity with the central government, and Shell for substantial pollution from exploration and pipeline spills and gas flaring and for seeking security assistance from Nigerian military forces. Violence broke out, in which several Ogoni chiefs were killed, and Saro-Wiwa and eight of his associates were arrested, tried, and found guilty of murder.

International human rights activists regarded the charges as groundless, and the trial as unfair. Activists called on the Nigerian government to commute the sentences, and on Shell to use its influence to this end. Shell's CEO and the Shell Nigeria managing director appealed for clemency on humanitarian grounds, but Saro-Wiwa and his associates were executed 10 days after the verdict. Shell was heavily criticized for not doing more to attempt to influence the government to free Saro-Wiwa.

These events prompted Shell to expand its attention to sustainable development. The company has a Social Responsibility Committee that directs its sustainable development policies and performance, and it annually produces an extensive sustainability report stating that sustainable development is part of the duties of every manager at Shell. Every one of Shell's businesses is responsible for complying with corporate sustainable development policies and achieving unit-specific targets in this area.

FUEL ALTERNATIVES

Shell expresses a commitment to help meet the energy challenge by providing more secure and responsible energy. Shell is developing more environmentally friendly fossil fuel technologies like gas to liquids (GTL), which turns natural gas into cleaner-burning fuels. While they don't receive the same financial support, Shell also supports several renewable energies. Shell was the first energy company to build demonstration hydrogen filling stations in Asia, Europe, and the United States, and is one of the world's leading distributors of biofuels. However, Shell has not yet provided the financial investment needed for hydrogen expansion, and the hydrogen is derived from fossil fuels.

In 2006, Shell sold over 3.5 billion liters of biofuels, mainly in the United States and Brazil, enough to avoid over 3.5 million tons of CO_2 production. Shell believes that "first generation" biofuels are unreliable, requiring too much acreage to be planted to feedstocks, thus putting strain on the environment and food supply. Shell has therefore invested in "second generation" biofuels, such as the production of ethanol from straw rather than corn. Shell claims this second-generation biofuel could cut well-to-wheel CO_2 production by 90 percent, compared with conventional gasoline. In early 2007, Iogen, acquired by Shell in 2002, was one of six companies selected to receive funding under the U.S. Department of Energy's cellulosic ethanol program.

Shell invested in CHOREN Industries to create the first demonstration-scale biomass-to-liquids (BTL) plant, scheduled to come online in late 2007. This process relies on the use of a woody feedstock, gasifies it, and then uses the Shell Middle Distillates Synthesis (SMDS) process to convert the gas into a high-quality fuel identical to GTL that can be blended with diesel fuel. If used at 100 percent concentration, it could also cut well-to-wheels CO2 production by 90 percent compared with conventional diesel. Shell also has small investments in solar and wind power. Currently, their financial impact on Shell is very small, and they are not seen as offering substantial room for growth.

GREENHOUSE GAS REDUCTION

In 1997, Shell started managing its CO_2 output with the goal of reducing total greenhouse gas emissions. In 2006, Shell facilities emitted 98 million tons of greenhouse gases, about seven million lower than in 2005 and more than 20 percent below 1990 levels. Yet, Shell has target emissions limits of only 5 percent below the 1990 level for 2010. Shell claims its standards are very aggressive, but agrees they may need to be reconsidered if they have already been met. Most of Shell's reductions came from ending the venting of natural gas. Most of its anticipated reductions will continue to come from ending continuous flaring and increasing energy efficiency.

In 2006, Shell missed its annual Energy Intensity target, as it had underestimated how much extra energy would be required to produce more environmentally friendly low-sulfur fuels, and because of unplanned equipment shutdowns at several facilities that required extra energy to restart. In 2007, Shell launched a new energy efficiency effort that will make up for part of the increase. Its plan is to continue efforts to end continuous flaring by 2008, except in Nigeria where the target is 2009. Further greenhouse gas reductions are planned from energy efficiency improvements at refineries and chemicals plants.

Shell also states it is trying to reduce its customers' CO_2 emissions. Shell's customers emit six to seven times (750 million tons of CO_2 in a typical year) more CO_2 consuming Shell products than Shell does producing them. Shell promotes the use of natural gas, which emits less CO_2 than coal, and is a more profitable part of Shell's business than coal. Shell has also patented a coal gasification technology that can reduce CO_2 emissions by up to 15 percent, compared to conventional coal-fired power plants.

Shell also actively supports governments in designing and implementing effective CO_2 trading schemes. They are part of the UN Partnership for Clean Fuels and Vehicles and the World Bank Clean Air Initiative in Asia to provide cleaner fuel and improve air quality in the developing world. Shell is also a member of the U.S. Climate Action Partnership created in 2007 by over 30 companies and environmental groups.

Shell's annual sustainability report is audited by an external review committee, which has praised Shell for its leadership and transparency in reporting, but has questioned whether the speed with which Shell is acting to tackle climate change is consistent with the urgent nature of the challenge. The committee specifically noted the expected rise in future emissions, the lack of published targets after 2010, how Shell will achieve future greenhouse gas reductions after it stops flaring, and the absence of adequate research and development fund allocation information to assess Shell's commitment to develop renewable energy sources and to greenhouse gas mitigation.

SEE ALSO: BP; Oil, Consumption of; Oil, Production of.

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Royal Meteorological Society

THE ROYAL METEOROLOGICAL Society is a British charity whose mission is to "continue to be a world-leading professional and learned society in the field of meteorology. It will encourage and facilitate collaboration with organizations that are active in Earth Systems Sciences. It will serve its professional and amateur members and the wider community by undertaking activities that support the advancement of meteorological science, its applications and its understanding." A Council and its committees are responsible for running the society, within the constraints of the Royal Charter.

The Council comprises a total of 21 officers and ordinary members of council elected at the annual general meeting. The president, elected for a two-year term, is supported by a vice-president for Scotland and three other vice-presidents, the treasurer, general secretary, four journal editors, four main committee chairmen and Ordinary Members of Council. The Council convenes five times a year to consider applications for membership and supervise the running of the Society through its Honorary Officers, Committees and permanent staff. The work of the Council is largely organized by the recommendations made by its Committees. The society staff are based at the society's headquarters in Reading where committee meetings are normally held. The society's patron is HRH The Prince of Wales. Its membership in 2006 consisted of more than 3,000 members worldwide.

The Royal Meteorological Society is the national British society for all those individuals whose profession or interests are in any way connected with meteorology or related subjects. It controls the national qualifications of the profession and, under its royal charter, follows its mission to advance meteorological science. The society intends the terms meteorological science in their broadest meaning which includes its day-to-day application in weather forecasting and in disciplines such as agriculture, aviation, hydrology, marine transport and oceanography, as well as in the areas of climatology, climate change, and the interaction between the atmosphere and the oceans. The society publishes the results of new research and provides support both for researchers and professional meteorologists and also for those whose work is connected to the weather or climate and for those who have a general interest in environment and the weather. The membership of the society thus includes a variety of figures: professional scientists, practitioners, and weather enthusiasts. Associate fellows may be any age and do not require any specific qualification in meteorology. Fellows normally require a formal qualification in a subject related to meteorology plus five years experience and must be nominated by two other fellows. The society has a number of regular publications: the monthly magazine *Weather*, the *Quarterly Journal of the Royal Meteorological Society, Meteorological Applications*, and the *International Journal of Climatology and Atmospheric Science Letters.*

The society was established in April 1850 with the name of the British Meteorological Society, and was later incorporated by Royal Charter in 1866, when its name was changed to the Meteorological Society. The privilege of adding 'Royal' to the title was granted by Her Majesty Queen Victoria in 1883. In 1921, the society merged with the Scottish Meteorological Society.

In 1995, the Royal Meteorological Society developed a set of atmospheric dispersion modeling guidelines to encourage good practice in the use of mathematical atmospheric dispersion models, stressing the importance of selecting the most suitable modeling procedures and of fully documenting and reporting the results of modeling assessments. The 1995 guidelines provided broad general principles of good practice for modeling studies applying across a wide range of modeling situations. The UK Atmospheric Dispersion Modeling Liaison Committee (ADMLC) commissioned an upgrading of the 1995 guidelines to take into account the new developments in modeling techniques. The updated guidelines were completed and published in 2004.

The Royal Meteorological Society has specific resources on global warming for teachers and for educational purposes. The society has acknowledged that global warming is taking place and that it is the result of human activity. Yet, one of its former presidents, Chris Collier, and one of its leading researchers, Paul Hardaker, complained in 2007 about catastrophism and the "Hollywoodization" of weather and climate that only work to create confusion in the public mind. They argue for a more sober explanation of the uncertainties about possible future changes in the Earth's climate so as not to undermine scientists' credibility. According to both Collier and Hardaker, several organizations, including the American Association for the Advancement of Science (AAAS), have overplayed the evidence that the phenomenon of global warming is causing short-term devastating impacts.

SEE ALSO: United Kingdom; Weather.

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Russia

SITUATED IN BOTH Europe and Asia, the Russian Federation has a land area of 6,592,800 sq. mi. (17,075,400 sq. km.), with a population of 142,499,000 (2006 est.), and a population density of 21.8 people per sq. mi. (8.3 people per sq. km.). Moscow, the capital and the largest city, has a population of 10,654,000, with a density of 25,022 per sq. mi. (9,644 per sq. km.). The second largest city, Saint Petersburg, has a population of 3,990,267.

In spite of the vast size of Russia, some 8 percent of the land is arable, with a further 4 percent assigned as meadows and pasture, and 46 percent of the country is forested, including vast expanses of the Siberian tundra. The per capita rate of greenhouse gas emissions from the Russian Federation was 13.4 metric tons in 1992, falling steadily to 9.9 metric tons per person by 2002, partially as the economy in the country was struggling, and then rising to 10.5 metric tons per person by 2004. Because of its climate, and the need for extensive heating, 60 percent of the country's carbon dioxide emissions come from the production of electricity, of which 66.1 percent is generated from fossil fuels, 18.9 percent from hydropower, and 14.7 percent from nuclear power. This heavy use of fossil fuels is largely because of the abundance of coal, and also the availability of locally extracted petroleum in parts of the country. However, by 1998, the use of natural gas from Siberia had become much more important, with gaseous fuels making up 48 percent of all carbon dioxide emissions, solid fuels making up 26 percent, and liquid fuels 24 percent. In terms of the sector producing the emissions, with the bulk created in electricity production, 14 percent came from manufacturing and construction, 13 percent from transportation, and 10 percent from residential use.

The coal-mining areas of western Russia still remain important, politically, but the discovery of the Siberian gas fields around Omsk and other cities has led to the Russian Federation's exportation of gas to neighboring countries, and also some parts of Western Europe. Russia has suffered some of the effects of global warming and climate change, with the melting of the Arctic sea ice creating major problems for the northern parts of the country. Satellite measurements of the Arctic Ocean have revealed that the area of perennial ice cover has fallen by about 7 percent per decade since 1978. There has also been the melting of some of the Siberian permafrost, which some Russians have welcomed, as it has the potential to open up more arable land. However, it has also caused damage to hundreds of buildings in cities of Yakutsk and Norilsk, with the average temperature of the permanently frozen ground at Yakutsk having warmed by 2.7 degrees F (1.5 degrees C) between 1968 and 1998. Lake Baikal has also experienced a shorter freezing period in the last century, with winter freezing taking place 11 days later than had been the case, and the spring ice breaking up some five days earlier. There has been a similar problem in the Caucasus Mountains, where half of all the glacial ice there has disappeared in the last 100 years.

Although the amount of arable land has increased, and some people have managed to survive more easily in an otherwise hostile climate in Siberia, there has been a threat to some of the native fauna and flora. In Khabarovsk, in the far eastern part of the Russian Federation, drought and high winds led to forest fires in 1998, which destroyed 3.7 million acres (1.5 million hectares) of coniferous forest, the taiga, and threatened nature reserves where the last remaining Amur tigers live.

The Russian government of Boris Yeltsin took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992. The Russian government of Aleksandr Rutskoy accepted the Kyoto Protocol to the UN Framework Convention on Climate Change on March 11, 1999, but the new government of Vladimir Putin was initially against the ratification of it, voicing opposition in 2003. However, Putin decided to support it, and the Russian Federation ratified it on November 18, 2004, with it entering into force on February 16, 2005. This immediately changed the entire situation as regards the Kyoto Protocol, making Russia a central player in international climate policies. The Russian ratification means that countries contributing to more than 55 percent of the world's carbon dioxide emissions in 1990 had ratified the treaty, and as a result, the Kyoto Protocol became international law on February 16, 2005, 90 days after the Russian ratification. To try to reduce its greenhouse gas emissions, the Russian government has embarked on a process of expanding its hydroelectric power generation, with the Boguchan Dam scheduled to be completed in 2012.

SEE ALSO: Glaciers, Retreating; Kyoto Protocol; Natural Gas.

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Rwanda

THE REPUBLIC OF Rwanda, located in central Africa, has a land area of 10,169 sq. mi. (26,798 sq. km.), with a population of 9,725,000 (2006 est.), and a population density of 829 people per sq. mi. (320 people per sq. km.), the second highest in Africa, and the highest on the African mainland. Some 35 percent of the country is arable land, with 18 percent used for meadows and pasture, and 10 percent of the country remains forested.

A fisherman in Lake Kivu struggles with his boat. The lake has declined in size due to increased temperatures.

In terms of its per capita carbon dioxide emissions, Rwanda had less than 0.1 metric tons per person in 1990, with 0.07 percent in 2003, making it the 10th lowest country in terms of per capita emissions. With less than 1 percent of this coming from cement manufacturing, the remaining 99 percent is the result of the use of liquid fuels. This is because 97 percent of the country's electricity production comes from hydropower, with only 3 percent from fossil fuels.

The effects of global warming and climate change in the country have been rising average temperatures, with a decline in the size of Lake Kivu, and also less irrigation water in the marshlands around the River Kagera and from the other lakes, Lake Rwanye, Lake Ihema, and Lake Mugesera. This also represents a threat to the rainforests where the mountain gorillas live, and which are also a home for 43 species of reptiles (including many frogs) and 31 species of amphibians.

The Rwanda government took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, which it ratified in 1998, and in 2001 ratified the Vienna Convention. It accepted the Kyoto Protocol to the UN Framework Convention on Climate Change on July 22, 2004, with it entering into force on February 16, 2005.

SEE ALSO: Deforestation; Forests; Species Extinction.

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Saint Kitts and Nevis

LOCATED IN THE West Indies, Saint Kitts and Nevis are two islands in the Leeward Islands chain. They have a land area of 68 sq. mi. (168.4 sq. km.) for Saint Kitts and 35.9 sq. mi. (93.2 sq. km.) for Nevis. They have an overall population of 50,000 (2006 est.) and a population density of 426 people per sq. mi. (164 people per sq. km.). Some 75 percent of the population lives on the island of Saint Kitts, with 49 percent of the overall population living in urban areas, even though the capital—Basseterre—has a population of only 14,000. Some 22 percent of the land is arable, with another 3 percent used for meadow and pasture.

Traditionally, the economy of Saint Kitts, and especially Nevis, was centered on the sugar industry, with sugar cane growing well on the volcanic slopes of both islands. Although demand for sugar for food has declined, its use in ethanol, in an effort made to reduce the world's dependence on gasoline, has become more important starting in the 1990s. Although Saint Kitts and Nevis do face trouble from Caribbean hurricanes, they face less of a problem than many other islands in the West Indies with regard to rising water levels. However, rising water temperatures are expected to have a major effect on the population of sea turtles and also on many other types of marine life that live around the black coral off the shores of Saint Kitts. This is expected to have an effect on the growing tourism industry, which now makes up some 12 percent of the country's economy. The effect of increased development on both Saint Kitts and Nevis has resulted in an increase in per capita carbon dioxide emissions, up from 1.6 metric tons per person in 1990 to 3 metric tons per person in 2003.

The government of Kennedy A. Simmonds took part in the United Nations Framework Convention on Climate Change, signed in Rio de Janeiro in May 1992, but the government of Denzil Douglas, which came to power in 1995, has so far not expressed any position on the Kyoto Protocol to the UN Framework Convention on Climate Change.

SEE ALSO: Greenhouse Gases; Kyoto Protocol.

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Saint Lucia

THE ISLAND OF Saint Lucia, located in the Windward Islands and surrounded by the Caribbean Sea and the Atlantic Ocean, has a land area of 239 sq. mi. (616 sq. km.), with a population of 165,000 (2006 est.) and a population density of 774 people per sq. mi. (298 people per sq. km.), making it the 39th most densely populated country in the world. About a third of the population lives in the capital, Castries, on the sheltered western coast, with 8 percent of the land being arable and a further 5 percent used for meadows and pasture. Some 41 percent of the exports of the country come from bananas.

Saint Lucia has a number of offshore coral reefs, the most well known being those near Soufrière, in the southeast of the island. Just south of these are other coral reefs that also attract many tourists. There are worries about their preservation, with signs of coral bleaching resulting from the increase in water temperatures. There is extensive public transport on the island, maintained by private bus companies. As with many other developing economies, Saint Lucia has seen a rise in carbon dioxide emissions per capita, going from 1.2 metric tons per person in 1990 to 2.2 metric tons in 1996 before falling to 1.4 metric tons in 1998, but rising again to between 1.9 and 2.1 metric tons per person since then. All the carbon dioxide emissions in the country come from liquid fuel, and all electricity production in the country comes from fossil fuels.

The government of John Compton took part in the United Nations Framework Convention on Climate Change, signed in Rio de Janeiro in May 1992, and ratified the Vienna Convention; two years later, Saint Lucia was represented at the Global Conference on the Sustainable Development of Small Island Developing States held in Barbados. The Saint Lucia government of Kenny Anthony signed the Kyoto Protocol to the UN Framework Convention on Climate Change on March 16, 1998, with the country ratifying it on August 20, 2003, and it entering into force on February 16, 2005.

Saint Lucia has seen a rise in carbon dioxide emissions per capita, from 1.2 metric tons per person to 2.1, since 1990.

SEE ALSO: Climate Change, Effects; Transportation.

BIBLIOGRAPHY. P.I. Gomes, ed., *Rural Development in the Caribbean* (C. Hurst, 1985); *St. Lucia Industrial Development* (National Development Corporation, 1973); "Vulnerable Caribbean Nations Prepare for Global Warming," *Environment News Service*, http://ens-newswire.com/ens/jun2001/2001-06-04-02.asp (cited September 2007).

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Saint Vincent and the Grenadines

SAINT VINCENT AND the Grenadines are part of the Windward Islands chain, surrounded by the Caribbean Sea and the Atlantic Ocean, and have a land area of 150 sq. mi. (388 sq. km.), of which the island of Saint Vincent itself accounts for 107 sq. mi. (240 sq. km.). The country has a population of 120,000 (2006 est.) and a population density of 798 people per sq. mi. (307 people per sq. km.), with Kingstown, the nation's capital, having a population of about 16,000.

Some 10 percent of the land is arable, much of which is used for the growing of coconuts and bananas, and a further 5 percent is used for meadows and pasture. Traditionally, few tourists visit Saint Vincent.

Some of the islands of the Grenadines are low lying, and the country faces major problems with the rising water level; its coral reefs are also threatened by the rising temperature of the water. The flooding feared in some parts of the islands threatens to increase the prevalence of insect-borne diseases such as malaria and dengue fever and also threatens low-lying parts of the country. Global warming has also been blamed for the deaths of many fish in 1999 off the coast of Saint Vincent and other nearby islands. The carbon dioxide emissions per capita in Saint Vincent remain very low, being 0.7 metric tons per person in 1990, although this number has risen significantly since then, reaching 1.6 metric tons in 2003. The carbon dioxide emissions come entirely from liquid fuels, with fossil fuels making up 73.2 percent of the electricity production in the country and the remainder—26.8 percent—coming from hydropower.

The government of James Fitz-Allen Mitchell took part in the United Nations Framework Convention on Climate Change, signed in Rio de Janeiro in May 1992, and two years later, Saint Vincent was represented at the Global Conference on the Sustainable Development of Small Island Developing States held in Barbados. In 1996, the government ratified the Vienna Convention, and on March 16, 1998, the Saint Vincent government signed the Kyoto Protocol to the UN Framework Convention on Climate Change, with the country ratifying it on August 20, 2003, and it entering into force on February 16, 2005.

SEE ALSO: Climate Change, Effects; Floods; Kyoto Protocol.

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Salinity

TWO ATTRIBUTES OF the oceans, temperature and salinity, determine the density of seawater, and the differences in density between the water masses in the world's oceans causes the water to flow in thermohaline circulation, thereby producing the greatest oceanic current on the planet.

Salinity is the distinct taste of seawater and is the result of the presence of dissolved salts (more than 85 dissolved constituents), among which chloride (Cl) and sodium (Na), the elements of common table salt, are the most abundant. The term *salinity* refers to the content of these dissolved salts and has been defined as grams of dissolved salts per kilogram of seawater. Salinity has been expressed as parts per thousand (‰ or ppt) and, more recently, by practical salinity units (psu).

On average, a kilogram of seawater has 35 grams of dissolved salts, so its salinity content is 35‰, or 35 psu. The accuracy of most laboratory salinometers (see below) is about 0.001 psu. Thus, only those components with a concentration over 0.001‰ will contribute to such salinity estimates. Only 15 of the dissolved salts have concentrations above that limit.

A key observational result (known as the principle of Dittmar, after William Dittmar, a Scottish professor of chemistry; the principle of Maury, after Matthew Fontaine Maury, an American astronomer, oceanographer, and geologist; or the hypothesis of Forchhammer, after Johan Georg Forchhammer, a Danish mineralogist and geologist) is that the relative concentration between some of these most abundant salts is virtually constant over much of the World Ocean. This finding indicates that the physical characterization of seawater is given by its temperature, pressure, and a single number reflecting the concentration of the most abundant components. Salinity is that number.

MEASURING SALINITY

In 1902, an international commission defined salinity as the total amount of solid material, in grams, contained in 1 kg. of seawater when all the carbonate has been converted to oxide, the bromide and iodine replaced by chlorine, and all organic matter completely oxidized. With this definition in hand, the commission estimated the salinity of several seawater samples and the fixed relationship between salinity (S) and chlorinity:

$$S(‰) = 003 + 1.805 \text{ Cl } (‰)$$

This was known as Knudsen's equation, after Martin Hans Christian Knudsen, a Danish physicist (1871–1949), and was redefined in 1969 as

$$S(‰) = 1.80655 \text{ Cl } (‰).$$

Defining salinity in terms of chlorinity alleviates the practical difficulties of measuring salinity through evaporating water samples to dryness. For calibration purposes, artificial water with salinity almost equal to 35‰, known as Copenhagen water, is manufactured to serve as a reference. Copenhagen water has a chlorinity of 19.381‰. This approach requires the chemical titration of water samples usually obtained by Nansen bottles, named after Fridtjof Bedel-Jarlsberg Nansen, a Norwegian explorer and scientist (1861–1930), which are self-closing containers that collect water from different depths.

Pure water is a poor electrical conductor. However, the presence of dissolved salts greatly increases its conductivity, which, in fact, is a function of pressure, temperature, and the degree of ionization of the dissolved salts. In the second half of the 20th century, technical improvements in the measurement of the electrical conductivity of seawater led to the development of the so-called salinometers. Conductive salinometers measure the ratio between the conductivity of the sample against that of a reference sample of known salinity. Researchers using conductivity salinometers in the beginning were giving a salinity value of 35‰ to any sample having the same conductivity as the Copenhagen water, even though the mass of salt per kilogram of water was not guaranteed to be the same in both cases. This was because conductivity depends on the degree of ionization of the dissolved salts and not on the absolute mass of salt. In 1978, the salinity scale was redefined in terms of the conductivity ratio, K_{15}, between any given sample and the reference solution:

$$S(\text{psu}) = 0.0080 - 0.1692\,K_{15}^{1/2} + 25.3851\,K_{15} + 14.0941\,K_{15}^{3/2} - 7.0261\,K_{15}^{2} + 2.7081\,K_{15}^{5/2}$$
$$K_{15} = C(S,15,0)/C(KCl,15,0),$$

where $C(S,15,0)$ is the conductivity of the water sample at a temperature of 15°C and atmospheric pressure, and $C(KCl,15,0)$ is the conductivity of a standard solution that contains 32.4356 g. potassium chloride (KCl) at the same temperature and pressure. The practical salinity unit is thus defined as a ratio of conductivities and has no physical units.

An alternative to conductivity salinometers are refractive salinometers, based on the fact that the speed of light through a medium depends on its density. In a refractive salinometer, a drop of sample water is placed on a prism. Because the water and the prism have different densities, light passing through the system is refracted at an angle that depends on the density (i.e., the temperature and salinity). On average, conductive salinometers have a precision of about 0.001 psu, whereas laboratory refractive salinometers have a precision of 0.06 psu, and handheld refractometers have a precision of 0.2 psu. Today's standard instrument for measuring both temperature and salinity is the Conductivity-Temperature-Depth profiler, which allows a quasi-continuous vertical sampling and a precision of 0.005 psu. Based on the same principle, conductivity/temperature instruments are mounted on autonomous profilers (e.g., Argo floats) and the thermosalinographs that use near-surface water intakes of ships to continuously measure temperature and salinity.

A promising approach for remote sensing of the salinity is the microwave radiometry measuring the emissivity or brightness temperature of the sea surface, because the dielectric constant of seawater depends on temperature and salinity. The largest sensitivity of the surface emissivity to salinity has been observed in the L-band (1.40–1.43 GHz). The Soil Moisture and Ocean Salinity of the European Space Agency and the Aquarius-SAC/D mission of NASA-Argentine Space Agency are the first two space missions designed to provide global, synoptic estimates of the sea surface salinity with an accuracy of about 0.1 psu every 30 days with a 100- to 200-km. spatial resolution.

PROCESSES AFFECTING SALINITY

Since the *Challenger* expedition in 1877, when the chemical composition of seawater was first reported, no changes in the composition of seawater have been observed. Thus, it can be supposed that for the timescales pertinent to climate change, viz., decadal to centennial, salinity behaves as a conservative tracer.

Thus, its time evolution is given by the three-dimensional transport of salinity by advection (as water parcels carry properties) or diffusion (tendency to smooth salinity gradients even in still water). At the surface of the oceans (up to a depth where the turbulent action of the wind is balanced by the laminarity of the stable ocean stratification), salinity concentrations are also modified by the dilution/concentration resulting from mass fluxes through the air-sea interface such as evaporation and precipitation, river runoffs, and the thawing/freezing of ice caps. In open oceans, the lowest values of salinity (below 30 psu) are found at high latitudes and at the mouth of the largest rivers. The highest salinities are found in the subtropics (over 35 psu), where evaporation dominates. In the tropics, which tend to be regions of strong precipitation, salinity is around 34 psu.

SALINITY AND CLIMATE

The range of temperatures on Earth allows water to be present as a solid (ice) in ice caps and glaciers; liquid (water) in oceans, groundwater, lakes, and rivers; and gas (water vapor) in the atmosphere. The idealized path of a water molecule from one phase to the other is known as the hydrological cycle. The residence times, that is, the average time that the molecules spend in each phase, range from a few days (water vapor in the atmosphere), to several months (seasonal snow cover, rivers), to the thousands of years (oceans and groundwater). Changes in the hydrological cycle affecting precipitation, evaporation, ice cap thawing, and river runoff have the potential to change the salinity of the oceans. The reverse is also true, and salinity changes may have an imprint in the hydrological cycle after thousands of years.

The mechanisms by which salinity affects the hydrological cycle are numerous. Because of its role in density variations, salinity gradients contribute to ocean currents transporting heat, salt, microorganisms, and nutrients across the oceans. In regions of strong precipitation, a layer of low salinity may isolate the uppermost surface of the ocean from the cold ocean below, forming the so-called barrier layer, which blocks the wind-stirring effects that cool the surface by mixing heat downward. This manifests as warmer sea surface temperatures, modifying the surface temperature gradients that drive surface winds. In the equatorial Pacific Ocean, such a phenomenon is of importance in the El Niño–La Niña cycles. Similar salinity effects also occur in the tropical Indian and Atlantic oceans and have potential feedbacks to the hydrological cycles in the region. Tropical surface anomalies may be advected to the deep convection regions, modulating the thermohaline circulation. One of the largest ocean climate events recorded in the Atlantic Ocean is the Great Salinity anomaly, which lasted from 1968 to 1982. A salinity anomaly propagated over thousands of kilometers reached the Labrador Sea and perturbed the thermohaline circulation intensity. The origin and evolution of these anomalies is still not fully understood because of the historical lack of salinity observations, and studies of the mechanisms by which these salinity anomalies evolve are usually based on ocean and climate models.

SEE ALSO: Climate Change, Effects; El Niño and La Niña; Hydrological Cycle.

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Samoa

SAMOA, KNOWN UNTIL 1997 as Western Samoa, has a land area of 1,093 sq. mi. (2,831 sq. km.), with a population of 187,000 (2006 est.) and a population density of 169 people per sq. mi. (65 people per sq. km.). With the economy dominated by subsistence agriculture, 19 percent of the country is arable, and 47 percent is forested.

From 1990 until 2003, the per capita carbon dioxide emissions from the country have been fairly stable, at between 0.7 and 0.8 metric tons per person. These emissions come entirely from liquid fuels, which are

Samoa is at risk of serious land loss because of global warming and climate change.

produced from transportation, electricity generation, and the running of small household and factory generators. Fossil fuels—petroleum—generate 59.2 percent of the electricity, with the remainder coming from hydropower.

Samoa is at risk of serious land loss because of global warming and climate change. Indeed, Upolu and Savaí, the two major islands in the country, have both experienced the loss of about 1.5 ft. (0.46 m.) of shore each year for the last 90 years. The only two other inhabited islands in Samoa—Apolina and Manono—have also suffered land loss, and some of the uninhabited islands are expected to become completely submerged if the water levels continue to rise.

The Samoan government ratified the Vienna Convention in 1992 and took part in the United Nations Framework Convention on Climate Change, signed in Rio de Janeiro in May 1992, ratifying it in 1994. It signed the Kyoto Protocol to the UN Framework Convention on Climate Change on March 16, 1998, which was ratified on November 27, 2000, and entered into force on February 16, 2005.

SEE ALSO: Climate Change, Effects; Floods.

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San Marino

THE LAND-LOCKED REPUBLIC, entirely surrounded by Italy, has a land area of 23.5 sq. mi. (61 sq. km.), with a population of 31,000 (2006 est.) and a population density of 1,198 people per sq. mi. (461 people per sq. km.), the 20th highest density in the world. It is a very prosperous country, with gross domestic product per capita being US$34,600. As a result, it makes heavy use of electricity—air conditioning in the hot summers and heating for the winter, as well as regular domestic and business use. All electricity for San Marino is supplied by Italy, which produces some 80 percent of its electricity from fossil fuels.

Because of its geographical position, there are few data available for San Marino for greenhouse gas emissions, with Sanmarinesi emissions usually included under Italy, which has had carbon dioxide emissions per capita ranging from 6.9 metric tons per person in 1990, rising to 7.7 metric tons per person by 2003. With tourism being the major source of income, most tourists come to the country in buses or by train from the nearby Italian town of Borgo Maggiore. The Sanmarinesi government took part in the United Nations Framework Convention on Climate Change, signed in Rio de Janeiro in May 1992, but has, so far, not expressed any policy position on the Kyoto Protocol to the UN Framework Convention on Climate Change.

SEE ALSO: Climate Change, Effects; Tourism.

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São Tomé and Principe

THE CENTRAL AFRICAN country of São Tomé and Principe, formerly a Portuguese colony, is located on two islands, São Tome and Principe, in the Atlantic Ocean. Together they have a land area of 372 sq. mi. (964 sq. km.), with a population of 158,000 (2006 est.), and a population density of 454 people per sq. mi. (171 people per sq. km.). About 42 percent of the population live in urban areas. Only 2 percent of the land is arable, with a further 1 percent used for meadows and pasture, with 75 percent of the country being forested.

Until the recent discovery of oil, the country has been poor, with the carbon dioxide emissions in the country being 0.6 metric tons per capita from 1990 until 2003 when the emission level was recorded as 0.62 metric tons per person. For the electricity production in the country, 58.8 percent comes from hydropower, with 41.2 percent from fossil fuels. The entire carbon dioxide emission comes from liquid fuels, being from car emissions, and also from small gas-driven generators. Gasoline prices in the country have been relatively low, but there is a very poor public transport system.

Both the islands of São Tomé and Principe might suffer flooding if global warming and climate change continue to raise the level of the Atlantic Ocean. The rising temperature of the water might also affect the country's fishing industry, which centers on catching shrimp and tuna. The São Tomé government took part in the United Nations Framework Convention on Climate Change signed in Rio de Janeiro in May 1992, and ratified the Vienna Convention in 2001. The government has so far expressed no opinion on the Kyoto Protocol to the UN Framework Convention on Climate Change.

SEE ALSO: Carbon Dioxide; Climate Change, Effects; Floods; Kyoto Protocol.

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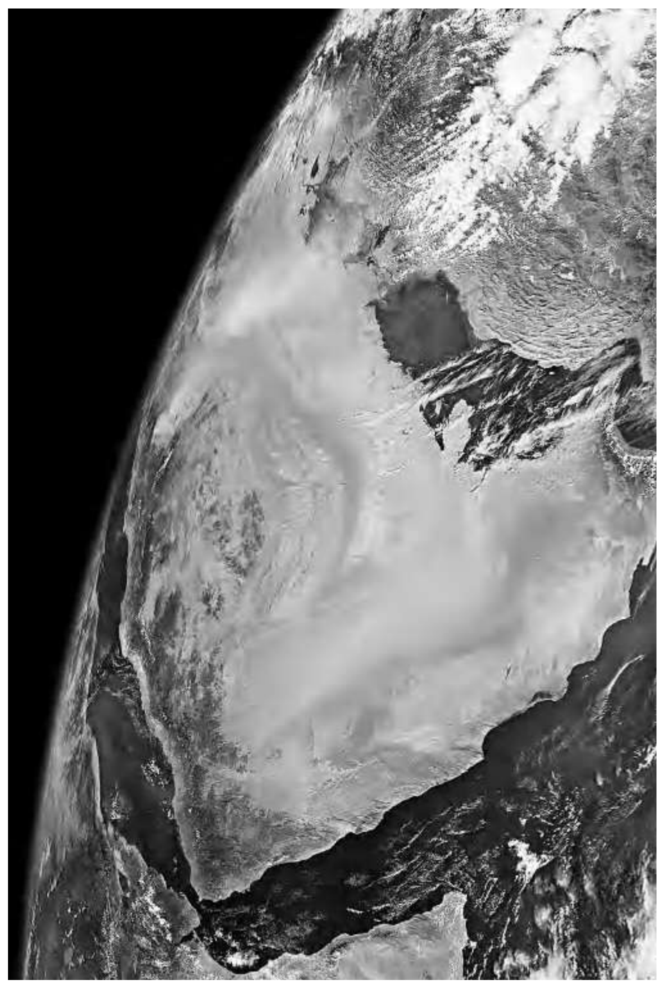
Saudi Arabia

COVERING MOST OF the Arabian Peninsula, the Kingdom of Saudi Arabia has a land area of 829,996 sq. mi. (2,149,690 sq. km.), with a population of 24,735,000 (2006 est.) and a population density of 29 people per sq. mi. (11 people per sq. km.). Riyadh, the capital and the largest city, has a population of 4,193,000 and has a population density of 3,891 per sq. mi. (1,500 per sq. km.). Some 2 percent of Saudi Arabia is arable land, with a further 56 percent used for meadows and pasture. With a high standard of living coming from the petroleum industry, and fossil fuels being used for all the country's electricity production, Saudi Arabia has a high rate of per capita carbon dioxide emissions, rising from 12.1 metric tons per person in 1990 to 18.4 metric tons in 1993.



Massive sandstorms over Saudi Arabia, seen from space. A rise in global temperatures is likely to increase desertification.

In 1998, emissions had fallen to 10.9 metric tons per person but rose to 13.4 metric tons in 2004.

Some 64 percent of the carbon dioxide emissions in the country come from liquid fuels, and 32 percent come from gaseous fuels. Electricity generation accounts for 30 percent of carbon dioxide emissions, with other energy industries contributing another 30 percent. Some 22 percent of carbon dioxide emissions come from manufacturing and construction, with 16 percent from transportation—Saudi Arabia has a high level of private ownership of automobiles and a limited public transport service.

Global warming and climate change, leading to a rise in the temperature, is likely to destroy more arable land, leading to increasing desertification. As the country has no perennial rivers or permanent water bodies, it has established power-hungry desalination plants. It has also drawn up plans for desert reclamation and irrigation schemes to try to achieve self-sufficiency in basic foods.

The Saudi Arabian government took part in the United Nations Framework Convention on Climate Change, signed in Rio de Janeiro in May 1992. It accepted the Kyoto Protocol to the UNñ Framework Convention on Climate Change on January 31, 2005, with it entering into force on May 1, 2005.

SEE ALSO: Climate Change, Effects; Deserts.

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Independent Scholar

Schneider, Stephen H. (1945–)

AMERICAN CLIMATOLOGIST AND professor in the Department of Biological Sciences, Senior Fellow at the Center for Environment Science and Policy of the Institute for International Studies, and professor by courtesy in the Department of Civil and Environmental Engineering at Stanford University since September 1992, Schneider has been an outspoken advocate of the global warming theory since the 1980s and has helped draw public attention to the issue of climate change. He has argued for sharp reductions of greenhouse gas emissions to combat the phenomenon. Schneider has also served as an adviser to different U.S. administrations and federal agencies since the presidency of Richard Nixon. His research includes modeling of the atmosphere, climate change, and the relationship of biological systems to global climate change.

Schneider was born on February 11, 1945, in New York. He received his Ph.D. in mechanical engineering and plasma physics from Columbia University in 1971. He investigated the role of greenhouse gases and suspended particulate material on climate as a postdoctoral fellow at NASA's Goddard Institute for Space Studies. He was appointed a postdoctoral fellow at the National Center for Atmospheric Research in 1972 and was a member of their scientific staff from 1973 to 1996, where he cofounded the Climate Project. Although Schneider emerged as a public figure in the global warming debate in the 1980s, his interest in the subject dates back to the early 1970s, when he coauthored an article in *Science* ("Atmospheric Carbon Dioxide and Aerosols: Effects

Stephen H. Schneider at the Center for Environment Science and Policy of the Institute for International Studies.

of Large Increases on Global Climate"), which examined the competing effects of cooling from aerosols and warming from CO_2. The paper, however, predicted that carbon dioxide would only have a minor role and warned about a large possible decrease of the Earth's temperature. In the late 1970s, Schneider modified his position stating that, at that time, it was not possible to be certain whether the climate was cooling or warming. In *The Genesis Strategy: Climate and Global Survival* (1976), he wrote that "consensus among scientists today would hold that a global increase in atmospheric aerosols would probably result in a cooling of the climate; however, a smaller but growing fraction of the current evidence suggests that it may have a warming effect."

It was with his 1989 book, *Global Warming: Are We Entering the Greenhouse Century?*, that Schneider became a main figure in scientific debates about human effects on the environment. In clear language exempt from academic jargon, Schneider argued his case for global warming. The burning of fossil fuels, he claimed, causes a buildup of greenhouse gases in the atmosphere. Those gases trap the solar energy reradiated by the earth that would otherwise escape into space. This phenomenon could have devastating effects such as droughts, more frequent and more powerful tropical storms, and a rise in sea level. Schneider believes that temperature change appears less noticeable than it would otherwise be thanks to the capacity of the oceans to absorb heat. He is persuaded of the necessity to improve climate models that will take fully into account the interactions between atmosphere and oceans.

Schneider has always tried to involve the public in his research and has frequently appeared in media events relating to environment. He has tried to popularize complex scientific ideas to make them more available to the larger public. This has earned him praise as well as criticism, as several of his colleagues have charged him with trying too hard to get media attention for himself and his ideas. Still others describe Schneider as an alarmist, as in their view, his statements are not always supported by evidence. Yet Schneider is aware that as a scientist he is ethically bound to tell the truth. At the same time, he is concerned that, to be effective, his ideas have to take hold of the public and its imagination. Schneider finds this a double ethical bind in which scientists frequently find themselves. This condition "cannot be solved by any formula. Each of us has to decide what the right balance is between being effective and being honest. I hope that means being both."

Schneider has served in many key positions as an academic and a policymaker. He has also received many honors for his research. He is the founder and editor of the journal *Climatic Change* and has authored or coauthored over 450 scientific papers, proceedings, legislative testimonies, edited books, and book chapters, as well as some 140 book reviews, editorials, published newspaper and magazine interviews and popularizations. He was a coordinating lead author in Working Group II IPCC TAR and is currently a coanchor of the Key Vulnerabilities Cross-Cutting Theme for the Fourth Assessment Report (AR4). For his ability to integrate and interpret the results of global climate research for both the academic community and the general public, Schneider was awarded the MacArthur Fellowship in 1992. For his furtherance of public understanding of environmental science and its implications for public policy, he also received, in 1991, the American Association for the Advancement of Science/Westinghouse Award for Public Understanding of Science and Technology. In 1998, he became a foreign member of the Academia Europaea, Earth and Cosmic Sciences Section. He was elected chair of the American Association for the Advancement of Science's Section on Atmospheric and Hydrospheric Sciences (1999–2001). Schneider was elected to membership in the U.S. National Academy of Sciences in April 2002.

SEE ALSO: Climate Change, Effects; Global Warming.

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Scripps Institute of Oceanography

SCRIPPS INSTITUTE OF Oceanography is the world's preeminent center for ocean and earth research, teaching, and public education. Also known as SIO, Scripps Institute of Oceanography is located in La Jolla, California. The mission of the institute is to seek, teach, and communicate scientific understanding of the oceans, atmosphere, Earth, and other planets for the benefit of society and the environment. A graduate school of the University of California, San Diego, Scripps's leadership in many scientific fields reflects its continuing commitment to excellence in research, modern facilities and ships, distinguished faculty, and outstanding students—and its horizons continue to expand. The institute offers a number of undergraduate and graduate courses in a variety of marine and earth science disciplines.

Research at Scripps encompasses physical, chemical, biological, geological, and geophysical studies. Ongoing investigations include the topography and composition of the seafloor, waves and currents, and the interchanges between the oceans and atmosphere. Scripps's research ships are used in investigations throughout the world's oceans. Today, the Scripps staff of 1,300 includes approximately 100 faculty, 300 other scientists, and some 225 graduate students, with an annual budget of more than $140 million. Other observations and collections are made by ocean devices, airplanes, remotely operated aircraft, land stations, and satellites. Scripps's educational program has grown hand in hand with its research programs. In its most recent survey of graduate schools, the National Research Council ranked Scripps the number one oceanographic program in faculty quality, distinction, and scholarly publications.

Instruction is on the graduate level, and students are admitted as candidates for a Ph.D. degree in oceanography, earth sciences, or marine biology. Academic work is conducted through the graduate department and eight curricular groups: biological oceanography, physical oceanography, marine biology, geological sciences, marine chemistry and geochemistry, geophysics, climate sciences, and applied ocean sciences.

The Scripps Institute of Oceanography department offers over 45 undergraduate courses covering a wide breadth of earth and marine sciences on several different levels. There are several introductory classes for nonmajors, as well as upper-division courses intended for a wide range of students in natural science majors. For students interested in careers in earth sciences, the Scripps Institute of Oceanography offers a B.S. degree and a contiguous B.S./M.S. degree in earth sciences. In addition, students may follow a chemistry/earth sciences major, a physics major with a specialization in earth sciences, or an environmental systems/earth sciences major. The program also offers an academic minor in earth sciences.

Scripps is one of the oldest and largest centers for global science research and graduate training in the world. More than 300 research programs are now conducted at the institute, aimed at gaining comprehensive understanding of the oceans, atmosphere, and structure of the Earth.

Oceanography, by its very nature, is interdisciplinary. It spans many sciences including physics, chemistry, geology, biology, meteorology, climatology, and paleontology. Scripps scientists pioneered exploration of the world's marine environments. They are leaders in studies of climate change, plate tectonics, ocean circulation, marine biology and ecology, marine pharmaceuticals, seafloor mapping, seismology, coastal processes, the El Niño phenomenon, biodiversity and conservation, and atmospheric sciences.

Graduate students play an integral role in the Scripps missions of teaching and research. Scripps offers excellent graduate instruction, and students perform a significant part of Scripps research activities. The stature of the institution is manifested in the quality both of the students it attracts to the program and of the scientists it graduates.

Climate sciences concerns the study of Earth's climate system, with emphasis on the physical, dynamic, and chemical interactions of the atmosphere, ocean, land, ice, and the terrestrial and marine biospheres. One of the central challenges is developing the ability to predict future climate changes, whether they are the consequences of human activities or the result of natural climatic cycles. A related challenge is understanding how and why the climate of the Earth has changed in the past.

To understand Earth's climate system requires understanding the mechanistic links between physical and chemical changes in the atmosphere (e.g., changes in winds, clouds, rainfall, sunlight, greenhouse gas abundance, or stratospheric ozone) and changes in the oceans (e.g., shifts in the current systems, temperature structure, or ocean biota), in the ice sheets (e.g., advances and retreats), and in land biota (e.g., changes in length of growing seasons or habitat range).

The climate system includes powerful feedback mechanisms. The amount of moisture in the atmosphere, for example, increases with global temperature, but the moisture also contributes to additional warming through the greenhouse effect. Scientists studying the climate system need experience in many disciplines, including meteorology, oceanography, geography, ecology, geology, and paleontology.

Observing the climate system depends increasingly on new measurement technologies, such as satellite and in situ measurements of the atmosphere, oceans, and land surface. These developments are enabling Scripps scientists to develop a more precise and detailed understanding of various conditions that affect climate, such as winds, ocean currents, clouds, and amount of vegetation.

Charles David Keeling, a professor of oceanography at Scripps, received the Tyler Prize for Environmental Achievement, which is awarded for accomplishments in environmental science, energy, and medicine that confer great benefit on mankind. Keeling, a world leader in research on the carbon cycle and the increase of carbon dioxide (CO_2) in the atmosphere, known to influence the greenhouse effect, has been affiliated with Scripps since 1956. Keeling was the first to confirm the accumulation of atmospheric carbon dioxide by very precise measurements that produced a data set now known widely as the Keeling curve. Before Keeling's investigations, it was unknown whether the oceans and vegetated areas on land would absorb any significant excess carbon dioxide from the atmosphere produced by the burning of fossil fuels and other industrial activities. Keeling became the first to determine definitively the fraction of carbon dioxide from combustion that is accumulating in the atmosphere.

Keeling's major areas of interest include the geochemistry of carbon and oxygen and other aspects of atmospheric chemistry, with an emphasis on the carbon cycle in nature. He has been a world leader in the study of the complex relationships between the carbon cycle and changes in climate. The Keeling record of the increase in atmospheric carbon dioxide measured at Mauna Loa, Hawaii, represents what many believe to be the most important time series data set for the study of global change.

SEE ALSO: Geography; Oceanography; University of California; Weather.

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Sea Ice

SEA ICE IS frozen ocean water. It forms primarily in and near the polar regions, though it can grow closer to the equator as far as 40 degrees N latitude and 55 degrees S latitude. Sea ice has a strong seasonal variability. In the Northern Hemisphere, the annual maximum extent occurs in late winter (March), covering about 5,791,532 sq. mi. (15 million sq. km.) on average. It then melts during spring and summer to an annual minimum extent of about 2,702,715 sq. mi. (7 million sq. km.) in September. In the Antarctic, the annual maximum is about 7,335,941 sq. mi. (19 million sq. km.) during September, and the annual minimum is about 1,158,306 sq. mi. (3 million sq. km.) in February or March. Overall, roughly 10 percent of the world's ocean area is covered with sea ice at some point during the year.

The point at which the ocean begins to freeze is a function of the salt content of the water, which for typical ocean salinities is around 29 degrees F (minus 1.6 degrees C). The saline nature of the ocean makes the formation of sea ice distinct from freshwater ice growth in lakes and rivers. Freshwater becomes less dense as it approaches the freezing point, keeping the coldest water at the surface and allowing ice to form as soon as the surface cools to the freezing point. However, the presence of salt changes the character of near-freezing water such that as saline water nears the freezing point, it continues to increase in density. Thus, cooling surface waters will become denser and sink. This means that there is overturning, and subsurface waters must also cool before ice can begin to form.

Sea ice typically grows to an average level thickness of 3 to 6 ft. (1 to 2 m.) in the Antarctic and 10 to 13 ft. (3 to 4 m.) in the Arctic. The ice is thinner in the Antarctic because most ice melts during the austral summer, whereas in the Arctic a significant fraction (~40 percent) remains through the summer and can grow over several years. A larger ocean heat flux at the bottom of the ice in the Antarctic also keeps the ice thinner.

However, thicker ice is not uncommon because of the effect of ice motion. Most sea ice is almost constantly in motion mainly because of the force of winds and ocean currents (other factors include the Coriolis effect, the slope of the ocean surface, and the internal structure of the ice). The speed of sea ice motion varies considerably; it can move 31 mi. (50 km.) or more in a day, though 1.2 mi. (2 km.) per day is typical. The motion of the ice can result in convergence between different parts of the ice cover, causing the ice to pile up into features called ridges. Ridges may easily rise 16 to 33 ft. (5 to 10 m.) above the surrounding level ice (and many tens of m. below the surface).

Sea ice plays an important role in climate. It has a much higher albedo than the unfrozen ocean, meaning that 60 to 70 percent of the sun's energy is reflected by the sea ice surface, whereas the unfrozen ocean reflects less than 10 percent of the sun's energy, resulting in much less energy absorption where ice is present. Sea ice is also a physical barrier between the ocean and atmosphere. This prevents the transfer of heat and moisture between the two and during winter. Thus, sea ice keeps the polar regions cooler and drier than they would be without ice. Sea ice also reduces fetch and dampens waves, limiting coastal erosion.

Sea ice has important effects on wildlife and human activities. Polar bears, seals, and other creatures rely on the ice to traverse and hunt, and during summer, the sea ice edge is a fertile area for phytoplankton and other microorganisms. Native communities in the Arctic are intimately tied into the presence of sea ice, and it plays an important role in their traditional culture and ways of life, such as hunting and transportation. Navigation of surface ships is severely limited or curtailed altogether, and for ships that do sail in or near ice-infested waters, it represents a significant hazard. Finally, sea ice plays a role in military operations, providing a useful cover for submarine activities.

Because of its location near the poles, the thin nature of the ice cover, and its interaction with the ocean and the atmosphere, sea ice is a sensitive indicator of the climate state. Sea ice in the Arctic has been decreasing dramatically over the past several decades. Overall, the Arctic has lost approximately 20 percent of the average summer ice extent since the late 1970s. Reductions during winter are less but are still significant. On the basis of current trends and projects by climate models, the Arctic may be ice free during summer by 2050 or earlier. This reduction in sea ice has been linked to warming temperatures resulting from the anthropogenic emission of greenhouse gases, though other factors also play a role. Unlike in the Arctic, there has been no significant trend seen in Southern Hemisphere ice, likely because of its remoteness relative to other continental land areas, the seasonal nature of the ice, and a greater ocean influence.

Changes in Arctic sea ice cover will have profound effects on climate, human activities, and wildlife, some of which are already being felt. Polar bears and other animals may be endangered, as well as the traditions of native communities. Less ice may also have benefits by opening up shipping routes and facilitating extraction of natural resources. Nonetheless, most effects are expected to be negative, and their implications for future climate will extend to regions far beyond the Arctic.

SEE ALSO: Animals; Climate Change, Effects.

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Sea Level, Rising

SEA LEVEL RISE is caused by thermal expansion of the oceans, melting of glaciers and ice caps, melting of the Greenland and Antarctic ice sheets, and changes in terrestrial storage. Changes in sea level will be felt through increases in the intensity and frequency of storm surges and coastal flooding; increased salinity of rivers, bays, and coastal aquifers resulting from saline intrusion; increased coastal erosion; loss of important mangroves and other wetlands (the exact response will depend on the balance between sedimentation and sea level change) and its effect on marine ecosystems (i.e., coral reefs).

Global sea level rose by about 394 ft. (120 m.) during the several millennia that followed the end of the last Ice Age (approximately 21,000 years ago) before stabilizing between 3,000 and 2,000 years ago. Sea level indicators suggest that global sea level did not change significantly from then until the late 19th century, when the instrumental record of modern sea level change shows evidence for onset of sea level rise. Estimates for the 20th century show that global average sea level rose at a rate of about 1.7 mm. per year.

Satellite observations available since the early 1990s provide more accurate sea level data with nearly global coverage. This decade-long satellite altimetry data set shows that since 1993, sea level has been rising at a rate of around 3 mm. per year—significantly higher than the average during the previous half century. Coastal tide gauge measurements confirm this observation and indicate that similar rates have occurred in some earlier decades.

Sea level rise is currently determined by the employment of two techniques: the use of tide gauges and satellite altimetry. Tide gauges provide sea level variations with respect to the land on which they lie. To extract the signal of sea level change resulting from ocean

The Lower Patuxent River in Maryland, showing the flooding of low-lying areas by extreme high tides. If climate change causes sea level to continue to rise, this type of flooding will become increasingly common.

water volume and other oceanographic change, land motions need to be removed from the tide gauge measurement. Sea-level change based on satellite altimetry is measured with respect to the Earth's center of mass and thus is not distorted by land motions, except for a small component resulting from large-scale deformation of ocean basins. The total 20th-century rise is estimated to be around 0.5 ft. (0.17 m.).

Sea-level rise is accelerating worldwide. Globally, 100 million people live within about 3 mi. (1 m.) of sea level. Eight to 10 million people live within 3 mi. (1 m.) of high tide in each of the unprotected river deltas of Bangladesh, Egypt, and Vietnam. Intergovernmental Panel on Climate Change (IPCC) reports estimate that the global average sea-level rose at an average rate of 1.8 (1.3–2.3) mm. per year between 1961 and 2003, and within that period, the rate of rise was faster between 1993 and 2003—about 3.1 (2.4–3.8) mm. per year. Overall, the IPCC concludes that there is high confidence that the rate of observed sea-level rise has risen from the 19th to the 20th century. The total 20th-century rise is estimated to be 0.17 (0.12–0.22) m. In 2001, IPCC projections were for a sea-level rise of between 9 and 88 cm. between 1990 and 2100 and a global average surface temperature rise of between 2.5–10.4 degrees F (1.4–5.8 degrees C). In 2007, IPCC projections based on different scenarios predict seal level rise from 0.18 to up to 0.59 mm. by 2099.

Toward the end of the 21st century, projected sea-level rise will affect low-lying coastal areas with large populations. The cost of adaptation could amount to at least 5 to 10 percent of gross domestic product. Mangroves and coral reefs are projected to be further degraded, with additional consequences for fisheries and tourism. Snowmelt runoff as a result of sea-level rise will have major consequences. For example, one change will be a change from spring peak flows to late winter peaks in snowmelt–dominated regions. Many species, both aquatic and riparian (i.e., riverine), have evolved to take opportunity of the spring flows as a result of snowmelt. For example, some fish time their reproduction strategies specifically to avoid the stress of springtime flows. Changes in springtime flow regimes, or high winter flows associated with rain or snow events, can scour streambeds and destroy eggs. Trees that provide riparian habitat along rivers may find it harder to reproduce, as they are dependent on high spring flows. Many species, such as salmon, that are already under pressure from other environmental effects will be significantly affected by climate change. For example, higher temperatures and a reduced stream flow in the Columbia River Basin may be increasing the mortality of juvenile coho salmon, or in some cases, increased temperatures may be creating thermal barriers for the migration of adult salmon.

There are a number of associated events that are the result of climate change and that will also have affects on sea-level rise. For example, the Kangerdlugssuaq Glacier in Greenland is moving much faster, now melting at a rate of 8.7 mi. (14 km.) a year in comparison to just 3 m. (5 km.) a year in 1988. This loss will also have serious implications for sea-level rise, with some scientists predicting that within the next 100 years, ice cover in this region will completely disappear over summer, and hence species living within it, such as polar bears, will be threatened. The complete melting of the Greenland Ice Sheet and the West Antarctic Ice Sheet would lead to a contribution to sea-level rise of up to 23 ft. and about 16 ft. (7m. and 5 m.), respectively.

The potential socioeconomic impacts of sea-level rise are as follows: direct loss of economic, ecological, cultural, and subsistence values through loss of land, infrastructure, and coastal habitats. For example, it is estimated that the total of people at risk of sea-level rise in Bangladesh could be 26 million, in Egypt 12 million, in China 73 million, in India 20 million, and elsewhere 31 million. This makes an aggregate total of 162 million people affected by sea-level rise. There will be an increased flood risk for people, land, and infrastructure. There will be other affects related to changes in water management, salinity, and biological activities. A rise in sea level would inundate wetlands and lowlands, accelerate coastal erosion, exacerbate coastal flooding, threaten coastal structures, raise water tables, and increase the salinity of rivers, bays, and aquifers. Similarly, the areas vulnerable to erosion and flooding are also predominantly located in the southeast, whereas potential salinity problems are spread more evenly throughout the coast. Such a loss would reduce available habitat for birds and juvenile fish and would reduce the production of organic materials on which estuarine fish rely.

Some of the most important vulnerable areas are recreational barrier islands and spits such as found within the Atlantic and Gulf coasts. Coastal barriers are generally long narrow islands and spits (peninsulas) with the ocean on one side and a bay on the other.

Typically, the ocean-front block of an island ranges from 6.5 ft. to 13 ft. (2 to 4 m.) above high tide, whereas the bay side is less than a meter above high water. Thus, even a 1-m. rise in sea level would threaten much of this valuable land with inundation. Erosion, moreover, threatens the high parts of these islands and is generally viewed as a more immediate problem than the inundation of their bay sides. Although inundation alone is determined by the slope of the land just above the water, coastal engineer Per Bruun showed that the total shoreline retreat from a rise in sea level depends on the average slope of the entire beach profile. For example, most U.S. recreational beaches are less than 30 m. (100 ft.) wide at high tide, thus even a 30-cm. (1-foot) rise in sea level would require a response.

Finally, a rise in sea level would enable saltwater to penetrate farther inland and upstream in rivers, bays, wetlands, and aquifers, which would be harmful to some aquatic plants and animals and would threaten human uses of water. In Delaware in the United States, for example, salinity is seen as a factor resulting in reduced oyster harvests.

Coastal areas worldwide will become more vulnerable to flooding as a result of sea-level rise because higher sea levels provide higher bases for storm surges to build on. In this context, a 1-meter rise in sea level would mean that a 15-year storm will flood many areas that today are only flooded by a 100-year storm. Beach erosion will make land more vulnerable to storm waves, and higher water levels will increase the effects of flooding caused by rainstorms by reducing coastal drainage. Sea level will also raise water tables in various systems.

There are many examples of nations vulnerable to sea level rise. Japan, for instance, is particularly vulnerable to the effects of sea-level rise; a 1-meter rise in sea level would increase the area situated below mean high water from 332 sq. mi. to 903 sq. mi. (861 sq. km. to 2340 sq. km.). Future estimates show this would affect up to 4.1 million people and cost 109 trillion Yen ($1,300 billion). Over 57 and 90 percent of the existing sandy beaches would be eroded by sea-level rises of 0.3 and 1.0 m., respectively. In response, Japan has initiated a new coastal policy that combines disaster prevention, human resource use, and nature conservation. This policy includes an increase in monitoring of changes in mean sea level and the frequency of extreme events, the consideration of climate-change scenarios when developing plans for ports and landfills, and the preparation of a set of technological countermeasures to prevent effects on port facilities and maintain coastal protection.

Egypt's Nile Delta is one of the world's areas most vulnerable to sea-level rise. It is estimated that about 30 percent of the area will be lost because of inundation, almost 2 million people will lose their homes, and approximately 195,000 jobs will be lost, with a predicted economic impact of over US$3.5 billion over the next century.

In the chapter on coasts, the United Nations Environment Programme Handbook on Adaptation and Mitigation Methodologies specifically outlines a suite of strategic responses to sea-level rise. It cautions, however, that before applying these strategies, policymakers must decide whether or not their adaptation is to be autonomous or planned, reactive or proactive.

There are three management responses to sea-level rise: retreat, accommodation, and protection. Retreat involves no effort to protect the land from the sea. The coastal zone is abandoned, and ecosystems shift landward. This choice can be motivated by excessive economic or environmental effects of protection. In the extreme case, an entire area may be abandoned.

Accommodation implies that people continue to use the land at risk but do not attempt to prevent the land from being flooded. This option includes erecting emergency flood shelters, elevating buildings on piles, converting agriculture to fish farming, or growing flood- or salt-tolerant crops.

Protection involves hard structures such as sea walls and dikes, as well as soft solutions such as dunes and vegetation, to protect the land from the sea so that existing land uses can continue.

SEE ALSO: Climate Change, Effects; Floods; Refugees, Environmental.

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Seasonal Cycle

THERE ARE SEVERAL versions of seasons. The classical concept of season is of the four seasons that divide the year—spring, summer, fall, and winter. Some regions of the globe have weather-based seasons, such as rainy or dry seasons. Certain natural occurrences are more frequent during particular times of year; therefore, we have hurricane season as well as tornado season.

Seasonal cycles for weather patterns occur because of the atmosphere. Although the atmosphere is hundreds of miles thick, weather occurs in the base 7 mi. (11 km.), called the troposphere. Wind patterns in the troposphere are affected by the earth's rotation. This pattern is stereotypical and is the cause for seasonal cycles such as monsoon season in the northern Indian Ocean.

Other seasonal cycles include patterned flooding of rivers, such as the Nile River in Egypt. Ancient Egyptians utilized flood patterns for agriculture; today many cultures try to alter flood patterns. For example, the Colorado River floods created the Grand Canyon; today those floods no longer occur, due to dams and rerouting of the river.

A well-known example of a seasonal cycle is El Niño. It usually occurs in late December, around Christmas; hence it was named with the word for "child" in Spanish. El Niño is a warm ocean current, typically based off of Australia, that once every three to five years travels northeast towards Ecuador and Peru. Its opposite cycle, La Niña, contains cooler winds. Additionally, El Niño weakens trade winds, while La Niña brings stronger trade winds.

Tornados typically follow a seasonal cycle as well. They usually occur in the spring, yet they can happen at any time. Tornados occur when warm air at the surface of the earth rises quickly, and for a long distance. Air that is actively warmed at the surface, as occurs during the spring, is more buoyant and more likely to form a tornado.

Although hurricanes can form year-round, June 1 through November 30 is officially the Hurricane Season on the Atlantic coast of the United States. Hurricanes generally arise in the Caribbean and travel westward to the coast. Typically during these months, the most frequent type of storm is a tropical storm. Hurricanes are more frequent in the months of August, September, and October; however, severe hurricanes are usually limited to September, the midpoint of hurricane season.

SEE ALSO: Atlantic Ocean; Australia; Ecuador; Egypt; El Niño and La Niña; Floods; Hot Air; Hurricanes and Typhoons; Indian Ocean; Monsoons; Peru; Somali Current; Trade Winds; Trophosphere; Weather.

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Seawater, Composition of

SEAWATER IS A solution of salts of nearly constant composition, dissolved in variable amounts of water. It is denser than fresh water. It is risky to drink seawater because of its high salt content. More water is required to eliminate the salt through excretion than the amount of water that is gained from drinking the seawater. Seawater can be turned into potable water by desalination processes or by diluting it with freshwater. The origin of sea salt is traced to Sir Edmond Halley, who in 1715 proposed that salt and other minerals were carried into the sea by rivers, having been leached out of the ground by rainfall runoff. On reaching the ocean, these salts would be retained and concentrated as the process of evaporation removed the water. There are more than 70 elements dissolved in seawater as ions, but only six make up more than 99 percent of all the dissolved salts; namely, chloride (55.04 weight percent [wt%]), sodium (30.61 wt%), sulphate (7.68 wt%), magnesium (3.69 wt%), calcium (1.16 wt%), and potassium (1.10 wt%). Trace elements in seawater include manganese, lead, gold, and iodine. Biologically important elements such as oxygen, nitrogen, and iron occur in variable concentrations depending on utilization by organisms. Most of the elements occur in parts per million or parts per billion concentrations and are important to some positive and negative biochemical reactions. Properties such as salinity, density, and pH could be used to highlight the composition of seawater.

Salinity is the amount of total dissolved salts present in 1 L. of water and is used to express the salt content of seawater. Normal seawater has a salinity of 35 g./L. of water; that is, 3.5 percent. The salinity of seawater is made up by the dissolved salts. Seawater is more enriched in dissolved ions of all types than freshwater. Salts dissolved in seawater come from three main sources: volcanic eruptions, chemical reactions between seawater and hot newly formed volcanic rocks of spreading zones, and chemical weathering of rocks. Because of some chemical reactions between seawater and hot newly formed volcanic rocks, the composition of seawater has been nearly constant over time. Salinity affects marine organisms because the process of osmosis transports water toward a higher concentration through cell walls. Marine plants and many lower organisms have no mechanism to control osmosis, which makes them very sensitive to the salinity of the water in which they live. The density of surface seawater ranges from 1,020 kg. per cu. m. to 1,029 kg. per cu. m., depending on the temperature and salinity: the saltier the water, the higher its density. Seawater pH is limited to the range from 7.5 to 8.4 and increases with phytoplankton production. The speed of sound in seawater is about about 4,921 ft. (or 1,500 m.) per second and varies with water temperature and pressure.

Carbon (IV) oxide in the sea exists in equilibrium with that of exposed rock containing limestone ($CaCO_3$). Seawater also contains small amounts of dissolved gases such as nitrogen, oxygen, carbon (IV) oxide, hydrogen, and trace gases. Water at a given temperature and salinity is saturated with gas when the amount of gas entering the water equals the amount leaving during the same time. Surface seawater is normally saturated with atmospheric gases such as oxygen and nitrogen. The concentrations of oxygen and carbon (IV) oxide vary with depth. The surface layers are rich in oxygen, which reduces quickly with depth to reach a minimum between 656 and 2,625 ft. (200 and 800 m.) in depth. The amount of gas that can dissolve in seawater is determined by the water's temperature and salinity. Increasing the temperature or salinity reduces the amount of gas that can be dissolved. As water temperature increases, the increased mobility of gas molecules makes them escape from the water, thereby reducing the amount of gas dissolved. The gases dissolved in seawater are in constant equilibrium with the atmosphere, but their relative concentrations depend on each gas' solubility. As salinity increases, the amount of gas dissolved decreases because more water molecules are immobilized by the salt ion. Inert gases like nitrogen and argon do not take part in the processes of life and are thus not affected by plant and animal life, but gases like oxygen and carbon (IV) oxide are influenced by sea life. Plants reduce the concentration of carbon (IV) oxide in the presence of sunlight, whereas animals do the opposite in either light or darkness.

The world under water is different from that above in the availability of important gases such as oxygen and carbon (IV) oxide. Whereas in air about one in five molecules is oxygen, in seawater this is only about four in every thousand million water molecules. Whereas air contains about one carbon (IV) oxide molecule in 3,000 air molecules, in seawater this ratio becomes four in every 100 million water molecules. Thus, carbon (IV) oxide is much more available in seawater than is oxygen. All gases are less soluble as temperature increases, and particularly nitrogen, oxygen, and carbon (IV) oxide, which become about 40 percent to 50 percent less soluble with an increase of 45 degrees F (25 degrees C). When water is warmed, it becomes more saturated, resulting in bubbles leaving the liquid.

SEE ALSO: Chemistry; Climate Change, Effects.

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Senegal

THIS WEST AFRICAN country, formerly a French colony, has a land area of 75,955 sq. mi. (196,723 sq. km.), with a population of 12,379,000 (2006 est.) and a population density of 153 people per sq. mi. (59 people per sq. km.). Some 31 percent of the country is forested, with 12 percent being arable and a further 16 percent being used for meadows or pasture, mainly for cattle and sheep.

Senegal's entire electricity production comes from fossil fuels. The country has maintained a relatively stable level of carbon dioxide emissions from 0.4 metric tons per capita in 1990, rising to 0.44 metric tons by 2003. About 85 percent of this carbon dioxide comes from liquid fuels, with the remainder coming from cement manufacturing. In terms of sectors, that covering electricity and heat production accounts for 38 percent of carbon dioxide emissions, with 33 percent from transportation, 18 percent from manufacturing and construction, and 10 percent for private residences. The high level of emissions from transportation comes from the lack of adequate public transport systems and the heavy use of old minibuses, which have inefficient fuel usage rates. Although there is a railway in Senegal, connecting Dakar with Bamako, the capital of Mali, few people use it for travel within the country.

The effects of climate change and global warming will result in potential flooding on the Atlantic coast of the country. This has already led to coastal erosion in some parts of the country, with illegal mining adding to this problem, especially around Malika and Rufisque to the north of the Cap Vert peninsula. A rise in temperature will lead to more arable land becoming marginal, and probably to increased desertification. The Senegal government of Abdou Diouf took part in the United Nations Framework Convention on Climate Change, signed in Rio de Janeiro in May 1992, and ratified the Vienna Convention in the following year. On July 20, 2001, Senegal signed the Kyoto Protocol to the

Net fishing in Nianing, near Dakar, Senegal. Senegal has experienced coastal erosion in some areas.

UN Framework Convention on Climate Change, with it entering into force on February 16, 2005.

SEE ALSO: Climate Change, Effects; Deserts.

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Serbia and Montenegro

SERBIA AND MONTENEGRO are two of six independent countries that formed after the disintegration of the former Yugoslavia in the early 1990s. These two countries neighbor each other in eastern Europe and cover geographic regions with diverse climates. Serbia is landlocked and geographically positioned in the region of mild continental climate, whereas Montenegro also has a coastal region with a Mediterranean climate. Both countries have significant local climate variations resulting from local atmospheric circulations, as well as mountainous and hilly terrain away from Montenegro's Adriatic coast. In general, the subalpine climate with short cold winters and relatively hot summers is typical for elevations of from 2,000 ft. (600 m.) to 4,000 ft. (1,200 m.), and the Alpine climate with long and snowy winters and short warm summers is characteristic for elevations above 4,000 ft. (1,200 m.).

The capital of Serbia is Belgrade. Belgrade has a moderate continental climate that has hot summers, cold winters, and moderate precipitation. The yearly average temperature in Belgrade is around 53.1 degrees F (11.7 degrees C). The capital of Montenegro is Podgorica. Podgorica has a Mediterranean climate that has dry and hot summers, as well as rainy and mild winters, resulting in yearly average temperature of 61.5 degrees F (16.4 degrees C). In the summer, the temperatures in both capital cities go over 104 degrees F (40 degrees C). Interestingly, a town in the costal region of Montenegro has the highest yearly average rainfall in Europe of 183 in. (465 cm.). Nevertheless, the inland regions of these counties have been in "on" and "off" drought conditions resulting from extremely hot summers and unusually low rainfalls and snowfalls since 2000. These drought problems are characteristic for the entire region of the eastern part of Europe, with the drought in 2007 being particularly severe.

SEE ALSO: Climate Change, Effects; Drought.

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Seychelles

THIS COUNTRY CONSISTS of 115 islands spread over 250,966 sq. mi. (650,000 sq. km.) of ocean and has a land area of 176 sq. mi. (451 sq. km.), with a population of 87,000 (2006 est.) and a population density of 458 people per sq. mi. (178 people per sq. km.). With 18 percent of the land forested, 2 percent is arable, and 13 percent is used for meadows and pasture.

The entire electricity production of the country comes from fossil fuels, and the country, largely because of this and a burgeoning luxury tourist industry, has a relatively high level of per capita carbon dioxide emissions. Although it was 1.6 metric tons per person in 1990, it has risen steadily, reaching 2.6 metric tons in 1996, and then, with a massive rise in tourist numbers, rose to 5.5 metric tons per person in 1997, rising again to 6.9 metric tons in 2003. All the carbon dioxide emissions of the country come from liquid fuels, with most of this resulting from little availability of public transport and heavy use of gasoline-operated generators.

The rising water levels and temperatures in the Indian Ocean are likely to have dramatic effects on Seychelles. The former might lead to the loss of some of the smaller islands in the Seychelles, and the latter has led to some coral bleaching, affecting some of the coral reefs around the Seychelles, along with its marine life. As a result, many of them are heavily protected, with the government keen on promoting ecotourism and with money from tourists being invested in environmental protection. This has been particularly true of Cousine Island in the Seychelles, where there have been serious attempts to protect the turtles breeding there and prevent soil erosion.

In 1990, the Seychelles drew up a 10-year environmental management plan, being the first African country to do this. The Seychelles government of France-Albert René took part in the United Nations Framework Convention on Climate Change, signed in Rio de Janeiro in May 1992, and in the following year ratified the Vienna Convention. The government signed Kyoto Protocol to the UN Framework Convention on Climate Change on March 20, 1998, which was then ratified on July 22, 2002, with it entering into force on February 16, 2005.

SEE ALSO: Climate Change, Effects; Floods; Tourism.

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Sierra Leone

SIERRA LEONE IS on the West African coast, covering 27,699 sq. mi. (71,740 sq. km.), which is equivalent to an area the size of South Carolina. Sierra Leone has a population of 6,017,643 people (est. in July 2005), with nearly one million people living in the capital, Freetown. Sierra Leone was the lowest ranking, among 177 countries surveyed, in the United Nations Human Development Indicators (2006), in part because of an 11-year civil war (1991–2002) that resulted in 50,000 deaths and the displacement of 2 million people. The civil war also accelerated the depletion of natural resources including diamonds, tropical timber, and wild game. Sierra Leone has a per capita gross domestic product of $600 (2004 est.), with 68 percent of the population living in poverty, most of whom are subsistence farmers. Products of economic significance to the country include cocoa, coffee, rice, palm oil, and fish. Alluvial diamond mining is the major source of hard currency earnings, whereas other extracted minerals include titanium ore, bauxite, iron ore, gold, and chromite. The geography is characterized by coastal mangrove swamps and wooded uplands inland, and the climate is tropical. Four environmental issues facing the country are overharvesting of tropical timber, clearing of forests for cattle grazing, deforestation and related soil erosion, and overfishing.

The contributions that Sierra Leone makes to human-induced climate change are minimal compared with the rest of sub-Saharan Africa. Per capita CO_2 emissions in 1998 were only 100 metric tons, compared with an average of 800 tons for the subcontinent and a global average of 4,100 metric tons. The burning of liquid fuels (petroleum products) represented 90 percent of the country's CO_2 emissions. Other non-CO_2 air pollution in Sierra Leone is low compared with the rest of the continent and the world. Nitrogen oxide and carbon monoxide emissions (in 1995) were 64,000 and 1,380,000 metric tons, respectively, making up just 0.007 and 0.008 percent of the totals for sub-Saharan Africa.

Climate change could have significant consequences on the people and the environment in Sierra Leone. With 248.5 mi. (400 km.) of coastline, significant areas, including the capital, could become more prone to flooding. A rising sea level would also destroy the extensive network of mangrove forests that covers much of the coastline. Climatic change leading to a shortened rainy season, especially inland, could facilitate the conversion of tropical forests to grazing land for livestock. With these land-use changes could come new diseases, as well as the elimination of others. For example, Lassa fever, which is endemic to the rainforest along the eastern border, could disappear with changes in climate and landscapes. However, the intensification of rainfall could accelerate soil erosion and instigate flash flooding (which is already a problem in Freetown), threatening people and their livelihoods.

SEE ALSO: Carbon Dioxide; Climate Change, Effects; Floods; Global Warming.

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Simulation and Predictability of Seasonal and Interannual Variations

MEASUREMENTS OF CHANGES in atmospheric molecular oxygen using a new itechnique shows that the oxygen content of air varies seasonally in both the Northern and Southern Hemispheres, and is decreasing from year to year. The seasonal variations provide a new basis for estimating global rates of biological organic carbon production in the ocean, and the interannual decrease constrains estimates of the rate of anthropogenic CO_2 uptake by the oceans.

One example of research into variations are the interannual and interdecadal zooplankton population changes that have been observed in parallel with temperature (SST) changes at Helgoland, in the North Sea, over a period of 32 years.

Temperature determines the phenological timing of populations for each species in a unique way as to be seen in multiannual regressions. Sign, inclination of the regressions of phenophases with temperature and determination coefficient vary from species to species. Besides the limited predictability of annual temperature dynamics the species specificity limits the predictability of future phenophase timing. However, the strong correlation of phenophase timing with preceding SST permits the prediction of the annual seasonality based on statistical models separately for each population.

The regressions determined in the correlation analyses are the first approach to the phenological prognoses which the the Senckenberg Research Institute calculates daily for 192 phenophases of zooplankton including ichthyoplankton on a daily basis and which it publishes since April 2004 on the home page of the institute at www.senckenberg.de/dzmb/plankton. The calculations are based on more than 30 years of weekly and more frequent sampling at Helgoland Roads (54°11'18" N 7°54' E), the only proper offshore island of the North Sea. Temperatures were provided by the Biologische Anstalt Helgoland and the German Weather Service. Beyond the historic data used, current temperature measurements for the operative daily calculations are obtained from the websites. They are corrected according to the historic deviations stemming from current temperature measurements for the position at Helgoland Roads, published on the internet and weather report measurements and are then used for the calculation of the minimum current error for phenophase prediction. The prognoses is exclusively restricted to temporal prognoses. Abundance predictions are not included.

SEE ALSO: Oceanic Changes; Oceanography.

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Singapore

THE REPUBLIC OF Singapore covers the main island of Singapore and 57 outlying islands, most of which are uninhabited. It covers a land area of 270 sq. mi. (704 sq. km.) and has a total population of 4,680,600 (July 2003 est.). This means that Singapore has one of the highest population densities in the world—more than 17,335 people per sq. mi. (6425 people per sq. km.). Combined with a high standard of living, Singapore has a high per capita emission level of carbon dioxide, with 15 metric tons of carbon dioxide per capita in 1990, rising to 19.1 metric tons in 1994 and then falling to 16.8 metric tons in 1997, after which date it has fallen significantly, reaching 11.3 metric

The Tanjong container port in Singapore. Singapore is the busiest port in the world in terms of tonnage shipped, and has a population of over 4.5 million people. It is noted for business, finance, manufacturing, exports, refining, and imports.

tons in 2003. Some 98 percent of the carbon dioxide emissions come from liquid fuel, with the remainder being from the manufacture of cement.

Many of the problems associated with global warming are prominent in Singapore, which has a large urban area and increasingly smaller wooded areas. The heavy usage of electricity has come from widespread use of air conditioners, as Singapore is located in the tropics. Not only found in homes and offices, the air conditioning of shops and shopping centers has resulted in significant levels of carbon dioxide emissions, as has heavy economic reliance on industrial development and oil refineries. Another very important contributing factor has been the tourist industry, which involves well over 7 million tourists visiting the country each year—the vast majority of them arriving by airplane, with the consequent effects on the ozone layer; Singapore's Changi airport is one of the busiest airports in the world.

As shown by its reduction in carbon emissions in recent years, Singapore has long been aware of the problems faced by the government. As early as 1963, Singapore's prime minister, Lee Kuan Yew, launched a "Garden City" program that encouraged the planting of trees and also the incorporation of grass verges, trees, and parks into city developments. Emphasis was made on local flora, and the project was extremely successful. The ministry of the environment was formed in 1972, with Lim Kim San as the minister, himself being succeeded by Edmund William "Eddie" Barker, who remained minister until 1979. Recent ministers have included Mah Bow Tan; Yeo Cheow Tong, who was joint minister of health and environment from 1997 to 1999; Lee Yok Suan; Lim Swee Say, acting minister and then minister; and Dr. Ibrahim Yaacob, who presided over the new ministry of the environment and water resources from 2004, reflecting the importance of water in the long-term development of Singapore.

On the international scene, Singapore has been a member of the United Nations Framework Convention on Climate Change, signed in Rio de Janeiro in 1992, and also ratified the Kyoto Protocol to the UN Framework Convention on Climate Change on April 12, 2006, coming into force on July 11, 2006.

The smog found in Singapore in 1999 and some succeeding years following the burn-off of forests in Sumatra has led to Singapore doing much to help combat global warming. There are limitations on the use of private automobiles, with the cost of running a car being high, and extra charges to alleviate city congestion. Combined with this there has been one of the best integrated transport systems in the world, with heavy public use of buses and trains (mass rapid transport), including an efficient bus and train service to neighboring Malaysia. In the center of Singapore island, and over to the northwest, there have been reforestation programs, especially on Bukit Batok and around the water reservoirs.

SEE ALSO: Climate Change, Effects; Pollution, Air; Tourism; Transportation.

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Singer, S. Fred (1924–)

CONTROVERSIAL ATMOSPHERIC PHYSICIST, distinguished research professor at George Mason University, emeritus professor of environmental science at the University of Virginia, and founder of the Science and Environmental Policy Project—a policy institution on climate change and environmental issues, S. Fred Singer has been a leading skeptic of the scientific consensus on global warming. He points out that the scenarios pictured by most scientists are alarmist, that computer models reflect real gaps in climate knowledge, and says that future warming will be inconsequential or modest at most. He has also challenged the connection between ultraviolet-B radiation and melanoma and between secondhand smoking and lung cancer. Singer's critics have pointed out that the financial ties of his nonprofit organizations to tobacco and oil companies make Singer a case of clear conflict of interest.

Dr. Singer was born in Vienna on September 27, 1924. He did his undergraduate work in electrical engineering at Ohio State University and holds a Ph.D. in physics from Princeton University. He has served in numerous government and academic positions such as acting as director of the Center for Atmospheric and Space Physics at the University of Maryland (1953–62); as special adviser to President Eisenhower on space developments (1960); as first director of the National Weather Satellite Service (1962–64); as founding dean of the School of Environmental and Planetary Sciences at the University of Miami (1964–67); as deputy assistant secretary for water quality and research, U.S. Department of the Interior (1967–70); as deputy assistant administrator for policy, U.S. Environmental Protection Agency (1970–71); as professor of environmental sciences, University of Virginia (1971–94), and as chief scientist, U.S. Department of Transportation (1987–89).

To Singer, climate change is not something humans should fear. He argues that the climate has changed constantly throughout this and previous centuries and that people have always successfully adapted to it. In addition, he believes that humans can affect climate at a local level. Yet, whether they can cause global weather changes has still to be proved. Singer has repeatedly claimed that the atmosphere has not warmed up in recent decades. In fact, he has claimed that since 1979, it has slightly cooled down. Surface records that show increases in temperature are not, according to Singer, reliable sources of information, as thermometers tend to be placed in or very near to urban areas, which are traditionally warmer than other locations. Singer claims that models and observations about global warming do not agree. Although climatic models show that there should be an increase of about 1 degree F per decade in the middle troposphere, observations contradict these models. Singer is critical of arguments based on laboratory experiments, as the atmosphere is much more complicated and does not function under controlled circumstances. He recognizes that the increase in atmospheric CO_2 might lead to a slight warming, yet he says that this phenomenon is counterbalanced by increased evaporation of the oceans. The production of aerosols also causes cooling, which may counterbalance the effects of carbon dioxide. Yet, although Singer admits that aerosols last for a maximum of few weeks but CO_2 stays for decades, he is critical of models emphasizing the role of aerosols in connection to carbon dioxide.

Singer argues that because aerosols are mostly emitted in the Northern Hemisphere, where industrial activities are rampant, we would expect the Northern Hemisphere to be warming less quickly than the Southern Hemisphere. Actually, according to such models, the Northern Hemisphere should be cooling. To him, however, the data show the opposite, as both the surface data and the satellite data agree that, in the last 20 years, the Northern Hemisphere has warmed more quickly than the Southern Hemisphere. This fact contradicts the whole idea that aerosols make an important difference and proves that aerosols cannot be invoked as an explanation for the discrepancies between models and observations.

Singer does not have much faith in computer models, which he describes as having been "tweaked" to produce the present climate and the present short-term variation. He also points out that the two dozen models presently used are not entirely consistent with each other. These models also fail to depict all types of clouds, which to Singer is a fundamental flaw. He compares the current concern over global warming and the urgent calls for action to buying insurance with a high premium against a risk that is small. The Kyoto Protocol, to Singer, is part of the high insurance premium. The reduction of energy use by about 35 percent within 10 years implies, according to Singer's estimate, giving up one-third of all energy use, using one-third less electricity, and demolishing one-third of all cars. In spite of accusations aimed at other scientists that they use an apocalyptic tone when describing global warming, Singer too uses apocalyptic overtones to describe the Kyoto scenario: "It would be a huge dislocation of our economy, and it would hit people very hard, particularly people who can least afford it."

To Singer, global warming is a big business, with governments pumping about $2 billion into climate research. Thus people have to justify this expenditure, which supports jobs and research. Yet George Monbiot has emphasized that Singer has strong ties with oil and tobacco company—a fact that constitutes a conflict of interest given his stance on CO_2 emissions and secondhand smoking: "In March 1993, APCO sent a memo to Ellen Merlo, the vice president of Philip Morris, who had just commissioned it to fight the Environmental Protection Agency: 'As you know, we have been working with Dr. Fred Singer and Dr. Dwight Lee, who have authored articles on junk science and indoor air quality (IAQ) respectively.'" Singer's Science and Environmental Policy Project also received multiple grants from ExxonMobil.

SEE ALSO: Climate Change, Effects; Climate Models.

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Slovakia

LOCATED IN CENTRAL Europe, formerly the eastern part of Czechoslovakia, Slovakia has a land area of 18,932 sq. mi. (49,035 sq. km.), with a population of 5,390,000 (2006 est.) and a population density of 287 people per sq. mi. (111 people per sq. km.). A strongly agricultural country, some 31 percent of Slovakia's land is used for arable purposes, with an additional 17 percent used for meadows and pasture.

In terms of its per capita carbon dioxide emissions, Slovakia ranks 56th in the world, with 8.1 metric tons of emissions per person in 1992, falling to 7 metric tons in 2003. Slovakia sources 35.3 percent of its electricity production from fossil fuels, with 47.6 percent nuclear power and 17.1 percent from hydro power. Because of the heavy use of coal, solid fuels account for 45 percent of the carbon dioxide emissions in the country, with 34 percent from gaseous fuels, 17 percent from liquid fuels (reflecting the fact that transportation accounts for 12 percent of emissions), and the remaining 4 percent from cement manufacturing. The high amount of fossil fuels used in electricity also shows itself in the emissions by sector, with 32 percent of emissions from electricity and heat production and 43 percent from manufacturing and construction. The fossil fuels also account for the nation's relatively high sulfur dioxide and carbon monoxide emissions.

The Slovakian government took part in the United Nations Framework Convention on Climate Change, signed in Rio de Janeiro in May 1992, and ratified the Vienna Convention in 1993. The government signed the Kyoto Protocol to the UN Framework Convention on Climate Change on February 26, 1999, ratified it on May 341, 2002, and entered into force on February 16, 2005.

SEE ALSO: Climate Change, Effects; Transportation.

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Slovenia

LOCATED IN THE Balkans, and formerly one of the constituent parts of Yugoslavia, Slovenia has a land area of 7,827 sq. mi. (20,251 sq. km.), with a population of 2,030,000 (2006 est.) and a population density of 251 people per sq. mi. (99 people per sq. km.). About 12 percent of the country is arable, with a further 24 percent covered in meadows and pasture and 54 percent in forests.

In spite of its large amount of forestry, because of its high standard of living, Slovenia ranks 50th in the world in terms of its per capita carbon monoxide emissions, with 6.3 metric tons per person in 1992, falling to 5.5 metric tons in 1994 and then rising dramatically to 7.1 metric tons in 1995 before reaching a peak of 8.1 metric tons in 1997, falling slightly to 7.8 metric tons in 2003. Heavily reliant on nuclear power from the nuclear power plant at Krsko in Dolenjska, which accounts for 35.4 percent of the country's electricity production, 34.9 percent of the electricity comes from fossil fuels and 29.4 percent from hydropower. There is heavy use of fossil fuels, especially by the thermal electric power stations using coal to provide electricity for Ljubljana, the capital, and also Sostanj and Trbovlje. This results in electricity and heat production accounting for 42 percent of the country's carbon dioxide emissions.

Apart from electricity generation, there is also heavy use of private automobiles, with 365 vehicles per 1,000 people, similar to the proportions in Germany and the United Kingdom. This leads to regular traffic congestion, especially on roads around Ljubljana and Celje, Koper, and Maribor. Combined with relatively cheap petroleum, compared with prices in Western Europe, this has resulted in transportation contributing 28 percent of all carbon dioxide emissions by sector and 48 percent of emissions by source. This is in spite of the country's small size and an excellent public transport network, with an electrified train network run by Slovenske Zeleznice; the five steam trains are maintained solely for occasional journeys for tourists. In addition, there is an extensive bus network.

The effects of global warming and climate change on the country have been seen first with higher temperatures resulting in the melting of the snow in the mountains, limiting the periods available for skiing and beginning to affect arable crop production. To combat this, the government has succeeded in reducing sulphur dioxide emissions by half between 1985 and 1995 and also in reducing nitrogen oxide emissions by 20 percent. The Slovenian government took part in the United Nations Framework Convention on Climate Change, signed in Rio de Janeiro in May

1992, ratifying the Vienna Convention in the same year. In 1999, the government drew up a National Environmental Protection Program, and although it signed the Kyoto Protocol to the UN Framework Convention on Climate Change on October 21, 1998, it was not ratified until August 2, 2002, and entered into force on February 16, 2005.

SEE ALSO: Automobiles; Climate Change, Effects; Transportation.

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Smagorinsky, Joseph (1924–2005)

AMERICAN METEOROLOGIST AND the first director of the National Oceanic and Atmospheric Administration's Geophysical Fluid Dynamics Laboratory (GFDL), Joseph Smagorinsky developed influential methods for predicting weather and climate conditions and lectured at Princeton for many years. With his decision to move the GFDL to Princeton, Smagorinsky made the university a leading center for the study of global warming.

Joseph Smagorinsky was born to Nathan Smagorinsky and Dina Azaroff. His parents were from Gomel, Belarus, but fled during the pogroms. Smagorinsky's father was the first to immigrate to the United States in 1913, settling in Manhattan's Lower East Side, where he opened a paint store. Three years later, he was joined by his wife and their children. Joseph was born on January 29, 1924, when the family was already living in the United States. Similar to his other three brothers, he worked in his father's paint store. He attended Stuyvesant High School for Math and Science in Manhattan. After high school, he expressed his wish not to stay in the family business and to go to college instead. As his intellectual skills had already become apparent, the whole family decided to support him in his decision. Smagorinsky earned his B.S. (1947), M.S. (1948), and Ph.D. (1953) at New York University. During his sophomore year there, he joined the Air Force and became a member of an elite group of recruits who had been selected for their talents in mathematics and physics. Because of his scientific interests, Smagorinsky was included in the Air Force meteorology program. As a part of the scheme, he was sent to Brown University to specialize in mathematics and physics for six months. Smagorinsky was then sent to the Massachusetts Institute of Technology to learn dynamical meteorology, under Ed Lorenz, the author of chaos theory. During World War II, Smagorinsky worked as a weather observer for the Air Force. In May 1948, Smagorinsky married Margaret Frances Elizabeth Knoepfel—one of the first female weather statisticians.

After the war, Smagorinsky concluded his studies. Although he had planned a career as a naval architect, the rejection of the Webb Institute led him to choose meteorology as a field. After a question-and-answer session with prominent Princeton meteorologist Jule Charney, Smagorinsky was invited to carry out the research for his doctoral dissertation at the Princeton Institute for Advanced Studies. In 1950, Smagorinsky was part of Charney's team of scientists who successfully solved Charney's equations on the Electronic Numerical Integrator and Computer, also known as ENIAC. This was a milestone event in modern meteorology, as it pioneered the use of computers for weather forecasting. At the Institute for Advanced Studies, Smagorinsky and Charney developed the technique of the so-called numerical weather prediction. This technique relied on data collected by weather balloon, which were then elaborated by computers according to the laws of physics. This enabled researchers to forecast the interaction of turbulence, water, heat, and other factors in the production of weather patterns.

After completing his doctorate, in 1953 Smagorinsky accepted a position at the U.S. Weather Bureau and was among the founders of the Joint Numerical Weather Prediction Unit. Two years later, at the suggestion of eminent meteorologist John von Neumann, the U.S. Weather Bureau created a General Circulation Research Section and appointed Smagorinsky to direct it. Smagorinsky conceived his task as the completion of the von Neumann/Charney computer modeling program. He wanted to obtain a three-dimensional, global, primitive-equation general circulation model of the atmosphere. The section was initially located in Suitland, Maryland, but was moved to Washington, D.C., where it was renamed the General Circulation Research Laboratory in 1959. In 1963, it became the GFDL before moving to Princeton University, where it is still located, in 1968. Smagorinsky continued to serve as director of the lab until his retirement in January 1983.

Under Smagorinsky's directorship, the GFDL expanded, and Smagorinsky was able to attract respected international scientists such as Syukuro Manabe and Kirk Bryan to work there. The laboratory's work profoundly influenced the practice of numerical weather prediction around the world. Thanks to the GFDL's climate models, scientists have been able to assess more precisely humans' capabilities to affect climate change. In his years at Princeton, Smagorinsky was also appointed as visiting professor in geological and geophysical sciences at the university. As a member of the teaching staff, he helped to develop the Program in Atmospheric and Oceanic Sciences, a doctoral program in the Department of Geosciences that collaborates closely with the GFDL. After his retirement as director of the GFDL in 1983, Smagorinsky became a visiting senior fellow in atmospheric and oceanic sciences at Princeton until 1998.

It is thanks to the connection established by Smagorinsky between Princeton and the GFDL that the university became a major center for the study of global warming. From the 1970s onward, scientists working under Smagorinsky created the first models illustrating how climate could change in the face of increasing levels of carbon dioxide in the atmosphere. These models provided the first modern estimates of climate sensitivity and stressed the importance of water vapor feedback and stratospheric cooling. Research at the laboratory also allowed the development of the first models coupling atmosphere–ocean climate for studies of global warming, establishing the important differences between "equilibrium" and "transient" responses to the growing levels of carbon dioxide.

SEE ALSO: Climate Models; History of Meteorology.

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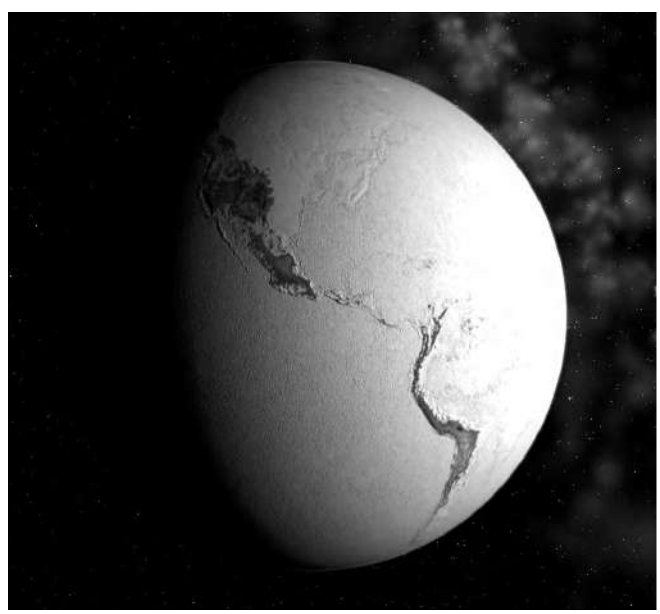
Snowball Earth

IN THE EARLY 1960s, Brian Harland, a geologist at Cambridge University, observed that rocks on several continents, dating from the Neoproterozoic era (approximately 800–680 million years ago), contain glacial debris. Some of the glacial debris included carbonate rocks, which are known to form in the tropics (e.g., in the present-day Bahama Banks). This conclusion later gained additional support from paleomagnetic data. One potential explanation is that the



The Snowball Earth hypothesis proposes that the Earth was entirely covered by ice in part of the Cryogenian period.

entire Earth was covered by ice and snow during the Neoproterozoic. This has come to be known as the "Snowball Earth" hypothesis.

One early problem was understanding how a global ice age could have commenced. During the 1960s, the Russian climate scientist Mikhail Budyko used a computer simulation to establish that a runaway ice–albedo feedback effect could lead to global glaciation. The term albedo refers to the amount of the sun's energy that is reflected by the Earth's surface. As glaciers grow in extent, they reflect more of the sun's energy, which causes the atmosphere to cool. This in turn causes the glaciers to grow. Budyko showed that if the glaciers extended beyond a certain critical point, this ice–albedo feedback could lead to a global ice age.

A second obstacle was understanding how a global ice age could ever end once it began. In the early 1990s, Joseph Kirschvink of the California Institute of Technology observed that during a global ice age, the carbon cycle would shut down. Volcanoes sticking up through the ice cover would continue to add carbon dioxide to the atmosphere. Having nowhere else to go, the carbon dioxide would then accumulate over millions of years until a runaway greenhouse effect caused the ice to melt.

One important rival to the Snowball Earth hypothesis is the high obliquity hypothesis. If the tilt of the earth's axis had been much different during the Neoproterozoic, the poles could have received more solar energy than the tropics. If so, it would be possible to explain the evidence for glaciers in the tropics without supposing that the entire planet had frozen over.

In his widely cited 1992 paper, Kirschvink also proposed an explanation for banded iron deposits observed in Neoproterozoic glacial debris. Iron is not soluble in seawater in the presence of oxygen. During a true Snowball Earth episode, the oceans would have become deoxygenated over time. Iron from thermal vents would build up in the seawater. Then, when the ice finally melted, and oxygen was once again exchanged between the oceans and atmosphere, oxidized iron would have been left along with the debris from the retreating glaciers.

During the 1990s, two Harvard scientists, Paul Hoffman and Daniel Shrag, gathered additional, highly suggestive evidence that seemed to favor the Snowball Earth theory. They found that in many places, the Neoproterozoic glacial debris occurs right below thick layers of carbonate rock (which are known as "cap carbonates"), and they showed how Kirschvink's proposal could account for this. During a Snowball Earth episode, very large amounts of carbon dioxide would have built up in the atmosphere. As the ice receded and the carbon cycle resumed, large amounts of carbon would have been washed out of the atmosphere during storms and ended up in the form of carbonate rock on the ocean floor. More controversially, Hoffman and Shrag also studied the ratio of carbon-12 to carbon-13 isotopes in the cap carbonates. They argued that an unusual dip in the carbon isotope ratio signified a temporary shutdown of photosynthetic activity in the earth's oceans.

CHALLENGES TO THE SNOWBALL EARTH THEORY

One potentially serious challenge to the Snowball Earth theory comes from paleontology. Today, most geologists agree that there were at least two major ice ages during the Neoproterozoic: the Sturtian, around 750 million years ago, and the Varanger, around 590 million years ago. The second of these episodes occurred shortly before the Cambrian Explosion of metazoan life. However, a true Snowball Earth episode would have killed off nearly all eukaryotic life, and it is not clear that there was enough evolutionary time for life to recover from a global ice age. Some scientists have used computer models to show that softer versions of the Snowball Earth episode might have been possible—for example, a mostly ice-covered planet with massive continental ice sheets in the tropics but largely ice-free tropical oceans.

Although scientists generally agree that there was low-latitude glaciation during the Neoproterozoic, they continue to use a combination of fieldwork and numerical modeling techniques to work out the details. The Snowball Earth scenario remains an intriguing live hypothesis.

SEE ALSO: Abrupt Climate Changes; Albedo; Carbon Cycle; Climate Feedbacks; Climate Models; Climate Thresholds; Computer Models; Earth's Climate History; Glaciology; Greenhouse Effect; Historical Development Of Climate Models; Ice Ages; Ice–Albedo Feedback; Ice Component of Models; Modeling of Ice Ages; Modeling of Paleoclimates; Ocean Component of Models; Paleoclimates.

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Social Ecology

SOCIAL ECOLOGY IS an ecological vision for the future developed by the anarchist thinker Murray Bookchin. This theory is part of a left-wing tradition that rejects notions of hierarchy, domination, power, and place to advocate political reformism, or restructuring that will resolve basic issues of societal, gender, and environmental imbalance. Social ecology is based on the understanding that all our present ecological problems are a result of deep-seated social problems. As Bookchin states, "economic, ethnic, cultural, and gender conflicts, among many others, lie at the core of the most serious ecological dislocations we face today." Specifically, social ecologists argue that the chief source of ecological destruction is the capitalist system and its products, such as overconsumption, consumerism, and concomitant economic growth.

Trade for profit, industrial expansion, and the association of progress with corporate self-interest are among others. Bookchin argues, therefore, that to separate ecological from social problems underplays not only the sources of the environmental crisis but also the interplay among all of these factors. Human beings must not downplay the importance of how they deal with each other as social beings. This, social ecologists argue, is the key to addressing the environmental crisis. The social ecological vision is to see a society that is based along social ecological lines. In this context, there are a number of principles that characterize social ecology.

First, a society based on social ecology would be one in which ecological regeneration would be inseparable from social regeneration. For example, social regenerative strategies might include the formation of ecocommunities and the adoption of ecotechnologies that establish a creative intersection between humanity and human nature. Spirituality, or what Bookchin calls regeneration of the spirit, is another principle, signifying the growth and development of a whole society. Such a society would be diverse and holistic in nature. Spirituality is defined as a natural phenomenon—one that focuses on the ability of humans to act as moral agents and actively promote the end to needless suffering, undertake ecological restoration, and foster aesthetic appreciation of all living things. Building on this spirituality will ensure the presence of liberty (in the sense of encouraging and nurturing individual and collective creativity, imagination, and personality) as a "continuum of natural evolution," resulting in a healthy society.

SOCIAL ECOLOGY AND THE ENVIRONMENT

Social ecology goes further, however, addressing the deep structural failures within society, and seeks to redress the ecological effects humans are having on the environment. Social ecology here seeks to change the definition of the very idea of a society based on hierarchy, class, and domination to one based on equity and the ethics of complementarity. In this case, social ecologists argue that humans must play a supportive role in maintaining the integrity of the planet. As such, they promote the establishment of community institutions that can embrace community-based ethical systems that in turn encourage the qualities of wholeness so integral to the social ecology vision. Societal structures that are supported by social ecology include confederal municipalism, in which municipalities conjointly gain rights to self-governance through the networks of confederal councils; empowerment of people; ecocommunities that are linked into the confederations of economy, fostering a healthy interdependence; and shared property.

Bookchin notes that "Social ecology calls upon us to see that nature and society are interlinked by evolution into one nature that consists of two differentiations: first or biotic nature, and second or human nature." By first nature, social ecologists refer to the way in which human beings are ultimately connected to their biological and evolutionary history. Second nature refers to the way in which humans produce or have a distinct social nature, as opposed to animals. As reflexive reflective beings, humans have the responsibility of being the voice of first nature. To understand and work within society, social ecologists argue we must understand and embrace both natures. Consistent with anarchist theory, social ecologists see social hierarchy to be the enemy of natural order.

In his early work, *The Ecology of Freedom* (1971), Bookchin in fact highlights a model of evolutionary human social development that suggests that social hierarchy first emerged in the Neolithic period with simple forms of governance within and between different social groups. As such, social ecologists perceive that humans are always rooted within their own biological evolutionary history. The separation of the current society of the human from the biological is a failure to think organically and to recognize wholeness. In this context, social ecologists argue that the human and the nonhuman must be seen as being part of an evolutionary continuum and, as such, we are in a state of continual becoming. Unlike deep ecology, which is underpinned by the belief that all organisms have intrinsic rights, proponents of social ecology argue that the environment has rights when and if they are conferred by humans.

Social ecologists also believe, however, that human beings have, by virtue of their innate creativity and powers of reason, intrinsic value. As such, Bookchin maintains that the most ethical standpoint is for humans to understand different forms of hierarchy in nature, that is, different ecosystems, patterns, and orders, without implying that humans thus have the right to dominate those hierarchies. Social ecology attacks capitalism at a fundamental level, believing that modern capitalism is "structurally amoral and hence impervious to any moral appeals." It believes that the driver for capitalism is to grow or die, and as such, that the system is inherently ecologically destructive. They advocate instead a society based on complementarity and mutual aid. In this way, social ecologists advance the need to redress the ecological effect humans have had on society by calling for social reconstruction based along ecological lines. The ethics of complementarity are based on a system in which human beings play a supporting role in upholding the integrity of the biosphere and the planet. Social ecologists argue we have a moral responsibility to do this, as well as to enshrine the ethics of complementarity within social institutions in ways that will enable active participation of all in the process of reconstruction. In such a society, property would be shared, which would ultimately give rise to individuals for whom there is no separation between the individual and collective interest, the private and the personal, the political interest and the social.

Social ecologists stress the social causes and consequences of the degradation of the environment above all else. In this context, social ecologists seek answers to societal problems that are organic. They argue that as human forms of hierarchy have evolved, so has the human capacity to impose forms of domination on nature. Hence, it is the responsibility of the human race to redress the inequalities and problems attendant on the imposition of our own social order on nature. If social change in line with the organic elements ascribed to does not occur, social ecologists believe that the biosphere as we know it is heading toward complete destruction.

Overall, the position of social ecologists has attracted critique from those who argue that their position is going too far in its interrogation of the link between society and the environment. Nonetheless, Bookchin's analysis of the relationship between society and the environment, and how this relationship constitutes and causes forms of domination—and hence ecological destruction—has played an important role in highlighting the nexus between social and natural dimensions of environmental decision making.

SEE ALSO: Climate Change, Effects; Ecological Footprint.

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Soil Organic Carbon

THE EARTH'S TERRESTRIAL ecosystems store over 2000 gross tons (Gt; 1 Gt = 1,015 g) of soil organic carbon (SOC), which is about four times more carbon than is stored in the atmosphere. Annually, soils release over 60 Gt Carbon to the atmosphere, which is about 10 times that amount released by fossil fuel combustion. Warming can increase the rate at which fresh organic matter (e.g., recently senesced leaves, fruits) decomposes, with the highest rates found where it is wet and warm. Less is known about how more thoroughly decomposed material (e.g., SOC) responds to changes in temperature, but it has been assumed that global warming will increase SOC decomposition rates, with the sensitivity of SOC decomposition to warming determining the extent to which SOC storage will be altered by climate change. Because the sensitivity of SOC decomposition to temperature remains poorly quantified, it cannot be accurately predicted whether global soils will change from a net sink to a net source of CO_2 as the planet warms.

SOC serves many important ecosystem roles. Because the supply of organic carbon exerts a dominant control on the activity of soil heterotrophic organisms—from bacteria to insects—SOC is critical to regulating the structure and functioning of soil communities. Further, during SOC decomposition, large quantities of nutrients are released from organic to mineral forms, and so SOC provides a critical source of nutrients to growing vegetation. The amount of SOC can also affect the water-holding capacity of a soil, as well as water movement through soils. Despite these important roles, the tremendous complexity of SOC in natural and agricultural systems presents important challenges to quantifying SOC formation and decomposition, including the sensitivity of these processes to climate change. This complexity results from the fact that very large quantities of organic matter are cycled through soils annually, but only a very small fraction remains in soils, typically in a highly transformed state that can persist in soils for millennia as a result of chemical recalcitrance or protection by clay minerals.

Given the important effect that climate may have on SOC decomposition, it is critical that tools be developed to accurately predict how SOC formation, decomposition, and storage respond to climate change. Of particular importance is quantifying interactions among driving variables, as these interactions will influence responses in difficult-to-predict ways. For example, warming in cold and wet climates may result in the loss of SOC, as warming can dry out often anaerobic soils in which oxygen supply limits decomposition rates. In contrast, warming in temperate or tropical climates may have little effect on or even slow SOC decomposition rates, especially if moisture is limiting for the soil microbes responsible for decomposing SOC. Reducing uncertainty is important for accurately predicting how the terrestrial carbon cycle, and hence the climate, will respond to global warming.

SEE ALSO: Chemistry; Climate Change, Effects; Soils.

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Soils

SOIL CONTAINS PULVERIZED rock, organic matter, and microorganisms, which convert the organic matter to humus. Soils range from loosely-packed sandy soil, to finely packed, sticky clay soil. Between these two extremes is loam, whose high content of organic matter makes it easy to cultivate. Soils are thin in the Mediterranean basin, and thick in northern Europe, Russia, and the American Midwest and Mississippi delta. As the basis of agriculture and as a factor in the formation of climate, soils have shaped the destiny of humans.

Soils warm when absorbing sunlight, and cool when reflecting sunlight. Soil temperature coincides with an area's climate. In tundra, for example, the air warms in spring and summer much faster than the soil does. Only the outermost layer of the soil warms enough to thaw, and then for only a few months, before winter returns. Not all soils absorb and reflect sunlight at the same rate. Wet soil darkens, and absorbs the most sunlight and gains the most heat. Dark soil absorbs as much as 86 percent of sunlight, gray soil absorbs 80 percent, and light soil absorbs only 20 percent of sunlight, reflecting the rest into the atmosphere. When water saturates soil, however, its color lightens. Being light, saturated soil reflects sunlight, yet the large amount of water that soil can hold increases the capacity of soil to absorb heat. Saturated soil absorbs and radiates heat slowly and in large quantities. Water evaporating from soil liberates heat, warming the surrounding air. Dry soil reflects more sunlight and heat than wet soil. Yet dry soil, because it contains little moisture, warms quickly on a cloudless day and becomes hot. At night, dry soil quickly cools, radiating heat back into the atmosphere.

The term *albedo* is the ratio of the amount of sunlight an object reflects to the amount it absorbs. A solid black object absorbs all sunlight and reflects none, and so has an albedo of zero. A white object absorbs no sunlight, reflects all of it, and has an albedo of one. The mean albedo of earth is 0.36. Dark soil has an albedo between 0.1 and 0.2. Clay soil has an albedo between 0.15 and 0.35. Sandy soil has an albedo between 0.25 and 0.45, and light soil has an albedo between 0.4 and 0.5.

At most sunlight penetrates only a few feet of soil. Infrared light, for example, penetrates to a depth of 3 ft (.9 m.). Because the amount of sunlight that soil receives varies during the day, soil temperatures vary. Soil temperatures also vary throughout the year. In Bridgewater, Massachusetts, for example, soil at a depth of one inch varied from a low of 35.2 degrees F (1.7 degrees C) in February to a high of 63.5 degrees F (17 degrees C) in August. Soil temperature therefore varies less than the temperature of air. Sunlight penetrates more deeply in rocky and wet sandy soil than in wet clay. Sunlight penetrates least in dry sandy soil.

Vegetation affects the capacity of soils to absorb sunlight. Plant cover decreases the albedo of light soil and increases the albedo of dark soil. Dense foliage blocks sunlight from reaching the soil, and so lessen the soil's absorption of sunlight and heat. Before the evolution of plants, soils must have been, along with the oceans, the major reservoirs of heat by absorbing sunlight. Like water, soil absorbs the most heat when the sun is overhead. Soil reflects increasing amounts of light as dusk approaches. Along with the oceans, the soil shapes the climate and influences the course of life.

SEE ALSO: Albedo; Climate; Plants.

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Solar Energy Industries Association (SEIA)

THE SOLAR ENERGY Industry Association (SEIA) is an American trade association for the solar industry, working to expand markets, strengthen and develop research, and improve education for the employment of solar energy. SEIA is affiliated with the PVNow coalition of photovoltaic companies, which aims to expand the North American–distributed, grid-connected photovoltaic market opportunities and eliminate market barriers. They are pursuing this goal through lobbying key state legislatures, utility rate–making authorities, and other state energy policymaking agencies. SEIA represents over 700 companies and 20,000 employees in the U.S. energy sector.

SEIA headquarters are located in Washington, D.C. The organization is divided into 14 state SEIA organizations. Members of the state organizations monitor and advocate in the state governments and also supply grassroots support for solar consumers

SEIA's mission is to reduce regulatory barriers to photovoltaic installations, increase photovoltaic markets across the nation.

and small businesses. SEIA chapters have up-to-date information on retailers and distributors in their area and frequently host workshops and discussion groups. SEIA's mission is to reduce regulatory barriers to photovoltaic installations, increase photovoltaic markets across the nation through meaningful and appropriate incentive programs at the state and federal levels, guarantee continuing federal research into high standards of photovoltaic devices, and supporting technologies such as inverters and balance-of-system equipment. SEIA campaigns for legislation in favor of renewable energy and technologies that could provide emission-free energy sources. It also advocates for a reduction of CO_2 emissions.

Rhone Resch is the president of SEIA. Together with his organization, he applauded the U.S. Congress and President George W. Bush for producing the strongest national policy for solar power since the 1980s. The solar tax benefits in the 2005 Energy Bill were acclaimed by SEIA as an important victory and as the measure necessary to allow the solar industry to meet the challenge of playing a significant role in supplying energy for the United States. To Resch, the United States has the best solar resources in the industrialized world, and by choosing solar energy, Americans can make a real contribution to their country's energy independence: "Installing solar energy on your roof is one of the most meaningful steps an individual can take to reduce our reliance on foreign sources of energy and help declare energy independence. Now solar comes with a more affordable price tag, and more consumers will take a step towards energy independence by choosing solar power. That means cleaner air, more jobs, and greater energy security for all." SEIA also supports the Solar Energy Research and Advancement Act of 2007—legislation that Resch described as "helping solar energy to make major strides in contributing to a clean, domestic, renewable supply of electricity."

SEE ALSO: Alternative Energy, Solar; Carbon Dioxide; Sunlight.

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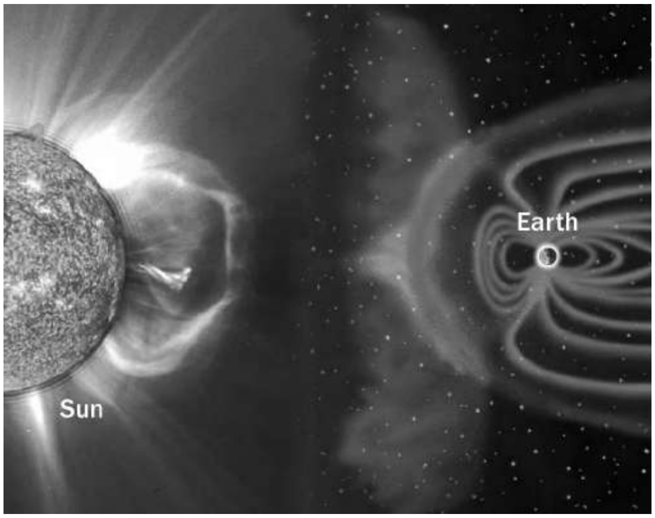
Solar Wind

TWO COMPETING THEORIES for global warming and their effect on Earth's changing climate persist today. The first theory suggests that the driver for global warming is the increasing amount of greenhouse gases dumped into the atmosphere as a result of humanity's burning of fossil fuels. The second theory posits that the solar wind and its associated magnetic field alters the Earth's cloud cover and adjusts the atmosphere's water vapor content, which leads to the steady temperature rise known as global warming.

The latter theory involves a stream of plasma, or high-energy charged particles, propelled from the sun's upper atmosphere. This stream of electrons and protons escapes the gravitational pull of the sun and creates the solar wind. It varies in speed from 190 to 500 mi. (306 to 805 km.) per second and passes by Earth as the sun rotates in space. The solar wind affects Earth's magnetic field and, in turn, is believed to have a major effect on climate change.

Opponents to the greenhouse gas theory of global warming argue that increasing radiation activity from the sun over the past 300 years has been the primary culprit—not an increase of atmospheric carbon dioxide. Researchers believe that because the doubling of the sun's magnetic flux recorded in the 20th century had led to increased sunspot activity as it follows its periodic 11-year cycle, the ferocity of the solar wind and the overall brightness of the sun also increased.

Proponents of global warming who subscribe to increasing carbon dioxide emissions as the cause of the problem avoid citing work done by NASA's Goddard Institute for Space Studies (GISS) or other scientific evidence offering credence to the solar wind theory. Just like the greenhouse gas theory, the GISS climate model is used to show that changes in the solar wind throughout the ages have varied surface warming. Climate researchers determined that the sun has played a role in modulating the atmosphere's moisture content and its circulatory patterns, causing droughts in ancient times. Backing up these computer-generated data are a number of natural records that correlate with the model's projections. Lake sediment analysis, fire records, and tree-ring measurements from the Yucatan Peninsula, Mexico, and Peru, to name a few locations, illustrate that periods of drought occurred during times of heightened solar output.



The Earth's magnetosphere, or magnetic field, protects us from most effects of the solar wind and from solar storms.

Increasing solar wind produces more ozone in Earth's upper atmosphere by breaking up oxygen molecules and heating the atmosphere. As a consequence, the circulation of the atmosphere is affected right down to the surface, which, in general, warms and reinforces existing rainfall patterns. Wet regions receive more rain, and dry regions become more susceptible to drought as the warmer air temperature pulls more moisture out of the soil. Droughts become more intense.

Although such facts are rarely disputed, the scope of the influence of solar wind is hotly debated. Some researchers state that the current period of global warming cannot be caused by the changes in solar output alone. Other researchers suggest that a double effect is in play, in which a more vigorous solar wind increases the global temperature, which in turn causes the oceans to warm, as made evident by melting sea ice. Because warm water absorbs less carbon dioxide, more of that greenhouse gas remains in the atmosphere. The debate boils down to whether all, some, or none of the burning of fossil fuels leads to global warming. As of this writing, most scientists and the popular media believe that human activity adds so much greenhouse gas to the atmosphere that this round of global warming could be catastrophic to life on Earth.

Solar-focused satellites have been monitoring the sun since the 1970s. More recently, the Solar and Heliospheric Observatory and the Wind and Advanced Composition Explorer have kept their instruments trained on the sun to measure the sun's temperature, capture the ion content of the solar wind, determine how the solar wind is accelerated, and more. Recently, the twin STEREO spacecraft were launched to expand on and augment existing satellite measurements by tracking the sun together and reporting on its solar behavior. The Solar Terrestrial Relations Observatory became operational in 2007 and will provide researchers the first three-dimensional space forecasts associated with solar activity.

Whatever the conclusion as to the ultimate cause of global warming, it is clear that the "third rock from the sun" will play a big role. The question for humanity is to determine which theory best describes global warming—greenhouse gas emissions or solar wind influences—and to develop policies to mitigate the effects on human civilizations.

SEE ALSO: Climatic Data, Historical Records; Computer Models; Goddard Institute for Space Studies; Sunlight.

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Solomon Islands

LOCATED IN THE Pacific, east of Papua New Guinea, the Solomon Islands have a land area of 11,157 sq. mi. (28,896 sq. km.), covering 249,000 sq. nautical mi., with a population of 496,000 (2006 est.) and a population density of 43 people per sq. mi. (17 people per sq. km.). Only 1 percent of the land is arable, with a further 1 percent being used for meadows and pasture and 91 percent of the country forested, although a massive timber industry is resulting in heavy deforestation.

The entire electricity production in the country is from fossil fuels, with liquid fuels making up the entire carbon dioxide emissions from the country. Because the country is largely undeveloped, the per capita carbon dioxide emissions rate is low, being 0.5

metric tons per person in 1990 and falling to 0.39 metric tons in 2003. The increasing deforestation of the islands, however, will start to lead to a heavy increase in the country's carbon dioxide emissions in subsequent years.

The possible effects of global warming and climate change on the Solomon Islands are significant. There is the strong probability of increased flooding, which in turn could lead to a rise in the prevalence of insect-borne diseases such as malaria and dengue fever. The flooding might also result in the inundation of some of the several hundred islands that make up the country.

The Solomon Islands government took part in the United Nations Framework Convention on Climate Change, signed in Rio de Janeiro in May 1992, and ratified the Vienna Convention in the following year. The government signed the Kyoto Protocol to the UN Framework Convention on Climate Change on September 29, 1998, and ratified it on March 13, 2003, with it entering into force on February 16, 2005.

SEE ALSO: Climate Change, Effects; Deforestation; Floods.

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Somalia

LOCATED IN NORTHEAST Africa—the "Horn" of Africa—Somalia has a land area of 246,201 sq. mi. (637,657 sq. km.), with a population of 8,699,000 (2006 est.) and a population density of 34 people per sq. mi. (13 people per sq. km.). About 80 percent of the population is dependent on agriculture, though only 2 percent of the land is arable, with a further 69 percent used for meadows or pasture, mainly low-intensity grazing of cattle, goats, and pigs. Some 14 percent of the land is forested.

Because the country is underdeveloped, it has a very low level of electricity usage, with the carbon dioxide emissions per capita being the lowest of any country in the world, even though accurate statistics have not been available for the last 10 years. Official statistics from 2001 give the entire electricity production for the country at 245 million kWh, with consumption levels at 228 kWh, with 100 percent of all electricity coming from fossil fuels.

The effects of global warming and climate change on Somalia are expected to be extensive. The rising temperature is expected to make more of the arable land unusable for the growing of crops and to render the pasture land even less productive than it is at the moment. There is also the possibility of flooding in some low-lying parts of the country.

The Somali government sent an observer to the United Nations Framework Convention on Climate Change, signed in Rio de Janeiro in May 1992, and ratified the Vienna Convention on 2001. Because of the instability in the country, there have been few measures introduced to combat some of the effects of climate change, and the current government has so far not expressed any opinion on the Kyoto Protocol to the UN Framework Convention on Climate Change.

SEE ALSO: Climate Change, Effects; Deserts; Floods.

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Somali Current

THE SOMALI CURRENT can be found on the surface of the northern Indian Ocean, serving as a western boundary of this ocean. It is a movement of waters around the Indian Ocean, dispersing heat. Atmospheric circulation and ocean circulation together are the major mechanisms for global heat distribution. As atmospheric circulation defines large-scale air movements around the globe, ocean circulation refers to the patterned movement of particular waters.

In summer, a southwest monsoon blows upward from the east coast of the Horn of Africa. Carried along with the monsoon are the waters of the western Indian Ocean, moving in a northeast direction underneath, and powered by winds. These waters may reach speeds of 9 mi. per hour (14 km. per hour). As the current reaches Somalia, the waters turn eastward. Some stay on near the Arabian Peninsula to form the East Arabian Current. Those that continue eastward eventually become the northeast monsoon during the autumn and winter, flowing southwest back to their origins. During the months of December and March, the Somali Current typically hovers between 5 degrees and 1 degree of latitude North of the equator, with this reach extending to span between 10 and 4 degrees latitude North during the central months of January and February.

The Somali Current is of interest because it creates an upwelling of cold water that is the only other region of such low surface temperatures within 10 degrees of the equator outside of Peru, and perhaps even colder. The cold surface temperatures around Peru are caused by the Peruvian or Humboldt Current which is related to El Niño.

The waters of the Somali Current swirl into what is known as the Great Whirl, an eddy with a diameter that can reach 500 km. (approximately 311 mi.), spinning in an anticyclonic direction. Anticyclonic direction is opposite to the earth's rotation; in the Northern Hemisphere the eddy therefore spins clockwise. The upwelling occurs during the months of May through September, and can lower the surface temperature in the western Indian Ocean by up to 9 degrees F (5 degrees C). Ocean surface temperatures are an important data source for monitoring global warming; therefore it is important to record the temperatures found during the northern (summer) swing of the Somali Current.

The Somali Current and other phenomena in the Indian Ocean were investigated at length in the year 1995 in a study that began in late 1994 and concluded in early 1996. It was an ambitious project that attempted to record all data related to the Indian Ocean during that year, and was undertaken by the World Ocean Circulation Experiment (WOCE) Indian Ocean Expedition.

SEE ALSO: El Niño and La Niña; Hadley Circulation; India; Indian Ocean; Modeling of Ocean Circulation; Monsoons; Oceanic Changes; Oceanography; Peru; Peruvian Current; Somalia; Thermocline.

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South Africa

THE REPUBLIC OF South Africa has a land area of 471,443 sq. mi. (1,221,037 sq. km.), with a population of 48,577,000 (2006 est.) and a population density of 101 people per sq. mi. (39 people per sq. km.). Some 10 percent of the country is devoted to arable purposes, with a further 67 percent used as meadows and pasture, much of it for low-intensity grazing of cattle and goats. Only 7 percent of the country is forested.

As the nation is a major producer of coal, some 92.6 percent of South Africa's electricity production comes from fossil fuels, with 6.7 percent from nuclear power and 0.7 percent from hydropower. In spite of its location, South Africa has made little use of solar power. In 1990, South Africa produced 7.8 metric tons per capita of carbon dioxide, and this level of emissions remained relatively stable until 2003, rising to 9.2 metric tons per capita in the following year. Coal and other solid fuels contribute to 80 percent of the country's carbon dioxide emissions, with 18 percent being from liquid fuels and 1 percent from gaseous fuels. By sector, 63 percent of South Africa's carbon dioxide emissions come from the generating of electricity, with 21 percent from manufacturing and 13 percent from transport.

Recently observed climates in South Africa, possibly attributable to global warming, include the following: The temperature of the Benguela Current has recently been increasing, resulting in a decrease in the fishing catch off the coast of the country. This, in turn, has led to a significant reduction in the diversity of species of fish in the region. In January 2000, following one of the driest Decembers on record, with many days having temperatures above 104 degrees F (40 degrees C), there were many bush fires along the coast of the Western Cape, leading to the destruction of woodland and other vegetation.

The South African government of Frederik W. de Klerk took part in the United Nations Framework Convention on Climate Change, signed in Rio de Janeiro in May 1992. They accepted the Kyoto Protocol to the UN Framework Convention on Climate Change on July 31, 2002, with it entering into force on February 16, 2005. In August 2005, Marthinus van Schalkwyk, the environmental affairs minister for South Africa, attended a week-long ministerial meeting in Greenland to discuss what became dubbed the Greenland Dialogue to examine further ways of making the Kyoto Protocol more effective.

A windmill near Johannesburg: Wind resources could be used to reduce carbon dioxide emissions from generating electricity.

SEE ALSO: Carbon Dioxide; Climate Change, Effects.

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South Carolina

SOUTH CAROLINA IS 32,020 sq. mi. (82,931 sq. km.), with inland water making up 1008 sq. mi. (2,610 sq. km.), coastal water making up 72 sq. mi. (186.5 sq. km.), and territorial water making up 831 sq. mi. (2,152 sq. km.) South Carolina's average elevation is 350 ft. (106 m.) above sea level, with a range in elevation from sea level on the Atlantic Ocean to 3,560 ft. (1,085 m.) at Sassafras Mountain. The major natural regions include what is referred to as the low country—the Coastal Plain with offshore islands (inland is rolling, and along the coast is flat)—and what is referred to as the up-country—piedmont (higher elevation, with forests and pastureland) and Blue Ridge (mountainous and forested). South Carolina has river systems; the large lakes are artificially created.

The state's hot summers and warm winters come from the combination of the state's relatively low latitude, low elevation, proximity of the warm Gulf Stream in the Atlantic, and the Appalachian Mountains. During the winter, the mountains limit cold air entering the interior of the continent. Low country summers are hot and humid, though a sea breeze brings some relief. The up-country is usually cooler than the low country, even in the middle of the summer. The highest temperature recorded in the state was 111 degrees F (44 degrees C) on June 28, 1954, and the lowest temperature recorded was minus 19 degrees F (minus 28 degrees C) on January 21, 1986. Winters in South Carolina are mild, with brief periods of cold (lakes and rivers rarely freeze over), throughout the state. Precipitation is abundant all year; snow falls in the mountains but is rare in other parts of the state. Most of the state receives about 48 in. of rain a year, though the mountains areas receive more.

Forests cover much of the state, and wood is commercially harvested for lumber, wood pulp, paper, and furniture. Agriculture products include tobacco, cotton, corn, soybeans, and wheat. South Carolina's electricity is generated by nuclear power plants and coal-fueled power plants, and a small portion is hydroelectric.

South Carolina is already experiencing the effects of higher temperatures and rising sea levels (nine in. in the last century), and hurricanes and other major storms have increased in intensity and duration by about 50 percent since the 1970s; they are linked to increases in average sea surface temperatures and eroding coastlines. The coastal plains have already experienced problems with water supplies, and the increased use of groundwater for irrigation has lowered groundwater levels.

Although climate models suggest an increase in temperature of 5.4 degrees F (3 degrees C) by the end of the 21st century, potential risks anticipated include sea levels rising an additional 19 in. or 48 cm. (causing beach erosion and saltwater incursion); decreased water supplies; population (both human and animal) displacement; changes in food production, with agriculture improving in cooler climates and decreasing in warmer climates; forest loss, with persistent drought and loss of trees unsuited to higher temperatures; change in rain pattern to downpours, with the potential for flash flooding (causing sediments, agricultural chemicals, and other substances to leach into water sources); and increased health risks of certain infectious diseases stemming from water contamination or disease-carrying vectors such as mosquitoes, ticks, and rodents and of heat-related illnesses.

In populated areas at higher elevations, as in northwestern South Carolina, water quality and amount may both become issues. Should the levels of streams, groundwater, and lakes decrease, shortages of water for industrial and municipal markets would occur. Shallow wells would be affected, with rural communities losing water supplies. Higher rainfall would increase flooding and erosion, as well as contaminating the remaining water supplies with runoff.

South Carolina's economy relies on tourism, and beach erosion resulting from climate change would damage the coastline.

On the basis of energy consumption data from the Energy Information Administration's State Energy Consumption, Price, and Expenditure Estimates (SEDS), released June 1, 2007, South Carolina's total CO_2 emissions from fossil fuel combustion in million metric tons for 2004 was determined to be 88.56, made up of contributions from commercial (1.53), industrial (14.59), residential (2.36), transportation (32.10), and electric power (37.98) sources.

South Carolina established the Governor's Climate, Energy, and Commerce Advisory Committee (CECAC) in February 2007 to research and evaluate, for presentation to the governor, recommended policy options to mitigate the effects of global warming. Appointed by the governor, the CECAC comprises a diverse group of stakeholders who bring broad perspective and expertise to the topic of climate change in South Carolina. Members represent the following sectors: energy, manufacturing, agriculture, forestry, tourism and recreation, heath care, nongovernmental organizations, academia, and state and local government. The advisory committee has held regular meetings considering options including renewable energy and recycling options.

Over the past three years, the University of South Carolina has purchased 70 flex-fuel vehicles that run on E-85, a mixture that is 85 percent ethanol and 15 percent gasoline. Much of South Carolina's renewable energy potential comes from biomass—organic matter such as plant fibers and animal waste that can be converted into electricity and fuel.

A number of programs have been undertaken for the conservation and improvement of South Carolina's soils, forests, and wildlife resources. Conservation efforts, including the protection of critical land areas, are carried on by a number of federal and state agencies as well as private organizations.

Watershed management considers economic interests as well as the protection of natural resources. Management plans are used to guide watershed management for water quality, recreation, wildlife management, and agricultural and forestry practices, balanced against community economic development.

The principal soil conservation effort is directed toward covering the badly eroded lands with pasture grasses or trees to prevent further soil removal. Reforestation, supervised cutting and replanting, and fire protection are practiced to provide adequate timber supplies in the present and future.

SEE ALSO: Climate Change, Effects; Floods; Tourism.

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South Dakota

SOUTH DAKOTA'S GEOGRAPHICAL location near the center of the North American continent provides it with a high degree of sensitivity to climatic change, as any variations from mean weather conditions will be readily apparent. The state is situated in a region that experiences all of the conditions of the continental climate classification, which usually means pronounced seasonality with long, cold winters; hot summers; midlatitude cyclonic storms; and variable precipitation. A border, running north-south, between the semihumid and semiarid precipitation regimes of North America, essentially divides the state (generally corresponding to the 100th meridian) and responds to changes, oscillating from east to west, in relation to overall global weather patterns. Thus, if there were significant changes in the global atmospheric system, such as warming resulting from anthropogenic or natural factors, climatic conditions would manifest themselves across the state.

This brief essay presents a summary of historical climate research and recent climate modeling in an effort to illuminate possible consequences of climate change on South Dakota's people and landscape. The state's climate parameters are summarized as follows: mean normal precipitation varies from 25 in. (635 mm.) in the southeastern part of the state to less than 14 in. (350 mm.) in the northwestern sector; temperatures range from summer highs in the lower 100 degrees F (40 degrees C) to minus 40 degrees F/C in winter, with an average annual temperature of less than 39 degrees F (4 degrees C). Record high and low temperatures are 120 degrees F (49 degrees C) and −58 degrees F (−50 degrees C.) Strong surface winds patterns, principally blowing from the north and northwest during the colder part of the year, also persist across the northern Great Plains, of which the state is a part. The region also experiences severe weather episodes such as tornadoes, hail storms, and blizzards in their respective seasons. The state's Black Hills subregion represents an anomaly to the general southeast-northwest precipitation and north-south temperature gradients, which vary temporally, with average wetter and warmer conditions prevailing at the higher elevations that support coniferous forest vegetation cover.

South Dakota's state climatologist presented research in 2001 revealing that the state had experienced a "definite climate shift" during the 1990s, recording an average increase of two or three in. (51–76 mm.) of precipitation annually over the previous three decades. The agricultural effect of increased moisture allowed advancement of the production of corn and soybeans westward toward the Missouri River—a feature that essentially divides the state into eastern and western sectors. Semihumid climatic characteristics associated with western Minnesota shifted as much as 200 mi. (320 km.) to the west, according to the report.

Contrary-wise, in the current decade, the semiarid extreme southwestern part of the state has been in the grips of a seven-year-long drought with severe consequences in terms of agricultural losses and forest and range wildfires, plus tendencies toward desertification conditions. The drought-affected area is the northeast extension of a multistate region in the western United States that has been experiencing prolonged, abnormally dry weather patterns.

In 2005, research was published indicating that future global warming may adversely affect wetlands within the eastern half of the state (Johnson et al., 2005) and, by implication, the general area as well. Eastern South Dakota's geologic landscape was produced mainly by Wisconsin age glacial deposits. The retreating ice left a terrain of ground moraines, outwash plains, and end moraines and a swath of tens of thousands of prairie potholes and larger kettles (shallow lake basins), which can be very productive waterfowl breeding areas when moisture conditions are favorable. The area is a part of the Prairie Pothole Region (PPR), which covers parts of five other states and two Canadian provinces. With large-scale Anglo-American settlement and development, beginning in the second half of the 19th century, much of the area has been transformed through drainage projects and intensive cultivation into a productive agricultural region, although a considerable acreage of natural wetlands remains. Western, or West River, South Dakota was unglaciated during the Pleistocene epoch, and the landscape is heavily influenced by the presence of the semiarid climatic regime. Contemporary agriculture is focused predominantly on cattle production, with some row crops, across vast areas of grasslands and rough terrain cut by a network of valleys occupied by mostly intermittent stream courses.

Johnson's research, based on climate modeling methodology, suggested that the most productive habitat for ducks in the PPR would shift under a drier climate from eastern South Dakota to areas to the east and much farther north—locations currently less productive or where most wetlands have been drained. The conclusion that was drawn indicates negative effects on both waterfowl production and commercial agriculture. This work concurs with other climate change studies that predict adverse consequences with a warming global climate in various areas of the world, especially in heavily populated or agriculturally productive regions of the Northern Hemisphere.

In sum, the climate region in which South Dakota is located has experienced a variable regime for millennia because of its geographical continentality. Temporally, the eastern half of the state was wetter than most of the early 20th century. However, if the current global climate change forecasts become reality, the outlook for South Dakota's environment for the next several decades, especially the eastern portion, becomes problematic, with anticipation of less precipitation and its associated effects on land and life. Some degree of mitigation may be possible in the shorter run, according to experts, if initiated in time, but the issue may be ultimately beyond any human control or even influence.

SEE ALSO: Climate Change, Effects; Global Warming.

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Southern Ocean

THE GLOBAL OCEAN influences the Earth's climate by storing and transporting vast amounts of heat, moisture, and carbon dioxide. Huge quantities of carbon are cycled annually among the biosphere (forests, grasslands, and marine plankton), the atmosphere, and the oceans. The oceans are the largest active reservoir of carbon, containing 50 times more carbon than the atmosphere. Of the 6 to 7 billion tons of carbon currently released into the atmosphere by human activities, approximately 3 billion tons remain in the atmosphere, 1 to 3 billion are absorbed by the oceans, and up to 2 billion appear to be absorbed by the terrestrial biosphere.

Oceanographers commonly refer to the oceanic region that surrounds the continent of Antarctica as the Southern Ocean. The northern boundary of the Southern Ocean is not well defined, but it coincides approximately with a broad zone of transition between the warm, saline surface waters of the subtropical regime and colder, fresher subantarctic waters, called the Subtropical Front, which occur between 40 degrees S and 45 degrees S. Using this definition, the surface area encompassed by the Southern Ocean represents approximately 29.7 million sq. mi. (77 million sq. km.), or 22 percent of the global surface ocean. Its unique geography makes it a key player in global climate.

The Southern Ocean is the only ocean that encircles the globe unimpeded by a land mass. It is home to the largest of the world's ocean currents: the Antarctic Circumpolar Current (ACC). The ACC carries between 135 and 145 million cu. m. of water per second from west to east along a 12,427 mile- (20,000-km.) path around Antarctica, thus transporting 150 times more water around the globe than the total flow of all the world's rivers. By connecting the Atlantic, Pacific, and Indian Oceans, the ACC redistributes heat around the Earth and so exerts a powerful influence on global climate.

Near the Antarctic continent, the Southern Ocean is a source of cold, dense water that is an essential driving force in the large-scale circulation of the world's oceans. The cooling of the ocean and the formation of sea ice during winter increases the density of the water, which sinks from the sea surface into the deep sea. This cold, high-salinity water includes Antarctic Bottom Water and Antarctic Intermediate Water. Antarctic Bottom Water originates on the continental shelf close to Antarctica, spills off the continental shelf, and travels slowly northward, hugging the seafloor beneath other water masses, moving as far as the North Atlantic and North Pacific. Antarctic Intermediate Water is less saline and forms farther north, when cold surface waters sink beneath warmer sub-Antarctic waters at the Antarctic Convergence at about 55 degrees S. Together, these motions form a complex, three-dimensional pattern of ocean currents that extends around the globe, known as the thermohaline circulation, or "great ocean conveyor." The thermohaline circulation has a critical influence on climate by transporting heat efficiently around the globe and by controlling how much dissolved inorganic carbon is stored in the ocean.

At the sea surface, seawater exchanges gases such as oxygen and carbon dioxide with the atmosphere at the same time that it is being cooled. As a result, sinking water efficiently transfers changes in temperature, fresh water, and dissolved gases into the deep ocean 2.5 to 3 mi. (4 to 5 km.) beneath the sea surface; in terms of carbon sequestration, this is called the solubility pump. Biological processes also play a role in the surface layer, where photosynthesis by single-celled marine phytoplankton can sequester carbon dioxide in the surface water and, through the process of sedimentation, transfer this organic carbon to deeper waters—the so-called biological pump.

The Southern Ocean is distinguished as a region of high levels of dissolved nutrients, but with modest rates of annual net primary production, so that the biological pump appears to be operating well below its maximum capacity. An interesting idea of recent years is that it may be possible to sequester much more atmospheric carbon if iron, an essential micronutrient, is added to the ocean to encourage the growth of marine phytoplankton, and thus stimulate the biological pump. The overall effect would be to lower the concentration of dissolved carbon dioxide in surface waters, allowing more atmospheric carbon dioxide to dissolve into the sea.

Understanding the global circulation and conditions under which surface waters penetrate into the deep ocean is critical for scientists estimating the timing and magnitude of climate change. At this time, the Southern Ocean is considered to be a net sink for atmospheric carbon dioxide; however, the magnitude of this sink has a high uncertainty, with mean annual estimates ranging between 0.5 and 2.5 billion tons. The degree of interannular variability in the Southern Ocean carbon sink, and its possible future response to climate change, is still poorly understood. However, climate model projections indicate that the Southern Ocean overturning circulation will slow down as the Earth warms. A decrease in the rate of overturning circulation will result in a decrease in the rate of carbon dioxide absorbed by the Southern Ocean, which represents a positive feedback and tends to increase the rate of climate change.

The presence of sea ice in the Southern Ocean is another factor that contributes to the Southern Ocean's important role in climate. Sea ice formation during the winter months is the largest single seasonal phenomenon on Earth, with approximately 7.7 million sq. mi. (20 million square km.) of ice formed annually, effectively doubling the size of Antarctica. This has a profound effect on both regional and global climate processes. Because of its high albedo, sea ice reflects the sun's heat back into space, intensifying the cold. However, it can also act as a blanket, insulating against heat loss from the ocean to the atmosphere. Its yearly formation injects salt into the upper ocean, making the water denser and causing it to sink downward as part of the deep circulation. As ocean temperatures increase in response to the global warming, the amount of sea ice is expected to decrease; this has already been observed in the Arctic Ocean. The resulting decrease in the planetary albedo would act as a positive feedback, increasing the amount of energy from the sun absorbed by the Earth and tending to further increase the rate of climate change.

SEE ALSO: Albedo; Antarctic Circumpolar Current; Arctic Ocean; Carbon Cycle; Climate Models; Phytoplankton; Sea Ice; Thermohaline Circulation.

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Southern Oscillation

FIRST DESCRIBED EXTENSIVELY by British meteorologist Sir Gilbert T. Walker in the 1920s, the Southern Oscillation refers to the periodic exchange of mass across the equatorial Pacific that is recorded in sea level pressure fluctuations between the eastern and western Pacific. Under normal conditions in the tropical Pacific, surface high (low) pressure prevails in the eastern (western) Pacific, with the easterly trade winds dominating surface wind and ocean flow.

This pressure pattern, also known as the Walker circulation, tends to support rising air motions and convectional precipitation near eastern Australia, as well as sinking air motions and dry conditions near coastal northern Peru. Every two to seven years, this generalized atmospheric surface pressure pattern weakens as equatorial Pacific air pressure rises in the west and lowers in the east. This shift in the pressure field considerably weakens the trade winds and promotes the eastward movement of warm surface water across the tropical Pacific. The associated abnormal warming in the eastern Pacific is known as El Niño. Because the reversals in pressure and associated ocean temperature fluctuations are often simultaneous, this coupled climate variability between the tropical Pacific Ocean and atmosphere is often collectively referred to as the El Niño/Southern Oscillation (ENSO).

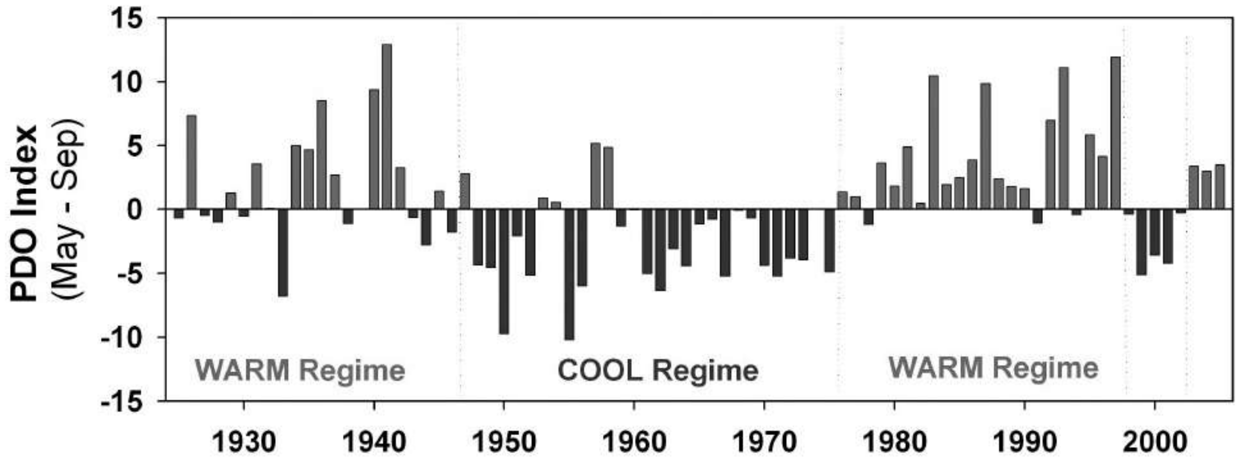
MEASURING SOUTHERN OSCILLATION

The mode and relative strength of the Southern Oscillation during a given time period is determined using one of several indices that signifies changes in the Walker circulation. A relatively simplistic and common method employed to gauge this change is the Southern Oscillation Index (SOI), which measures the monthly or seasonal sea level pressure differences between two stations, one located in the central Pacific at Tahiti and the other in the western Pacific at Darwin, Australia. Negative SOI values result from abnormally low pressure occurring in Tahiti and high pressure occurring at Darwin, which tends to indicate an El Niño episode; positive SOI values indicate the cold phase of ENSO, or La Niña. The sea level pressures at these two stations thus are negatively correlated and are associated with significant, yet contrasting shifts in regional temperature and precipitation patterns. Some of the most severe Australian summer droughts and heat waves (e.g., in 1983) have been associated with a strongly positive SOI.

ENSO events often affect the temperature and precipitation regimes in tropical regions. The magnitude of these effects differs with the intensity of individual ENSO events. Climatic anomalies associated with ENSO's warm phase in other tropical regions include dry summers and autumns for northern South America, Central America, and southeastern Africa (including Madagascar), as well as less rainfall during the Indian monsoon. Drier-than-normal conditions negatively affect crops—a particularly serious concern in developing regions. Such atmospheric conditions are also conducive to the threat of wildfires. Wetter conditions pervade the Chilean coast, as well as parts of east-central Africa.

EFFECTS OF ENSO

Despite being primarily a tropically located phenomenon, ENSO also has extensive effects on extratropical global precipitation and temperature variability. This is achieved, in part, by shifts in storm



The term PDO Index refers to Pacific Decadal Oscillation. The horizontal scale is marked in units of decades from 1925 to 2006, in the months of May through September. The vertical lines show positive (warm) years and negative (cool) years.

tracks. Changes in large-scale atmospheric circulation include deviations from the normal jet stream paths and persistent pressure systems, which in turn steer storms in new directions. During the warm ENSO phase in winter, a deepened Aleutian Low moves southeast of its average position. This is coupled with a strong subtropical jet stream and a weak polar jet stream over eastern Canada, setting up the circulation pattern that redirects storms into the southern United States. The winter cold ENSO phase is characterized by a blocking high forming in the Gulf of Alaska and a split polar jet. The main branch flows from Alaska and northern Canada south toward the western and northern United States; the jet's southern branch moves from the Pacific Ocean toward the Pacific Northwest.

Winter tends to bring the strongest North American precipitation and temperature responses to ENSO, though effects are noted in other seasons. Warm ENSO events typically result in wetter-than-normal conditions for much of the southern United States, with California often experiencing flooding as a result of the position of the stronger-than-normal subtropical jet stream, which directs storms into the region. Conversely, dry conditions tend to occur in the midwestern United States. Warm ENSO events also bring mild, warm winters into western Canada and Alaska, as well to Canada's Maritime Provinces. Cold ENSO events bring considerably drier, warmer winters to the American Southeast and below-average temperatures to western and central Canada and the northern tier of the United States.

Global climate models have been used in recent decades to predict how changes in our current climate will affect the frequency, strength, and position of cycles of interannular variability such as the Southern Oscillation. Although the predictability of the Southern Oscillation has been subject to differences between observed and predicted timescales, researchers have shown that the current climate models do tend to place warm ENSO events within the observed two- to seven-year timescale. Ensemble forecasts, in which average forecasts are generated by running models with slight variations in initial conditions, produce good results, with multimodel ensembles generally outperforming single-model ensembles. These models serve to enhance our understanding of atmosphere-ocean interactions, such as ENSO, for improving long-range weather and climate forecasts.

SEE ALSO: El Niño and La Niña; Walker Circulation.

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Spain

THE COUNTRY OF Spain lies on the Iberian Peninsula on the Mediterranean and Atlantic and is separated from Europe by the Pyrenees Mountains. The central plateau is drained by three rivers. Special geographic features include two sets of archipelagos, with the Balearic Islands in the Mediterranean and the Canary Islands in the Atlantic off the coast of Africa. Spain has a variety of ecosystems: snowcapped peaks in the Pyrenees, green meadows in Galicia, orange groves in Valencia, and desert in Almeria. The Partido Socialista Obrero Espanol government set aside more than 400 protected areas covering 15,444 sq. mi. (40,000 sq. km.) and protecting a broad range of ecosystems including mountains, wetlands, islands, wood and forest, and volcanic landscapes.

With extremes in temperature and low rainfall, water is a valuable resource. Droughts in the 1950s, 1960s, and 1990s were the driving force behind water policy. The Tajo-Segura water diversion system can divert 600 cu. m. of water per year from Tajo region in central Spain to the Valencia and Murcia regions. In 2000, a National Water Plan (Plan Hidrologico Nacional) intended to double the amount of water diverted from Rio Ebro basin was heavily protested, and in 2004 the plan was cancelled. Although climate models vary on what the temperature increase will be for Spain, from a conservative 3 degrees –4 degrees C to a pessimistic 6 degrees–7 degrees C by the end of the century, Spain is already experiencing the effects of global warming, with glacier melt in the Pyrenees (continued warmer winters would reduce snow cover and tourism to the area for winter sports); Europe's first hurricane (Hurricane Vince), which made landfall on the southwestern coast of Spain in October 2005; and an 11 percent decrease in average rainfall in 2005–06, which followed an extreme drought the year before.

Precipitation is expected to decrease, though not in all areas. Spain's northeast could see an increase in autumn and winter rainfall, and there may be a decrease in rainfall in the arid southwest. Spring and summer precipitation would be expected to decrease, except in the Canary Islands. Higher storm activity under climate change over the adjacent Atlantic is likely to lead to an increase in the intensity of winds over some parts of the country by the end of the century. Maximum wind speeds could increase by 2–4 percent in northwestern Spain by the end of the century, whereas in Galicia, the number of days with high winds could increase by up to 10 percent. Northern Spain could expect increased yield for most crops, and southern Spain could expect decreased yields.

In May 2002, Spain ratified the Kyoto Protocol, an international and legally binding agreement to reduce greenhouse gas emissions worldwide, entered into force on February 16, 2005, with Spain's entry into force on the same date.

In 2005, Spain became the second-highest wind capacity electric generator by adding 1,764 megawatts of wind power for a total of 10,027 megawatts, surpassing their 2010 goal.

In July 2007, the Spanish government approved numerous legislative measures related to environmental preservation and mitigating climate change. Spain has made fighting climate change a priority in the government's working agenda. By approving the Spanish Strategy for Climate Change and Clean Energy, Horizon 2007–2012–2020, issued by the Minister of environment, the government reinforced a commitment to the Kyoto Protocol. In addition to a plan for reducing government energy consumption and greenhouse gas emissions from government buildings and for the increasing use of blended biofuel in official vehicles, increasing energy efficiency with equipment and appliances as well as heating and cooling is a priority. Vehicle registration taxes will be directly related to emissions and responsibility will be put on the consumer (low-emission vehicles will be exempt from the tax, and higher-emission vehicles will be taxed at the highest rate).

SEE ALSO: Climate Change, Effects; Kyoto Protocol.

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Species Extinction

CHANGING CLIMATES INCREASE the uncertainties of life for all organisms. A long-term warming trend would alter the distribution of life on the planet as colder habitats shrink and warmer ones expand. Some species would become more common, and others would become rarer. We cannot predict with any precision which species will become extinct—or when. Plants and animals that are highly adapted to already extreme (hot, cold, or dry) climates are most likely to be the first and most drastically affected.

We consider a species to be extinct once all known individuals of that type have died. Many interacting factors affect the survival of individual organisms, and therefore the persistence of their species. In general, extinction results when a species' requirements and abilities no longer match the resources and hazards in its environment. For animals, these factors include food, water, and shelter from predators and weather extremes. For plants, they include water and nutrients and the action of herbivores and pollinators. Sometimes a factor is critically important, like rainfall in a desert. It determines whether enough individuals will survive that a species can persist. If that "limiting factor" changes in some way, survival rates may rise or fall. If they fall far enough, extinction results. Climate is a major limiting factor for life on Earth. When it changes, life on Earth also changes. A continuing trend of global warming, cooling, or drying will lead to extinctions that might otherwise not occur as soon. We still know little about the precise climate limits or thresholds of most species. Because it is also difficult to predict precisely what the climatic conditions will be like in any given place at any given time in the future, it is even harder to predict which species will become extinct as a direct result of climate change, and when it will happen. In addition, because species interact and rely on each other in many ways, climate change produces many sometimes indirect or complex effects among them. This adds further layers of uncertainty to predictions about extinctions. For the most part, we can make only very general predictions about climate change and extinctions. This uncertainty leads many climate scientists and ecologists to conclude that humans would be wise to avoid or resist contributing to the uncertain risks of climate change whenever it lies within our power to do so.

CLIMATE, BIOGEOGRAPHY, AND EXTINCTION

Climate change is complex. Tracking the local effects of regional or global change requires a great deal of data. Much of this information is now collected via remote sensing devices like radar and satellite-mounted cameras. So much data is collected that they can only be compiled into a usable form with very high-speed computers. However, those technologies are very recent. Scientists began collecting accurate and extensive climate measurements in the 18th century, recording data by hand. Naturalists like Alexander von Humboldt and H.C. Watson first correlated climates and species distributions in the early 19th century. Thus began the study of biogeography.

Long before there were biogeographers, it was evident that different kinds of plants and animals occupied different kinds of places. Biogeography added mathematical precision to the folk knowledge that temperatures were lower at higher elevations and higher latitudes and that mountain ranges received more precipitation to windward than to leeward and were warmer on the sunnier slopes facing the equator. More climate and biogeographical data became available at the same time that cartography and species inventories were improving. All were necessary for accurately describing what lived where and for predicting what sorts of species would live in various places. Repeated inventories, measurements, and mapping were needed to show whether and how biogeography was changing.

Among the first patterns understood by biogeographers was that average temperatures on the earth's surface changed with latitude. Temperatures tended to be low in polar regions and higher near the equator. At the same time, they saw that temperatures near sea level tended to be warmer than temperatures at higher elevations. They found that even near the equator, the tops of very tall mountains (such as the Andes) were as cold as the poles and discovered that the plants and animals of polar and alpine locations were very similar. As observations accumulated, biogeographers were able to begin mapping the ranges of different species. Climate measurements helped biologists determine the limits of heat, cold, and precipitation that various species could tolerate.

It was long debated whether species actually could become extinct. It was not until large, easily observed birds like the dodo and the great auk could no longer be found and the fossilized remains of large, otherwise unknown animals were being discovered, that the fact of extinction was established. Not until the third quarter of the 19th century did it become clear that extinctions might regularly follow as the unintended consequences of intensive human activities. Climate changes traceable to human activities were hardly recognized for over another century, during which our population doubled twice over. During the roughly same period, our major technologies changed from being mostly animal, wind, and water powered to being combustion powered, using wood and fossil fuels.

CLIMATE DYNAMICS AND LIFE ON EARTH

Conditions on the Earth's surface and in its atmosphere have undergone many changes over time. Some of these changes were quite drastic and had proportionally drastic effects on living things. We can say with some confidence that the Earth's climate has sometimes been much warmer than it is today, and we know that at other times it has been much colder. This much can be inferred partially from recorded history but more reliably from fossils and other geological evidence. Scientists have proposed many plausible explanations for these climate changes, but since the events cannot really be modeled in detail or rep-

With global warming, newly ice-free Arctic lands would potentially become available for mining, oil and gas development, and manufacturing activities. Greater human density could affect survival rates of large mammals such as the Caribou, above.

licated for study, they can only agree about general effects, rather than local specifics.

Paleontologists and others who study the evolutionary history of life on earth have concluded that most of the species that ever inhabited the planet are now extinct. They have also estimated, as a sort of rule of thumb, that any given species, on average, persists for about a million years. Estimates of the total number of species that have existed on the planet range from tens of millions to hundreds of millions. Some of these species are known from the fossil record to have persisted much longer than a million years, and others for much shorter periods. Estimates and averages are only as good as the actual data and methods used to make them. Even if the data we have to work with are reliable, the fossil record is far from complete, and different methods of analysis continue to yield different estimates.

Because our planet is changeable, or dynamic, extinction seems to be normal and inevitable for species, much as death is inevitable for individuals. At the same time, however, evolution also generates new species from some of the old ones, as the average characteristics of a population change and "adapt" to emerging conditions. Overall, there is still life on Earth because the rate at which species evolve has exceeded the rate at which they become extinct.

No one is credibly predicting that all life on earth would end, and all species would go extinct, as a result of human-caused global warming, but many scientists are concerned that any continuing trend in climate change would increase the rate of extinctions, changing life as we know it and perhaps making life more difficult or less interesting for humans as a result. Many people want to preserve life as we know it and to prevent extinctions of other species caused by human activities. Global warming is one of many environmental changes human activities may bring about. The combined effects of human activities, along with those of geological and even cosmic events, are complex. Among the extinctions that occur during the foreseeable future, we will probably be able to blame very few solely, or even mostly, on human-caused climate change. However, if apparent trends continue, climate change will probably contribute in some way—large or small—to almost any extinction that occurs.

ECOLOGY AND CLIMATE CHANGE

It is difficult to distinguish extinctions caused mostly or mainly by climate change from those caused by other factors such as directly converting habitats to human uses. Conservation biologists have long considered habitat destruction to be the most likely cause of extinctions. Habitat has been described many ways, but it generally means an environment in which enough individuals of a particular species can survive and reproduce to keep their population from decreasing to zero. In other words, each species has a habitat, and each needs a persisting habitat to continue as a species.

Some habitats are more complicated than others, but all habitats can be thought of as having two general kinds of components. Biotic components are living things: all the other organisms that somehow affect the life of a plant or animal. Abiotic components are factors like terrain, minerals, water, sunlight, and temperature. Climate change can directly affect some of the abiotic components of a habitat. When particular places become warmer or cooler, or drier or wetter, the ability of any particular species to persist in that place also changes.

Some abiotic habitat components, such as temperature and humidity, will vary daily or seasonally. Organisms have to be able to tolerate the extremes of night and day, summer and winter, and wet and dry seasons. When the climate of a place changes to the point that one of an organism's tolerances is exceeded, a habitat literally ceases to exist.

Because of the shape of the Earth, less sunlight reaches the poles than the tropics. Habitats are limited by the climatic effects of latitude. If we could look down from space at the North Pole and see all the way to the equator, but still recognize all the land plants and animals, we would see that similar kinds of organisms are roughly arranged in a series of bands or zones centered on the pole, like a target. Working out from the center, each zone is slightly warmer than the one immediately inside it. When the average global temperature falls, the polar center of the target expands and the hottest equatorial zones shrink or even disappear. This happened during the Ice Ages, when glaciers covered much of the Northern Hemisphere. Animals and plants had to change, migrate, or become extinct. When the average global temperature rises, the polar center shrinks, and each climate zone moves toward it. The icy center may even disappear, and the next zone takes its place. Meanwhile, entirely new, hotter zones may appear at the equatorial edge.

Because the atmosphere is less dense in the mountains than at sea level, all habitats are also limited by the climatic effects of elevation. Higher elevations are colder. Seen from directly above, a tall mountain has bands of similar plants and animals, just as the whole planet does. A general trend in climate change means that these bands move down and up the mountain just as the latitude bands move toward and away from the poles.

CLIMATE-RELATED CAUSES OF EXTINCTIONS

Extinctions can occur gradually or suddenly. Large numbers of extinctions have sometimes occurred during relatively short periods of time. These "mass extinctions" resulted when a catastrophic event such as an asteroid impact suddenly made large areas of the earth's surface, or its oceans, uninhabitable. The effects produced by such catastrophes probably included sudden, drastic climate changes, but not enough evidence has been found to say with certainty how great these changes were or exactly how long they lasted.

Changing climates affect the survival prospects of individual organisms. As a result, changing climates affect the survival and reproduction rates of whole populations and species. Populations may rise or fall as climates change. Some increases or decreases will be dramatic and obvious. Others will be almost unnoticeable to us. Almost all such population changes will result from combinations of many small changes, rather than a few catastrophic ones.

As average global temperatures increase (or decrease), populations will migrate to follow shifts in local conditions. Some organisms can do this quickly and easily. Many animals already migrate to follow seasonal changes in food and water supplies. There are rare exceptions, but many individuals, such as rooted plants, cannot move at all. Their populations can migrate only as seeds are dispersed and new individuals germinate and survive in newly suitable locations. Meanwhile, the old individuals, trapped in increasingly unsuitable locations, gradually die out. When populations cannot shift to new locations quickly enough, species may become extinct. Extinctions also follow when no new locations become available or when potentially suitable locations exist but cannot be reached in time. We can easily imagine scenarios that include the extinction of plant species unable to disperse to new habitats. Because the phenomenon is so complex, scientists have been reluctant or unable to publish firm, reliable estimates of the numbers of species that could become extinct as a result of climate change, or to predict when such extinctions will occur.

Climate change is most likely to directly produce species extinctions in already extreme, barely survivable environments. These are the very cold, hot, wet, dry, or chemically unusual places in which only relatively few types of highly specialized organisms can exist. Where such extreme conditions are climate induced, even small temperature changes can be highly significant. Organisms in extreme environments are likely to be living near the limits of physiological possibility. When extreme environments become more extreme, some organisms die. When extreme environments become too extreme, nothing can survive in them—but that is only part of the story.

When extreme environments become more moderate, more species can move into them, leading to increased competition for living space and other resources. They may become "too moderate" for specialists that have lost, or perhaps never evolved, ways to compete or escape in highly diverse and densely populated environments. In other words, given a trend of global warming, hot, dry environments may become hotter and drier, crossing some survival threshold of survival for desert-adapted species. Individuals of those species will have to emigrate or die. However, some hot, dry environments might become wetter, or cooler, or both, even as average global temperatures are rising. This will allow species adapted to the new, more moderate conditions to immigrate and to compete with, prey on, or infect the existing populations in unprecedented ways.

DIRECT EFFECTS OF CLIMATE CHANGE ON SPECIES EXTINCTIONS

The direct effects of climate change are most likely to affect organisms of polar regions, mountaintops, and equatorial areas. Under a general trend of increasing temperatures, the very coldest climates—the Arctic and alpine tundras—could disappear, and along with them would likely disappear at least some of the species adapted to tolerate them. As the warmer habitats move toward the poles and up the mountains, their species will follow. Those that cannot migrate or disperse as fast as their potential habitats are shifting will either have to evolve new climatic tolerances or die out.

When abiotic factors change, some habitats may contract, even to the point of disappearing altogether. Others may expand, and new ones may appear. Overall, they can be imagined as flowing slowly across the landscape, expanding in some directions while retreating from others, sometimes forming and seemingly evaporating like puddles. The most obvious response for organisms that can move is to follow the changes in habitat or to find and occupy the new habitat. As long as enough individuals of a species can somehow keep up with these movements, their species may persist.

An expected direct effect of climate change with the potential for causing species extinction is a rise in sea level caused by the melting of polar and alpine glaciers. Large areas of low-lying coastal lands would be inundated by rising sea levels. In effect, some areas of terrestrial habitats would be converted to areas of aquatic habitats. Some low-lying oceanic islands would disappear, and along with them any land plants and animals that might be found nowhere else. Whether as a result of habitat inundation or other effects, species with very restricted ranges, called endemics, are likely to be more significantly affected by climate change than those with larger ranges.

Every species has different abiotic tolerances, so the edges of their potential habitats, based on moisture or temperature, rarely correspond exactly. Instead, these habitat edges usually overlap. Not only do they overlap, but climate change will affect each one differently, so different species habitats will move, grow, or contract at different rates. As we have seen, not all species are equally mobile. This means that two species may experience different direct, abiotic affects in the same place. These differences create the possibility of many indirect effects of climate change as species interact in new ways and places.

INDIRECT EFFECTS OF PERSISTENT CLIMATE CHANGE

Most effects on species resulting from any continuing climate change trend will be indirect. All animals rely on other species as sources of food. Many plants rely on insects and other animals to pollinate them or disperse their seeds. When different species come to depend on each other in predictable ways, their relationship is called a symbiosis. Symbioses range from pure exploitation, where only one species benefits, to cooperation or mutualism, where both species benefit. In many cases, such as those of internal parasites or intestinal bacteria, one organism actually becomes the entire habitat of another. Far more often, individuals of different species have no obvious interactions at all but do influence each other in much more subtle ways, such as by preying on another species' competitors, or its predators, or its pollinators, or by spreading its disease organisms.

The possibilities for changing species interactions are seemingly endless, but we can describe only a few examples here. Individuals of predatory species might find themselves able to range farther north, or higher into the mountains, where they will encounter potential prey species that have never seen them before. These prey animals may lack defensive or escape behaviors, and their populations may be significantly reduced. This does not mean that tropical cats like jaguars will be decimating caribou herds. Most of the land animals in the world are insects, as are most of the predators. We are hardly aware of predation at the insect level, but it is cumulatively enormous and enormously influential.

Most insects are unable to regulate their body temperatures except by seeking shelter. Flying insects have to meet minimum temperature requirements before their muscles work efficiently, allowing them to lift off. However, flying insects are highly mobile. Once aloft, they are often carried great distances by winds, sometimes to places where they normally cannot survive. However, if climates warm and their habitats move and expand, insects are likely to arrive in any newly suitable locations pretty quickly. If these pioneering insects are herbivores, they may find plants that have evolved no defenses against them. This could hasten the demise of individual plants and reduce populations that were physiologically capable of tolerating the direct effects of warmer temperatures.

Many plants rely on insects for pollination. Some plant populations could be reduced if predatory insects begin to survive in areas formerly unavailable to them because of climate factors and begin preying on the local pollinators. If pollinators become too scarce, plant reproduction could be reduced to levels that cannot maintain a population. Both the plants and the pollinators could be affected.

Polar ice caps and alpine glaciers are composed of accumulating snow. If they melt, the resulting water is fresh, not salty. There is not enough fresh water in these sources to significantly dilute the world's oceans and change the fundamental chemistry of seawater. However, fresh water is less dense than salt water, and until the two mix, fresh water entering the oceans actually floats as a surface layer. The addition of massive amounts of cold, fresh water to the Arctic, North Atlantic, and north Pacific oceans, and to the south polar regions of the Atlantic, Pacific, and Indian oceans, would affect the way currents flow and nutrients circulate in these areas. This would affect the types and distribution of plankton, and thus all the many levels of oceanic food webs in those areas. Reduced plankton production would ultimately mean less prey for aquatic predators of polar seas such as polar bears, penguins, and some toothed whales, seals, and sea lions. Added to the direct effects of reduced pack ice, such changes could lead to the extinction of animals highly specialized for life under cold polar conditions that would no longer exist.

Hot deserts have fewer rivers, lakes, and ponds, but many of them have springs and small water courses that support endemic aquatic species including fishes, amphibians, reptiles, and many invertebrates and microorganisms. If these hot deserts become even hotter or drier because of climate change, these "oases" could literally dry up. In the process, numerous rare aquatic species that cannot move to other habitats (even if they existed) would become extinct in the process.

Aquatic species endemic to small tributary streams in any watershed face various new conditions when a region becomes drier or wetter. Neither trend is automatically beneficial. If it becomes drier, the smaller tributaries become ephemeral or intermittent, forcing fully aquatic species downstream into larger, more permanent waters, where they may encounter more (and larger) predators, at least for a time. If the region becomes wetter, the small tributaries will become larger, and the larger predators may move upstream. In high, steep terrain, the physical characteristics of the newest small tributaries may make them unsuitable for colonization.

In wet tropical areas, the effect of climate change will most easily be seen if it results in changes to the flow of atmospheric moisture to the region and, as a result, to the seasonality and overall amount of precipitation. At its simplest, a rainforest with less rain will gradually become another kind of forest, having fewer species requiring high moisture or seasonal inundation by floodwaters and more that tolerate drier conditions. As in all cases, if suitable habitat disappears or appears only at an unreachable distance, some species could become extinct. The complexity and diversity of tropical forests is such that not only some tree species, but also their dependent animals (and, in turn, their own dependent animals), could become extinct in the process. Our knowledge of the flora and fauna of these regions is insufficient to support any precise estimate of the number of species present, much less the number that could be affected by any particular degree of climate alteration.

CLIMATE-RELATED EXTINCTIONS INVOLVING OTHER HUMAN ACTIVITIES

In anticipation of a continued warming trend in polar regions, various countries are already positioning themselves to take advantage of ice-free Arctic seas and increasingly temperate high latitudes. Others are bracing for possible desertification in tropical grass and scrublands. Areas likely to experience intensified human use may have higher likelihood of species extinctions.

Increasing commercial ship traffic in Arctic waters would produce the same sorts of side effects that shipping has elsewhere. Leaks and spills of fuel and cargo oil would affect the biota of littoral zones. Ballast water exchange would further redistribute aquatic species, leading to new predation and competition among aquatic species without prior experience of each other.

Newly ice-free Arctic lands would potentially become available for mining, oil and gas development, and allied manufacturing activities. This will require an influx of workers and equipment, along with creation of the physical, economic, and cultural infrastructure needed to support them. Each activity entails a direct conversion of some existing habitat to human use. This could fragment the habitats of migratory birds such as snow geese and affect survival rates for large mammals such as caribou and musk oxen.

More ship traffic, mining, and oil exploration would encourage more permanent human settlements to service, and be serviced by, these industries, leading to a greater likelihood of chemical pollution and of sewage and solid waste management issues. Human population centers would encourage the establishment of human commensals and inquilines, such as dogs and cats, rats and mice, cockroaches and houseflies. Each potentially adds a new challenge to the persistence of Arctic species.

Under a continued warming trend, farmers in Europe, Asia, and North America would experience the same northward and upward shift in habitat bands affecting uncultivated plants and wild animals. For example, grain production will likely be possible farther north, in the Canadian "Prairie Provinces." This would require "sodbusting" of existing grasslands or logging of forests to convert them into farms, reducing or eliminating their habitat value to most wildlife. All the world's major crops—corn, soybeans, wheat, rice, and cotton, along with most every other valued plant—would become economically viable in new areas while becoming impractical in others where they have been traditionally grown. The net effects on agricultural production are hard to estimate, as are the potential effects on other species.

SEE ALSO: Agriculture; Animals; Antarctic Circumpolar Current; Arctic Ocean; Atlantic Ocean; Biology; Botany; Cetaceans; Climate Zones; Conservation; Desertification; Deserts; Ecosystems; Geography; Glaciers, Retreating; History of Climatology; Ice Ages; Indian Ocean; Land Use; Marine Mammals; Modeling of Ocean Circulation; Modelling of Paleoclimates; Oceanic Changes; Pacific Ocean; Penguins; Phytoplankton; Plants; Polar Bears; Rainfall Patterns; Sea Level, Rising; Upwelling, Coastal; Upwelling, Equatorial.

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Sri Lanka

THE DEMOCRATIC SOCIALIST Republic of Sri Lanka, formerly known as Ceylon, is a small, pear-shaped island of 25,332 sq. mi. (65,610 sq. km.) lying off the southeastern coast of India. Sri Lanka has an extraordinary diversity of wildlife and vegetation because of its location near the equator and its remarkable range of terrain and climate. Although only a minute contributor to greenhouse gas emissions, the island is vulnerable to the effects of climate change.

Sri Lanka's carbon emissions per capita are 161st out of 211 countries measured worldwide but more than doubled in the 10 years from 1990, largely in response to the country's increasing population. Like much of the rest of South Asia, Sri Lanka relies heavily on carbon-neutral biomass such as collected wood and animal waste for its domestic energy needs, particularly in rural areas. Biomass accounted for 80 percent of total residential energy consumption in 2005 and is expected to remain as high as 70 percent through 2020.

Oil consumption more than doubled between 1990 and 2005 in response to a growing demand for transport fuels. Sri Lanka imports all of its daily crude oil consumption of 87,000 barrels, and in recent years, it has further increased oil imports to avoid overreliance on hydroelectricity for industrial power. Hydropower currently provides the majority of Sri Lanka's electricity, making the country vulnerable to changing rainfall patterns. In an effort to diversify, the Sri Lankan government is developing fossil-fuel-fired power plants.

Sri Lanka's rich biodiversity includes an unusually large number of endemic species living in cloud forests, grasslands, and wetlands, as well as freshwater, coastal, and marine ecosystems. The island is both ecologically and economically vulnerable to climate change. Its famous tea plantations remain an important source of economic activity, and the island's rich cultural heritage, together with its tropical forests, beaches, and wildlife, make it a world-famous tourist destination. Climatic conditions and rich biodiversity are therefore key to maintaining Sri Lanka's economy. However, logging and population pressures continue to lead to deforestation and habitat loss. Large tracts of forest have been cut down for fuel wood or for timber export and have been replaced by rice, coconut, rubber, and coffee farms. Many species are in danger of extinction, including cheetahs, leopards, several species of monkeys, and wild elephants. Sri Lanka's coral reefs, already damaged by bleaching and the 2005 Asian tsunami, are being destroyed by human refuse and sewage and by dynamite fishing. Climate change–induced ecological stress will compound these eco-economic concerns.

Overall, the importance of environmentally sustainable behavior is underappreciated in the general population, as concerns such as poverty and the ongoing conflict between Tamil separatists and the Sinhalese government are dominant. Even so, the government of Sri Lanka has taken action to conserve wildlife. Over 13 percent of the land is protected, and the Sinharaja Forest Reserve, which protects the largest remaining stand of primary rainforest on the island, was declared a World Heritage Site in 1988. Indeed, Sri Lanka has a long history of conservation, being the first country in the world to establish a wildlife reserve.

SEE ALSO: Deforestation; Developing Countries; India; Rainfall Patterns; Tourism.

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STANFORD UNIVERSITY IS a private university located approximately 37 mi. (59 km.) southeast of San Francisco and approximately 20 mi. (32 km.) northwest of San Jose in Stanford, California. Stanford is situated adjacent to the city of Palo Alto, near Silicon Valley. The university enrolls approximately 6,700 undergraduates and 8,000 graduate students. The university has approximately 1,700 faculty members. Forty percent of the faculty is affiliated with the medical school, and a third serves in the School of Humanities and Sciences. Graduate studies in the Department of Geological and Environmental Sciences involve academic course work and independent research. Students are prepared for careers as professional scientists in research or for the application of the earth sciences to mineral, energy, and water resources. Programs lead to M.S., Engineer, and Ph.D. degrees. Course programs in the areas of faculty interest are tailored to the student's needs and interests with the aid of his or her research adviser. Students are encouraged to include in their program courses that are offered in other departments in the School of Earth Sciences, as well as courses offered in other departments in the university.

Launched in December 2002, the Global Climate and Energy Project (GCEP) at Stanford University seeks to find new solutions to one of the grand challenges of this century: supplying energy to meet the changing needs of a growing world population in a way that protects the environment. The primary goal of the project is to conduct fundamental research on technologies that will permit the development of global energy systems with significantly lower greenhouse gas emissions. With the support and participation of four international companies (ExxonMobil, General Electric, Schlumberger, and Toyota), the GCEP is a unique collaboration of the world's energy experts from research institutions and private industry. The project's sponsors will invest a total of $225 million over a decade or more as GCEP explores energy technologies that are efficient, environmentally benign, and cost effective.

The Stanford Climate Change Campaign, a project of Students for a Sustainable Stanford, in conjunction with People for the American Way Foundation, Global Exchange, and other student groups, has made a public commitment to lead the fight against global warming and to reduce its own carbon footprint.

The Center for Environmental Science and Policy (CESP) began as a specialized research center within the Freeman Spogli Institute for International Studies (FSI) in September 1998. It evolved as an outgrowth of the more informal Global Environmental Forum, which had existed within FSI for nearly a decade. CESP is also an affiliated center of the Woods Institute for the Environment. Formed in 2004, Woods is Stanford's principal initiative for assessing environmental science, technology, and policy on local, national, and global scales.

The center has grown considerably under the experienced leadership of a series of codirectors—Walter Falcon, Donald Kennedy, Pamela Matson, and Stephen Schneider. Leading scholars from the natural and social sciences, these individuals reflect CESP's integrative approach to research, which balances the analyses of environmental problems from both scientific and policy perspectives.

The CESP plays a crucial role in mobilizing a multidisciplinary network of scholars, students, policymakers, and leaders in understanding and helping to solve international environmental problems through science and policy research. The work of the center engages scholars from disciplines as varied as the biological and geological sciences, civil engineering, economics, and law to develop new methods for environmental assessment, negotiation, remediation, and protection.

Workshops, policy briefings, and publications link CESP with other public policy and scholarly institutions within and outside Stanford. The center houses the Program on Energy and Sustainable Development, a multiyear, interdisciplinary program that draws on the fields of engineering, political science, law, and economics to investigate how the production and consumption of energy affect sustainable development. CESP does not award degrees, but it is heavily engaged in graduate and undergraduate education. The center holds a close affiliation with Stanford's Interdisciplinary Graduate Program on Environment and Resources and also directs the Goldman Honors Program, an interschool honors program in environmental science, technology, and policy.

SEE ALSO: California; Impacts of Global Warming; Sustainability.

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Stockholm Environment Institute (SEI)

THE STOCKHOLM ENVIRONMENT Institute (SEI) is a nonprofit, independent research institute specializing in sustainable development and environmental issues. SEI headquarters are located in Stockholm, Sweden, with centers in the United States and the United Kingdom. They work at the local, national, regional, and global policy levels. Their mission is to support decision making and induce change toward sustainable development around the world by providing integrative knowledge that bridges science and policy in the field of environment and development. The institute was established in 1989 following an initiative by the Swedish government to develop an international environment/development research organization. Each center has its own personality and foci of interests, and each operates with significant autonomy while participating in the five SEI research programs.

SEI's Climate and Energy Program addresses these challenges in collaboration with a global network of partners, enabling them to perform work in locally defined interests and resources. For the last two decades, projects in Africa, Asia, Europe, and Latin America have spurred innovative energy strategies that support the goals of social equity, environmental sustainability, and efficient economic development. Emissions of air pollutants to the atmosphere have had, and continue to have, significant effects on human health and well-being, crops and food security, ecosystems and biodiversity, and materials and cultural monuments.

The Atmospheric Environment (AE) Program within SEI contributes to the goal of reducing the local, regional, and global effects of the emission of pollutants to the atmosphere.

SEI's U.S. center conducts a diverse program focusing on the social, technological, and institutional requirements for a transition to sustainability. Funding is received from the United Nations, the World Bank, and numerous foundations and national governments such as the United States, Sweden, Denmark, Germany, the Netherlands, and the United Kingdom.

In addition to providing policy-relevant analyses, the center works to build capacity in developing countries for integrated sustainability planning through training and collaboration on projects. Its decision support tools are widely used: LEAP for energy planning and climate change mitigation, WEAP for water resources planning, and PoleStar for evaluating sustainable development strategies.

The center is organized into three programs: the Climate and Energy Program, which conducts energy system analyses, examines environmental consequences of energy use such as global warming, and develops policies for a transition to efficient and renewable energy technology; the Water Resources Program, which brings an integrated perspective to freshwater assessment—one that seeks sustainable water solutions by balancing the needs for basic water services, development, and the environment; and the Sustainable Development Studies Program, which takes a holistic perspective in assessing sustainability at the global, regional, and national levels.

SEE ALSO: Climate Change, Effects; United Nations.

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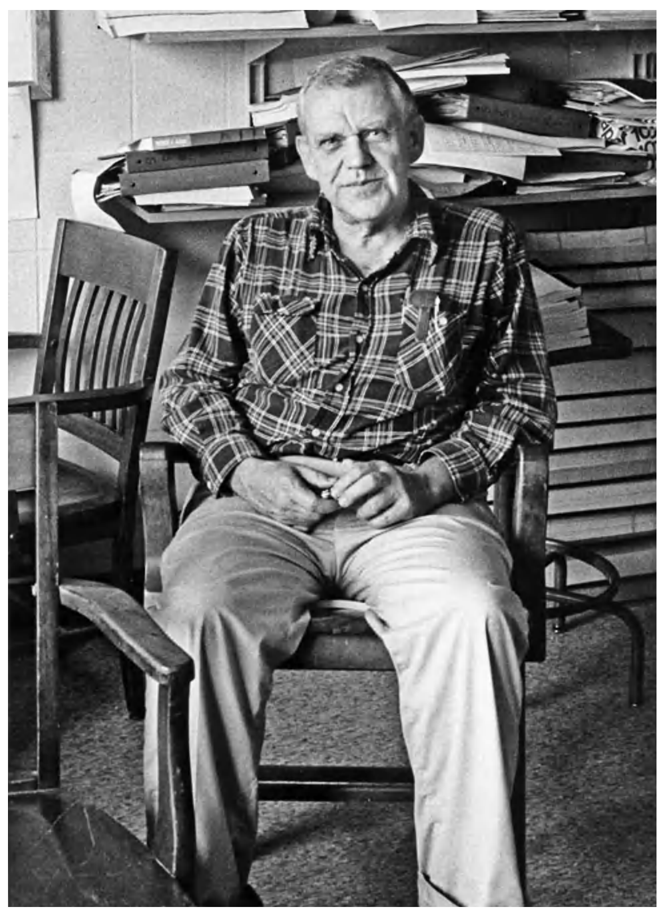
Stommel, Henry (1920–92)

HENRY STOMMEL IS an American oceanographer and meteorologist whose theories on general circulation patterns in the Atlantic Ocean made him the creator of the modern field of dynamical oceanography. Stommel carried out a series of research studies and first suggested that the Earth's rotation is responsible for the Gulf Stream along the coast of North America. He theorized that its northward thrust must be balanced by a stream of cold water moving in the opposite direction beneath it. Carl Wunsch has described Stommel as "a transitional figure, being probably the last of the creative physical oceanographers with no advanced degree, uncomfortable with the way the science had changed, and deeply nostalgic for his early scientific days." Stommel has been praised for being both a creative theorist and an acute observer who was willing to spend months at sea.

Stommel was born in Wilmington, Delaware, on September 27, 1920, into a family of extremely mixed background. His ancestors came from such different places as the Rhine Valley, Poland, Ireland, the Netherlands, England, and France, and they also had a trace of Micmac Indian. Henry's father, Walter, was a chemist born in northern Germany and trained in Darmstadt and Paris. During World War I, Walter Stommel



Henry Stommel theorized the circulation patterns of oceans and cold water moving in the opposite direction beneath it.

emigrated to Wilmington, where he was employed by Dupont Chemical. While in the United States, he married Marian Melson. Their son Henry was born shortly after the marriage. Although the reason is not completely clear, perhaps because of anti-German sentiment following World War I, the family then moved to Sweden. Henry's mother, however, soon left Sweden with Henry and returned to Wilmington. Because of his mother's decision not to see her husband again, Henry and his sister Anne grew up in a single-parent family. When Henry was 5 years old, his mother moved with the two children to Brooklyn, New York, to live with her parents and other relatives. Marian supported the entire household thanks to her job as a fund-raiser and public relations officer at a hospital. Henry and his grandfather, Levin Franklin Melson, developed a meaningful relationship in a household dominated by women.

Stommel attended New York City's public schools. He spent one year at Townsend Harris High School but finished high school at Freeport, Long Island, because his family had moved there. Thanks to his receiving a full scholarship, he was able to enroll at Yale University, from where he graduated in 1942. He remained at Yale for two years following graduation, teaching analytic geometry and celestial navigation in the Navy's V-12 program. He also spent six months at the Yale Divinity School, but his lifelong ambivalence toward religion made the ministry an unsuitable vocation for him. In 1944, renowned astrophysicist Lyman Spitzer suggested that Stommel apply for work at the Woods Hole Oceanographic Institution in Woods Hole, Massachusetts—an organization that was fast becoming a decisive part of the U.S. war effort. Stommel was recruited to work in acoustics and antisubmarine warfare but disliked his assignment and tried to be employed in other areas.

In 1948, Stommel wrote "The Westward Intensification of Wind-Driven Ocean Currents," a paper that is unanimously regarded as constituting the starting point of dynamical oceanography. In it, he explained the Gulf Stream deductively by fluid dynamics. In particular, he discovered the mechanism (the latitudinal change of the Coriolis force on the rotating Earth) that produced the westward intensification of oceanic currents. Stommel proposed a global circulation model similar to a conveyor belt: surface water sinks in the far north to supply the deep, south-flowing current, and water rises in the Antarctic region to contribute a northward flow along the eastern coasts of North and South America. His important book *The Gulf Stream* was probably the first true dynamical discussion of the ocean circulation. He put the Gulf Stream in the wider context of the general circulation and paved the way for the development of the so-called thermocline theories. Stommel also concluded that changes in density caused by cooling and evaporation at the sea surface can be responsible for deep flows in the ocean. He was thus responsible for establishing the basic factors that helped to establish theories about global circulation. His thermocline theories stressed the role of oceans and sea currents in the definition of global climate and thus anticipated debates on global warming.

In December 1950, Stommel married Elizabeth Brown. The couple had three children. Although Stommel liked working at the Woods Hole Oceanographic Institution, he did not get on well with his director Paul Fye. Therefore, he accepted an invitation to become a professor at Harvard University in 1959, lured by the prestige of the institution. He spent four unhappy years there, where his democratic ideals clashed with a rigid sense of hierarchies. After Harvard, Stommel went to work at the Department of Meteorology at the Massachusetts Institute of Technology (MIT). There he worked with the most famous meteorologists of the day, such as Jule Charney, Norman Phillips, Edward Lorenz, and Victor Starr. Stommel worked enthusiastically with these scientists to improve theories of general circulation. He also worked on other important topics such as the classification of estuaries and the effect of volcanoes on climate.

Stommel worked at MIT for 16 years as a professor of physical oceanography. He returned to the Woods Hole Oceanographic Institution when Fye retired and continued to work there until his death on January 17, 1992. Stommel established several stations for the study of ocean currents, including the PANULIRUS station (begun in 1954) in Bermuda. He was elected to the National Academy of Sciences in 1962 and received the National Medal of Science in 1989.

SEE ALSO: Oceanography; Thermocline.

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Stratopause

THE STRATOPAUSE IS one of the layers into which the atmosphere is divided. It is the buffer region of the atmosphere that lies between the stratosphere and the mesosphere, from a height of about 31 to 34 mi. (50 to 55 km.) above the Earth's soil. The atmospheric pressure is about 1/1000th of the pressure at sea level. In the stratopause, the temperature reaches a peak because of the heating generated by the absorption of ultraviolet radiation by ozone molecules in the stratospheric ozone layer. In this region, the catalytic cycles, which are less efficient at colder temperatures because of reduced O density, produce a significant ozone increase (~15 percent). Because of the considerable ozone presence in the stratopause, the understanding of this region is considered crucial to understanding the changes in climate and in the composition of the ozone layer. Above the stratopause, the temperature starts again to decrease with height as a result of the reduced solar heating of ozone.

The depletion of the ozone layer resulting from the emission of halogen atoms and the photodissociation of chlorofluorocarbon compounds is of particular concern to scientists, as the layer prevents the most harmful ultraviolet-B wavelengths from passing through the Earth's atmosphere. Near the stratopause, the ozone reduction is slightly smaller in the drier stratosphere because of the stronger temperature dependence of the drier atmosphere.

Studies of the temperature in the stratopause have also been important to assess the validity of global circulation models. For example, a study published in 2002 by the University of Illinois at Urbana-Champaign, and the High Altitude Observatory of the National Center for Atmospheric Research in Boulder, Colorado, showed that wintertime warming caused by sinking air masses was not as strong as the models had assumed. The study employed lidar laser measurements and balloon observations made at the Amundsen-Scott South Pole Station from December 1999 to October 2001. These measurements and observations were then used to calculate the monthly mean winter temperature profiles from the surface to about 63 mi. (110 km.). The measured temperatures during midwinter in both the stratopause and mesopause regions were 20–30 degrees Kelvin colder than current model predictions. These differences were caused by weaker than expected compressional heating associated with subsidence over the polar cap. The study showed that the greatest difference occurred in the month of July, when the measured stratopause temperature was about 0 degrees F (minus 18 degrees C) compared with the about 40 degrees F (4.4 degrees C) predicted by the models.

SEE ALSO: Atmospheric Composition; Atmospheric Vertical Structure.

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Stratosphere

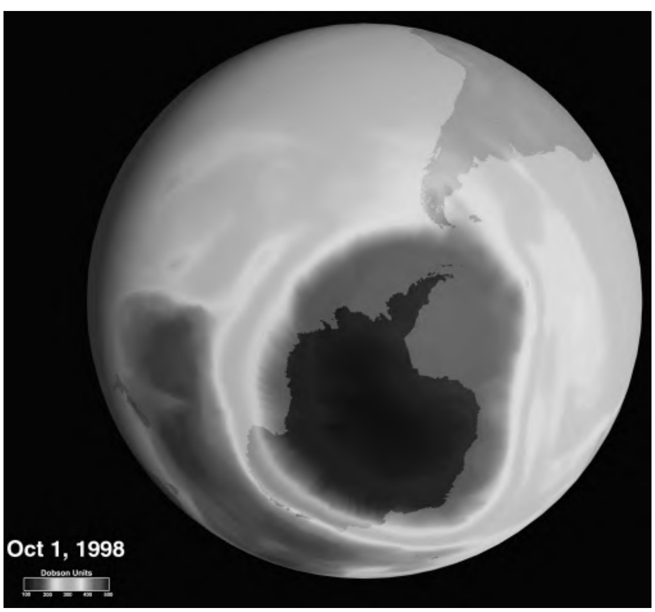
THE STRATOSPHERE IS a layer in the atmosphere that extends between about 9 to 31 mi. (15 and 50 km.) in altitude. It is characterized by a vertical temperature structure that is nearly isothermal (no temperature change with altitude) in the lowermost stratosphere and a pronounced inversion (increase of temperature with altitude) above. The stratosphere owes its name to the strong stratification, which is a consequence of this thermal structure.

The stratosphere plays an important role in the climate system. It contains the ozone layer, which shields the Earth's surface from harmful ultraviolet radiation and is responsible for the temperature of the stratosphere. Radiative processes in the infrared part of the electromagnetic spectrum also play an important role. Because, in the stratosphere, chemistry, dynamics, and radiative processes operate under very different conditions than in the troposphere, the stratosphere is susceptible to climatic forcings in a different way than the troposphere. As a consequence, stratospheric processes play an important role for climate variability and change.

The stratosphere was discovered independently by Teisserence de Bort and by Richard Assmann around 1900. It has been explored by balloon-borne observations since around the 1930s and by satellite observations since the 1970s.

The lower boundary of the stratosphere is the tropopause, the altitude of which varies with latitude (higher over the tropics than over the poles), season, and on a day-to-day scale related to weather systems. The upper boundary of the stratosphere is the stratopause. Below and above the stratosphere are the troposphere and mesosphere, respectively.

Because of its thermal structure (strong static stability), the circulation of the stratosphere is quasi-horizontal. The most important features of the zonal circulation are the vortices in the polar regions and the Quasi-Biennial Oscillation (QBO) in the tropics.



The large ozone opening over the poles (dark area). Stratospheric ozone blocks harmful ultraviolet radiation produced by the sun.

The polar vortices form over both poles during the corresponding winter season and vertically extend through the entire stratosphere. The Arctic vortex is subject to strong variability on short timescales (during so-called sudden stratospheric warmings, the vortex can break down completely within days) and on interannular timescales. The Antarctic vortex varies much less. The QBO is an oscillation of the zonal wind in the equatorial stratosphere, with changes from westerlies to easterlies and back to westerlies within approximately 28 months.

Compared with the zonal flow, the meridional circulation and associated vertical motion in the stratosphere are very weak but are, nevertheless, important. The meridional circulation is caused by planetary waves originating from the troposphere, which break and dissipate in the stratosphere and thereby deposit momentum, decelerating the zonal flow and inducing a meridional flow component. The meridional flow is compensated for by vertical motion in the tropics and in the polar areas, forming a single meridional circulation cell, which in the context of trace gas transport is often referred to as Brewer-Dobson circulation. Air enters the stratosphere in tropical areas. On passing the tropopause, the air loses almost all of its moisture; hence, the stratosphere is very dry and mostly cloud free. In the stratosphere, the air slowly moves upward and poleward toward the winter hemisphere (the summer hemisphere is dynamically quiet). In the subpolar and polar region, the air descends and can eventually enter the troposphere in conjunction with midlatitude weather systems. The stratospheric meridional circulation has a turnover time of one to three years.

Chemically, the stratosphere is characterized by a layer of ozone (O_3) formed from atomic (O) and molecular (O_2) oxygen in the presence of ultraviolet radiation. Ozone can be destroyed by catalytic processes that involve radicals of chlorine, bromine, nitrogen oxides, or hydrogen oxides. The most important source of chlorine radicals are manmade chlorofluorocarbons (CFCs), which have caused a reduction of the ozone layer since the 1970s, as well as, since the 1980s, the Antarctic ozone hole (a substantial reduction of the total stratospheric ozone amount over Antarctica). The Montreal Protocol of 1987 and its amendments have led to a strong reduction in CFC emissions worldwide. However, because of the long lifetime of CFCs, a full recovery of the ozone layer is only expected for the mid-21st century.

The anthropogenic greenhouse effect, as well as ozone depletion, causes a cooling of the stratosphere, whereas volcanic eruptions lead to warming. The stratosphere plays an important role for climate at the Earth's surface. Perturbations of the stratospheric circulation can propagate downward and affect weather at the ground. This provides a pathway through which some of the forcings can affect climate. For instance, it is now believed that part of the climate effect of strong volcanic eruptions operates via the change in stratospheric circulation induced by the heating effect of volcanic aerosols. Similarly, changes in solar irradiance could affect climate via stratospheric ozone chemistry and their subsequent effects on circulation.

SEE ALSO: Atmospheric Vertical Structure; Climatic Data: Atmospheric Observations; Mesosphere; Stratopause; Tropopause; Waves, Rossby.

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Sudan

SUDAN IS A sub-Saharan African (SSA) country that has been combating global warming for many decades. Similar to other SSA countries, Sudan can expect an increase in temperature of 0.4–0.9 degrees F (0.2–0.5 degrees C) per decade, which may lead to the climate becoming drier. In Sudan, rainfall is predicted to decrease by 25 percent over 30 years, leading to desertification in a country that is already 50 percent desert.

Since the 1930s, the desert in Sudan expanded between 31 and 124 mi. (50 and 200 km.), which has led to severe water shortages. It has been predicted that 350 to 600 million people will face water shortages in Sudan by the middle of the 21st century. Water shortages, especially in western Sudan, have led many herders from northern Sudan to migrate to southern areas onto farmers' lands in search of water. This conflict over water, which is a precious resource in Sudan, has led to violence and to 2.4 million people being displaced in 2003. Increases in livestock, which has degraded the land, and deforestation (loss of 12 percent of forests over the last 15 years) have also contributed to continuing desertification. The drying climate has threatened the food security of 1.7 million people, as 90 percent of the people in Sudan depend exclusively on rain-fed agriculture.

Positive adaptive measures have, however, been taking place since 1992 in drought-prone western areas of Sudan, such as the Bara Province. In this area, rangeland rehabilitation measures are being taken through community participation to manage land and water resources and promote agroforestry and sand dune fixation. This has helped prevent overexploitation of resources and restore the productivity of rangelands.

Although Sudan is facing many challenges because of climate change, it hardly contributes to worldwide greenhouse gas emissions. For instance, in 1998, Sudan's total carbon dioxide emission was 3,597 thousand metric tons (tmt) compared with 515,001 tmt for SSA and 24,215,376 tmt for the world. Non–carbon dioxide emissions for Sudan in 1995 were 132 tmt compared with 5,345 tmt for SSA and 141,875 tmt for the world. Even though Sudan hardly contributes to global warming, the government of Sudan intends to adapt to the consequences of the problem. It has prepared the National Adaptation Plans for Action, which highlight several policy measures to adapt to climate change. These include increasing irrigation and low-water crops, water management and conservation technology, sustainable forest resource consumption, and reduction of livestock. The government of Sudan has also ratified the United Nations Framework Convention on Climate Change.

SEE ALSO: Carbon Dioxide, Climate Change, Effects; Drought.

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Sulphur Dioxide

SULPHUR DIOXIDE (SO_2) is an important component of the atmosphere, present as the result of both natural and human activity. Although it is a primary pollutant in its own right, causing respiratory irritation and damage to plants, it is the secondary pollutants produced from SO_2 that are particularly important in connection with global climate change. Sulphur dioxide is notorious as the cause of acid rain, but it is also a precursor to the formation of clouds. Hence, its release to the atmosphere is a major contributor to global dimming, a process that is thought to offset some of the effects of global warming.

There are, therefore, important implications of SO_2 release for the global climate change agenda. The reduction in SO_2 pollution in recent decades, stimulated by health concerns and by the effects of acid rain, is removing an unexpected and previously unidentified protection against increasing global temperatures. This illustrates the complexity of climate science that compounds the social and political responses to the threat of climate change.

Once in the atmosphere, SO_2 is rapidly oxidized, ultimately producing sulphuric acid. Although this transformation is well known in the formation of acid rain, it also has broader climatological significance. The liquid sulphuric acid forms as an aerosol (tiny droplets suspended in the air), and this sulphuric acid aerosol attracts water vapor, which dissolves in the acid. In this way, the gas-to-liquid conversion of SO_2 to sulphuric acid brings about the nucleation of clouds: sulphuric acid aerosol is a cloud condensation nucleus (CCN).

Clouds play important roles in the atmosphere and in the climate, principally acting to transport water (and energy) between regions and to affect the Earth's radiation balance. Clouds have a very strong tendency to reflect sunlight (they have a high albedo) and also absorb energy from the sun, so that the amount of cloud present in the atmosphere affects the amount of sunlight reaching the surface: more clouds result in a dimmer planet. This dimming effect of clouds is well documented.

SULPHUR DIOXIDE AND CLIMATE CHANGE

Furthermore, the influence of SO_2, and subsequent aerosol formation, has been observed directly during volcanic eruptions. For example, the 1991 eruption of Mount Pinatubo in the Philippines released an estimated 20 megatons (20,000,000 tons) of SO_2 into the atmosphere. The force of the explosion injected a large fraction of this material, along with dust particles, directly into the stratosphere, from which removal via rainout is very slow. The aerosol and clouds that formed as a consequence of this lasted for many years, with measurable effects on global temperatures. In the year following the eruption, the global average temperature reduced by 0.9 degrees F (0.5 degrees C), and even in 1993 the temperature was depressed by as much as 0.45 degrees F (0.25 degrees C).

In the lower atmosphere, the rate of SO_2 gas-to-liquid conversion is increased in the presence of other materials, notably particles such as soot, and this has an important effect on cloud condensation. The typically hydrophobic—water-repelling—surfaces of soot particles catalyze the chemical reactions that convert SO_2 to sulphuric acid, so that the soot ends up coated with a water-loving, hydrophilic layer. The simultaneous emission of SO_2 and soot (e.g., from burning coal or diesel fuel) therefore increases the concentration of cloud condensation nuclei in the air, affecting both the amount and nature of cloud formation.

Because there are many more cloud condensation nuclei under these conditions than in the clean atmosphere, clouds form with smaller, more numerous droplets. More numerous particles means that the clouds reflect more light, and smaller droplets take longer to form raindrops. Hence, the clouds formed on sulphate/soot aerosol CCN are longer lived and have a higher albedo than ordinary clouds. In this way, SO_2 emissions in combination with soot increase the amount of incoming sunlight reflected away from the Earth, effectively dimming the planet's surface.

Sulphur dioxide pollution–related global dimming is thought to explain the slight global cooling trend in the period from 1950 to the late 1970s. With the recent, legislation-driven decrease in emissions of SO_2 and soot particles from industry and transport in industrialized nations, there has been a steady rise in the amount of sunlight reaching the earth. It is suspected that reducing this form of pollution is removing an effect that has been offsetting the full force of anthropogenic global climate change.

SEE ALSO: Aerosols; Cloud Feedback; Volcanism.

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Sulphur Hexafluoride

SULPHUR HEXAFLUORIDE (SF_6) is the most powerful of all the greenhouse gases recognized by the Kyoto Protocol and evaluated by the Intergovernmental Panel on Climate Change. Although its concentration in the atmosphere is low, the combination of a high global warming potential and a very long lifetime make emissions of SF_6 a considerable concern. It is primarily used as an electrical insulator in the high-voltage distribution network, and major industrial users are beginning to restrict the use and emission of SF_6.

The Kyoto Protocol requires developed nations to cut their emission of six greenhouse gases. The Intergovernmental Panel on Climate Change periodically assesses these gases and estimates a global warming potential (GWP) for each. The gasses, with their respective GWPs, are as follows: CO_2 (1), CH_4 (21), N_2O (310), PFC (9200), HFC (11,700), and SF_6 (23,900). In this list, HFC and PFC are groups of chemicals, and the value quoted is for the member of the group with the highest GWP. Despite the low atmospheric concentration of SF_6 (5.6 parts per trillion), its extremely high global warming potential and long lifetime (probably in excess of 1,000 years) mean that present emissions will have an effect on climate for a long time to come.

As SF_6 gas is denser (heavier) and more electrically insulating than either dry air or dry nitrogen, it is an ideal electrical insulating material. The gas is used extensively in electrical applications, and its principal use is in the electrical generation and high-voltage distribution industry. There are two specific advantages of SF_6 in these applications. First, its highly insulating character means that less space is needed between high-voltage components, so that equipment can be made significantly smaller than is possible when air or nitrogen are use as insulators. Second, gas-insulated switch gear using SF_6 rather than air demands a controlled environment, and the equipment is consequently more robust with regard to environmental pollutants and weathering than would be the case with simpler air-insulated equipment. In addition to these advantages, the gas is unreactive, nontoxic and nonflammable. In the United States, the electric power distribution industry works on a voluntary basis with the SF_6 Emissions Reduction Partnership for Electric Power Systems to identify and implement technologies for reducing SF_6 emissions.

Another large-scale use of SF_6 is in magnesium metal manufacturing and casting. Magnesium metal is extremely reactive in air, particularly when hot or molten. The high density and low chemical reactivity of SF_6 make it a suitable choice as a protective gas layer preventing contact of the molten, highly reactive metal with oxygen and water in the air. A voluntary SF_6 Emission Reduction Partnership for the Magnesium Industry exists in the United States in association with the U.S. Environmental Protection Agency, which, together with the International Magnesium Association, is committed to eliminating SF_6 emissions from the industry by 2011.

SF_6 is also used in certain medical applications, including eye surgery and ultrasound scanning. Once again, it is the gas's high density and low toxicity that are used. In eye surgery, the gas is commonly used to form a plug to seal the retina during surgery. Its high density means that the gas stays in place and does not enter the blood at an appreciable rate. The density of the gas also makes it an excellent contrast agent in medical ultrasound scanning.

Similar to the perfluorocarbons, SF_6 is also used in the semiconductor industry, and there is concern about the growth of this industry leading to uncontrolled increases in the amount of SF_6 released to the atmosphere.

Paradoxically, because of its high chemical stability, low toxicity, and low natural abundance, SF_6 has been extensively used by atmospheric scientists as a tracer gas to understand the movements and mixing of air. The gas has, for instance, been injected into the exhaust plumes from power stations in an attempt to understand the origins of acid rain. In the United Kingdom, SF_6 tracer experiments have demonstrated that power stations are capable of delivering acid rain pollution to Scandinavia. For similar reasons, SF_6 is used to trace the movements of air within ventilation and air conditioning system tests. Recently, the gas was released on the London Underground in an attempt to understand the way toxic gases would spread throughout the system in the event of a terrorist attack.

SEE ALSO: Global Warming; Intergovernmental Panel on Climate Change; Kyoto Mechanisms; Kyoto Protocol; Perfluorocarbons.

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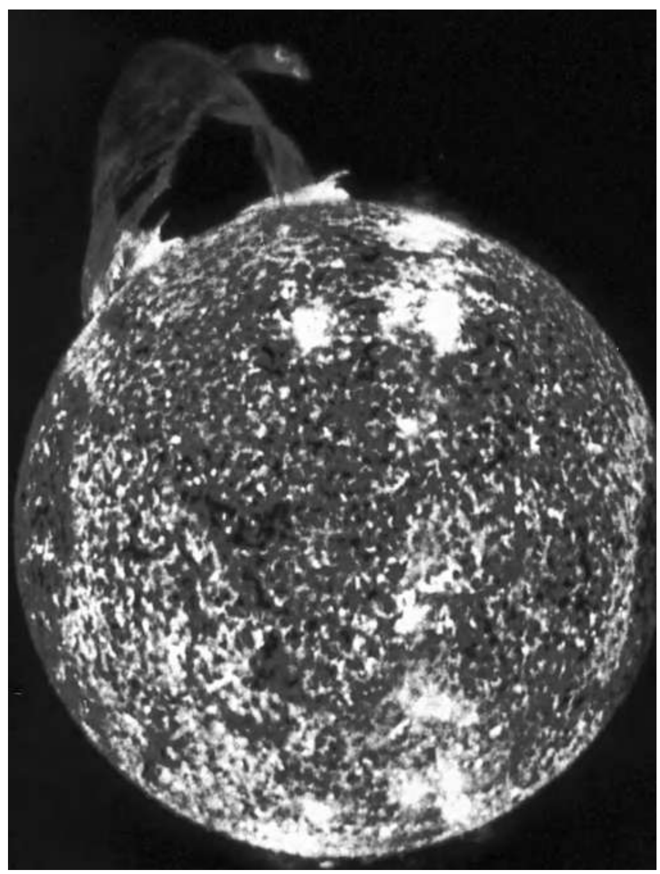
Sunlight

SUNLIGHT IS THE electromagnetic radiation given off by the sun. It is passed through the atmosphere to the Earth, where the solar radiation is reflected as daylight. Sunshine results when the solar radiation is not blocked. Sunlight is the primary source of energy to the Earth. It provides infrared, visible, and ultraviolet (UV) electromagnetic radiation with different wavelengths. Small sections of the wavelengths that are visible to the human eye are reflected as rainbow colors. Sunlight may be recorded using a sunshine recorder. Electromagnetic waves are waves that are capable of transporting energy through the vacuum of outer space and that exist with an enormous continuous range of frequencies known as the electromagnetic spectrum. The spectrum is divided into smaller spectra on the basis of interactions of electromagnetic waves with matter.

The longer-wavelength, lower-frequency regions are located on the far left of the spectrum, and the shorter-wavelength, higher-frequency regions are on the far right. Two very narrow regions within the spectrum are the visible light region and the X-ray region. The visible light region is a very narrow band of wavelengths located to the right of the infrared region and to the left of the UV region. Though electromagnetic



Sunlight is Earth's primary source of energy, providing infrared, visible, and ultraviolet electromagnetic radiation.

waves exist in a vast range of wavelengths, human eyes are only sensitive to the visible light spectrum. The visible portion of the solar spectrum lies between 400 and 700 nm. and separates the UV region of shorter wavelengths from the infrared region of longer wavelengths. A combination of waves results in white light. Red has the longest visible wavelength, whereas violet has the shortest. Waves longer than red are known as infrared, and waves shorter than violet are called UV.

The sun is the closest star to the Earth and the most closely studied. It is at the center of the solar system and accounts for about 99.8 percent of the mass of the solar system. The planets revolve around the sun. The sun is composed of hydrogen, helium, and other trace elements and goes around the center of the Milky Way galaxy at a distance of about 26,000 light years from the center of the galaxy. The amount of solar energy incident on the Earth's atmosphere is about 342 Watts per sq. m.r, based on the surface area of the Earth. Although the Earth's surface continuously radiates energy outward to space, only part of the surface area receives solar radiation at a time. Most of the solar energy incident on the Earth is in the UV region of shorter wavelengths. The sun is the source of heat that sustains life on Earth and controls the climate and weather. Only the sun's outer layers, which consist of the photosphere, the chromosphere, and the corona, can be observed directly. These three regions have different properties from one another, with regions of gradual transition between them. The sun has basically the same chemical elements as are present on the Earth. However, the sun is so hot that all of these elements exist in the gaseous state. Energy generated in the sun's core takes a million years to reach its surface. Solar energy is created deep within the core of the sun, where nuclear reactions take place.

SUNLIGHT AND THE DANGER OF SKIN CANCER

Every living thing exists because of the light from the sun. Sunlight is important in photosynthesis. For humans, UV light in small amounts is beneficial because it helps the body produce vitamin D from the UV region of sunlight. However, excessive exposure to sunlight is dangerous, as it can cause sunburns, skin cancer, and aging. UV light wavelengths are short enough to break the chemical bonds in skin tissue, and when the skin is exposed to sunlight, most skin will either burn or tan. The skin undergoes certain changes when exposed to UV light to protect itself against damage. The epidermis thickens, blocking UV light, and the melanocytes make increased amounts of melanin, which darkens the skin, resulting in a tan. Melanin absorbs the energy of UV light and prevents the light from penetrating deeper into the tissues. Sensitivity to sunlight varies according to the amount of melanin in the skin. Darker-skinned people have more melanin and therefore have greater protection against the sun's harmful effects. The amount of melanin present in a person's skin depends on heredity as well as on the amount of recent sun exposure. Albinos have little or no melanin. The more sun exposure a person has, the higher the risk of skin cancers, including squamous cell carcinoma, basal cell carcinoma, and malignant melanoma. Actinic keratoses (solar keratoses) are precancerous growths also caused by long-term sun exposure.

UV light, although invisible to the human eye, is the component of sunlight that has the greatest effect on human skin. Sunlight deficiency could increase blood cholesterol by allowing squalene metabolism to progress to cholesterol synthesis rather than to vitamin D synthesis, as would occur with greater amounts of sunlight exposure. Larger amounts of UV light damage the body's DNA and alter the amounts and kinds of chemicals that the skin cells make. UV light may also break down folic acid, sometimes resulting in a deficiency of that vitamin in fair-skinned people. UV light is classified into three types, UVA, UVB, and UVC, depending on its wavelength. Although UVA penetrates deeper into the skin, UVB is responsible for at least three quarters of the damaging effects of UV light, including tanning, burning, premature skin aging, wrinkling, and skin cancer. The amount of UV light reaching the Earth's surface is increasing, especially in the northern latitudes. This increase is attributable to chemical reactions between ozone and chlorofluorocarbons that are depleting the protective ozone layer, creating a thinner atmosphere with some holes. The key to minimizing the damaging effects of the sun is avoiding further sun exposure. It should be noted that damage that is already done is difficult to reverse.

SEE ALSO: Chemistry; Climate Change, Effects.

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Suriname

LOCATED IN THE northeast of the South American mainland, Suriname, formerly a Dutch colony, has a land area of 63,251 sq. mi. (163,270 sq. km.), with a population of 458,000 (2006 est.) and a population density of 7 people per sq. mi. (2.7 people per sq. km.). With 97 percent of the land covered in forests, and a relatively small timber industry, there is little arable land available.

For electricity production, in 2001, 64.2 percent of the country's electricity came from hydropower, with the remaining 35.8 percent coming from fossil fuels. Much of the hydropower comes from a number of hydroelectric plants in the country. Although most provide electricity for the government, some were constructed to provide electricity for specific businesses, such as the Brokopondo Reservoir for the nearby Alcoa aluminum plant. Most of the fossil fuels used in Suriname come from petroleum, with liquid fuels being responsible for 95 percent of the carbon dioxide emissions from the entire country. On account of this reliance on liquid fuels, in spite of being largely undeveloped, Suriname had a per capita rate of carbon dioxide emissions of 4.5 metric tons per person in 1990, rising steadily to 5.1 metric tons in 2003.

The effects of global warming on Suriname include a greater possibility of flooding, with the increased risk of insect-borne diseases such as malaria and dengue fever. There is also the risk of alienating some of the arable land in the country, possibly making it dependent on imported food. Furthermore, the rising water temperature is already having an effect on the leatherback turtles at the Galibi Nature Reserve. The Suriname government took part in the United Nations Framework Convention on Climate Change, signed in Rio de Janeiro in May 1992, ratifying it four years later, with the government ratifying the Vienna Convention in 1997. On September 25, 2006, Suriname became the 163rd country to ratify the Kyoto Protocol to the UN Framework Convention on Climate Change.

SEE ALSO: Climate Change, Effects; Floods.

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Sustainability

THE LANGUAGE OF sustainability emerged during the 1970s, though the concept was introduced as sustainable development in 1980 in the World Conservation Strategy and was popularized in 1987 by the World Commission on Environment and Development (also known as the Brundtland Commission after its Norwegian chairperson Gro Harlem Brundtland). Today there are numerous definitions of sustainability, but the important question to ask is, What is to be sustained? Is it the planet, particular environments, individual species, current lifestyles, certain rates of economic growth, a specific level of profit?

Sustainability, especially as constructed in mainstream definitions of sustainable development, is very similar to the concept of conservation espoused by the American forester, Gifford Pinchot, in the late 19th century. Conservation emphasized using natural resources wisely, not depleting nonrenewable resources, ensuring that all American men received a fair share of the distribution of benefits, and that consideration be given to the needs of their descendents. Sustainable development globalizes the discourse. The World Commission on Environment and Development report in 1987 defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." This definition is used today in many parts of the world by governments, businesses, environmental groups, and educators. The history of the concept, and the specific term, mean that it may be interpreted as a repackaging of environmental management. The managerial focus and faith in technological progress evident in this definition of sustainability mean that it is critiqued by more radical sustainability advocates.

In Australia, the term ecologically sustainable development emerged as a unique approach as a result of the power of major environmental groups in Australia in the early 1990s. In 1992, ecologically sustainable development was defined as "using, conserving and enhancing the community's resources so that ecological processes, on which life depends, are maintained and the total quality of life, now and in the future, can be increased." This terminology and definition, which arose as a result of the political power of environmental groups in the early 1990s in Australia, highlights the dependence of all life on ecological processes (thermodynamics, hydrological cycles, nutrient cycles, and so on).

The Australian definition leans toward what has been termed strong sustainability, meaning that humans should not be substituting human-made capital for natural capital. In contrast, weak sustainability advocates substitution provided the total store of capital is not diminished. Critics of the weak sustainability approach point out that this is what has been happening for thousands of years, leading to the destruction of the environment. Other critics reject the notion of turning nature into "natural capital" and therefore do not engage in the strong versus weak sustainability debates.

CONFERENCES ON SUSTAINABILITY

The concept of sustainable development was the basis for a massive conference in Rio de Janeiro in 1992 that was chaired by Maurice Strong and attended by 178 governments, including 118 heads of state. The United Nations Conference on Environment and Development (UNCED, otherwise known as the Earth Summit) was the five-year follow-up to the release of the Brundtland Report. The conference attempted to move from debates about the notion of sustainability and sustainable development to working out how to implement this idea. The idea of expanding the global economy, although controversial, was accepted within sustainable development discourses because development was seen as being necessary to overcome poverty. Sustainable development was intended to allow economic growth to continue but to make this growth greener. Growth was seen as essential for developing countries and also for developed countries, so as to facilitate trade and help the poorer countries of the world. This concept of sustainability was compatible with that of the newly founded business organization, the World Business Council for Sustainable Development, which was influential in shaping the idea of sustainable development and how it would be implemented.

Implementation has been the focus of subsequent conferences in New York (1997) and Johannesburg (2002) and in the ongoing work of the United Nations Commission on Sustainable Development. Many countries, states/provinces, and local governments, as well as some businesses, have also introduced departments focused on implementing sustainability within their organization. Implementation is challenging because there are many barriers to implementing sustainable development. These include corporate cultures, countervailing market signals, and jurisdictional issues. Another issue is that although the temporal emphasis within the concept of sustainability is apparent, the spatial or geographical scale is unclear. This has led to various scales of analysis and implementation, including concepts such as sustainable lifestyles, sustainable cities, and sustainable regions. The UNCED Conference in 1992 produced five important documents including Agenda 21, which was a 40-chapter document outlining the actions needed to implement sustainable development. Importantly, chapter 28 highlighted the important role of local government in implementing the concepts introduced at the global level. This led to the development of Local Agenda 21 (LA21). At the Johannesburg Conference in 2002, LA21 was relaunched as Local Action 21, which is the second decade of this program containing a focus on action and implementation.

FUTURE PLANNING

There are also different ways of conceptualizing sustainable development vis-à-vis sustainability. Some authors present sustainability and sustainable futures as being the goals to be reached by a process called sustainable development. Other authors maintain a distinction between sustainable development and ecological sustainability on the basis of their approach to existing structures and institutions. Sustainable development is seen as more of a reformist approach by advocates who primarily support the existing institutions but want them to be greener, whereas those activists and authors who emphasize sustainability or ecological sustainability often question the structures that perpetuate unsustainable practices.

Today it is impossible, given the adoption of legislation related to sustainability, not to be planning for sustainability. However, many of the differences in various concepts of sustainability can be attributed to the relative weight given to the economic, social, cultural, and environmental components of sustainability. The differences are also caused by the perception of how these components fit together.

There are two main approaches to conceptualizing sustainability, with numerous variations on these approaches. The dominant, mainstream representation of sustainable development that emerged from the Brundtland Commission, and that has been adopted by many governments and business groups throughout the world, is the balanced approach. Although the notion of balance has been largely discredited in scientific ecology, it is still a powerful metaphor within the environmental literature. In many models of sustainable development, balance is achieved by the construction of three circles of equal size to represent the economy, society, and environment. At the intersection of these three equal-sized circles is sustainable development. In contrast, more radical advocates of sustainability may posit a hierarchical approach, in which the hierarchy may vary between models. It often includes ecological considerations at its base, followed by society—because there would be no society without an environment, and then a smaller economy—because there would be no economy without society. Variations may include the use of thermodynamic processes to support biochemical cycles that allow ecosystems to flourish, eventually reaching human social and individual scales.

Some environmental groups avoid using the term sustainable development, partly because of its perceived cooption. Other groups use the term sustainability, whereas some groups attempt to avoid this language altogether. The challenge for sustainability advocates is to be able to implement something that moves humankind and the rest of the planet away from a state of being unsustainable at a rate that is needed to avoid catastrophe.

SEE ALSO: Australia; Conservation; Culture; Norway; Resources; World Business Council for Sustainable Development (WBCSD).

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Sverdrup, Harald Ulrik (1888–1957)

HARALD ULRIK SVERDRUP is a Norwegian meteorologist and oceanographer known for his studies of the physics, chemistry, and biology of the oceans and considered as the founding father of modern physical oceanography. Sverdrup explained the equatorial countercurrents and helped develop the method of predicting surf and breakers. A unit of water flow in the oceans was named after him by oceanographic researchers: 1 sverdrup (Sv) is equal to the transport of 1 million cubic meters of water per second. The American Meteorological Society honored him with the Sverdrup Gold Medal, which recognizes researchers for outstanding contributions to the scientific knowledge of interactions between the oceans and the atmosphere.

Sverdrup was born on November 15, 1888, in Sogndal, Sogn, Norway, into an ancient and respected family of university lecturers, lawyers, politicians, and Lutheran ministers. His father Johan was a teacher and, following the family tradition, became a Lutheran minister of the State Church of Norway. In 1894, his father became minister in the island district of Solund, about 40 mi. (64 km.) north of Bergen, and then moved to Rennsö near Stavanger. In 1908, he became professor of church history in Oslo. Because of his father's different jobs, Sverdrup spent much of his boyhood in various sites in western Norway and was taught by governesses until he was 14 years old. At that age, he went to school in Stavanger. During his adolescence, Sverdrup experienced conflicts between his interest in natural science and the religious background of his family. It was particularly difficult for him to reconcile the concept of evolution with his religious upbringing.

SVERDRUP'S FORMAL TRAINING

As he was not aware of the possibility to study science at university, he first opted for the classical curriculum in 1903. Within this field, his major interest became astronomy. Sverdrup left the gymnasium with honors and spent a year in Oslo preparing for university preliminary examinations. Military service was compulsory at the time, so he decided to combine it with his scientific education, enrolling at the Norwegian Academy of War. This training was combined with the study of physics and mathematics. The physical training that he received while at the academy was extremely useful for his survival during his later long arctic expeditions.

When Sverdrup entered university, he decided to major in astronomy. In 1911, he was offered an assistantship with Professor Vilhelm Bjerknes, the preeminent Norwegian meteorologist and founder of the Bergen School, which allowed him to enter one of the brightest scientific circles in the country. The Bergen School was supported by an annual grant that Bjerknes received from the Carnegie Institution of Washington almost from its founding. Sverdrup initially planned to continue his research in astronomy, but he became increasingly interested in meteorology and oceanography and thus changed his major. When, in 1912, Bjerknes went to Germany to work at the University of Leipzig as professor and director of the new Geophysical Institute, Sverdrup followed him, remaining in Germany from January 1913 to August 1917. He also continued his thesis for the University of Oslo and received his doctorate in June 1917 on a published paper on the North Atlantic trade winds.

CAREER HIGHLIGHTS

In July 1918, Sverdrup joined Roal Amundsen's expedition in the Arctic, on the *Maud*, as a chief scientist. Although the planned duration of the expedition was from three to four years, it lasted for seven and a half years. Sverdrup did not return to Norway until December 22, 1925. He was enthusiastic about the experience and defined the most interesting period as the eight months between 1919 and 1920 spent in Siberia, living with nomadic reindeer herders, the Chukchi. Sverdrup's arctic expedition was interrupted for six months between 1921 and 1922, when the meteorologist had the chance of spending a profitable period of time at the Carnegie Institution. From the arctic expedition, Sverdrup gained better understanding of the basic physical oceanography of currents. He argued that the effect of the Earth's rotation, a fundamental aspect of the dynamics of the oceans, is best observed in the polar regions, because it reaches its greatest level there. On his return to Norway, Sverdrup married Gudrun Bronn Vaumund.

By 1926, Sverdrup was a well-established scientific researcher and was offered the chair of meteorology at Bergen, which had been previously held by Bjerknes. The Carnegie Institution had also offered Sverdrup a permanent position twice, but the Norwegian scientist refused the American offer and took up the position at Bergen. In this capacity, Sverdrup edited the scientific report of the *Maud*. He also continued to collaborate with the Carnegie Institution. In 1931, he led the scientific group in the Wilkins-Ellsworth North Polar Submarine Expedition, during which valuable information was gathered despite its failure to achieve the chief goal of the expedition, the submarine exploration of the Arctic in the *Nautilus*.

In 1936, Sverdrup accepted the position of director of the Scripps Institute of Oceanography in La Jolla, at the University of California, remaining there for almost 12 years. During his tenure as director, Sverdrup expanded the Scripps Institute, making it an institute with a research program, and developing closer ties between Scripps and the University of California, Los Angeles. During World War II, Sverdrup was involved in the U.S. war effort, although he did not directly work for the University of California Division of War Research. He worked on problems related to forecasting surf conditions for military beachhead assaults. His current and wave forecasting methods were applied by military weathermen to predict landing conditions for Allied invasions.

Sverdrup was a central figure in the postwar development of oceanography and allied sciences. He served on many scientific committees after the war, and his contributions to science were increasingly recognized. He was elected to the National Academy of Sciences in 1945. He joined the Executive Committee of the American Geophysical Union in 1945 and presided over the American Geophysical Union Oceanography Section. In 1946, he became president of the International Association of Physical Oceanography. He chaired the Division of Oceanography and Meteorology at the 1946 Pacific Science Conference. Sverdrup returned to Norway in 1948, where he worked as a professor of geophysics at the University of Oslo until his death on August 21, 1957.

SEE ALSO: History of Climatology; Oceanography.

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Swaziland

THE KINGDOM OF Swaziland is landlocked, with its neighbors being South Africa and Mozambique. It has a land area of 6,704 sq. mi. (17,363 sq. km.), with a population of 1,141,000 (2006 est.) and a population density of 153 people per sq. mi. (59 people per sq. km.). Some 11 percent of the land is arable, with much of it used for subsistence farming, and also for growing maize, cotton, rice, sugar cane, and citrus fruits. In addition, 62 percent of the country is used as meadows or pasture for low-intensity grazing of cattle, sheep, and goats. About 6 percent of the country is forested, with a significant logging industry.

Because the country is largely undeveloped, there is a relatively low use of electricity, with a significant component being used for heating in winter. Electricity production in Swaziland comes from fossil fuels (55.8 percent) and hydropower (44.2 percent), with most of it imported from South Africa. In terms of its carbon dioxide emissions, Swaziland ranks 144th in the world, with emissions of 0.5 metric tons per person in 1990, falling to 0.1 metric tons per person in 1993 but rising steadily to 0.92 metric tons per person by 2003. All the carbon dioxide emissions in Swaziland are attributed to the use of solid fuels, with most of the electricity generated and also the residential and business heating done by coal or wood. This has resulted in a significant per capita emission of carbon monoxide.

As a result of global warming and climate change, Swaziland has seen the effects of water shortages for some of its crops, such as rice, and desertification of some areas previously used for farming. The Swaziland government took part in the United Nations Framework Convention on Climate Change, signed in Rio de Janeiro in May 1992, signing the Vienna Convention in the same year. On January 13, 2006, the country accepted the Kyoto Protocol to the UN Framework Convention on Climate Change, being the 155th country in the world to do so, with it coming into force on April 13, 2006.

SEE ALSO: Climate Change, Effects; Drought

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Sweden

SWEDEN IS ONE of the few nations expected to meet or exceed its target according to the Kyoto Protocol and is lauded as one of the countries that has adopted the most stringent measures to address global warming on the basis of emission levels and trends and climate policy. Since 2000, greenhouse gas emissions in Sweden have been an average of 3.7 percent below levels in 1990 and are expected to be 4 percent lower in 2010. This meets Sweden's national target of reducing emissions by 4 percent between 1990 and 2012.

A traditional windmill in southern Sweden. Sweden has invested heavily in the development of wind and water power plants.

Sweden has committed to becoming the world's first oil-free nation by 2020. The Swedish Government's Commission on Oil Independence proposed measures necessary to eliminate Sweden's dependence on fossil fuels for transport and heating and promotes the use of renewable alternatives. In 1970, 77 percent of Sweden's energy came from oil, but this amount decreased to 32 percent by 2003. Nuclear power will be phased out, and Sweden has invested heavily in the development of wind and water power plants. Innovative programs including the use of boilers that use wood-based pellets have dramatically decreased the use of oil for home heating, and tax exemptions enabling drivers to use ethanol-based fuel have increased compliance among residents. Sweden's climate strategy involves partnerships between the business community, scientists, and politicians.

Recent modelling scenarios indicate an increase in annual mean temperature in Sweden of between 4.5–8.1 degrees F (2.5–4.5 degrees C) by 2100, with a greater increase in temperature and rate of precipitation during the winter than the summer. Specific effects include flooding resulting from increased precipitation and heavier rainfall. Summer drought and water shortages are expected in southern Sweden because of changes in precipitation rates and increased evaporation. Although the flora and fauna of Sweden may be enriched by a number of southern species, northern species and those indigenous to the Baltic Sea region will be displaced.

Agricultural yields are likely to benefit from warmer temperatures, with extended growing periods and better conditions for cultivation leading to increased harvest yields of around 20 percent and an increased number of commercial crops. A warmer climate would result in elevated levels of pests and disease, leading to the more frequent usage of pesticides. Anticipated changes in temperature and salinity in the Baltic Sea are expected to have an adverse effect on species of importance to the fisheries sector such as Baltic herring, cod, salmon, turbot, and plaice. Species composition is expected to shift as new fish and shellfish species are introduced from the south. Reduced sea-ice cover may also have an adverse effect on reproduction for flatfish, whereas warm-water species such as pike, perch, and carp may benefit from higher water temperatures.

SEE ALSO: Kyoto Protocol; Renewable Energy Policy Project (REPP); Stockholm Environmental Institute (SEI).

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Switzerland

SWITZERLAND HAS A long-standing tradition of environmental awareness and protection and has been active in bringing the debate on climatic change to the forefront of international environmental affairs. Switzerland was a strong supporter of the Intergovernmental Panel on Climate Change from its inception in 1988 and an important negotiator for the UN Framework Convention on Climate Change, leading *inter alia* to the Kyoto Protocol. Climate research is high on the agenda of Swiss academia, with recognized expertise in paleoclimate reconstructions, climate modeling, and impacts studies. In 1987, the Swiss Academy of Science set up a unique scientific platform at the interface of science and policy (ProClim, the Swiss Forum on Climate and Global Change) to facilitate the transfer of knowledge to decision makers and to the media.

The keen awareness of Switzerland to climatic change is the result of many climate-driven changes in the Alpine environment already being perceptible, such as the retreat of mountain glaciers. The climate of Switzerland is rendered complex by the interactions between the Alpine topography and atmospheric flows and the competing influences of a number of contrasting climate regimes that converge into the region (the Mediterranean, continental, Atlantic, and polar systems). Temperatures have risen by up to 3.6 degrees F (2 degrees C) in many parts of Switzerland since 1900—well above the global average 20th-century warming of about 1.3 degrees F (0.7 degrees C).

Future climatic change in the Alps will be a complex aggregate of decadal- to century-scale forcing factors related to the North Atlantic Oscillation, the Atlantic Multidecadal Oscillation, and the anthropogenic greenhouse effect. Regional climate models suggest that by 2100, Swiss winters will warm by 5.5–9 degrees F (3–5 degrees C) and summers by 11–12.5 degrees F (6–7 degrees C); in parallel, precipitation is projected to increase in winter and to sharply decrease in summer. Strong heat waves similar to the 2003 European event are likely to become the norm by 2100, and both drought and intense precipitation are projected to increasingly affect the country.

The effects of climatic change on Switzerland will change the natural environment and economic activities. Alpine glaciers may lose between 50–90 percent of their current volume, and the average snow line will rise by 492 ft. (150 m.) for each degree of warming. Hydrological systems will respond in quantity and seasonality to changing precipitation patterns and to the timing of snowmelt in the Alps, with a greater flood potential in spring and drought potential in summer and fall. More extreme events will trigger frequent slope instabilities, and at high elevations, melting permafrost will compound these problems. The distribution of natural vegetation will change as plants seek new habitats with similar climatic conditions to those of today. A rapidly warming climate will result in a loss of mountain biodiversity, as not all species are capable of adapting to change. The direct and indirect effects of a warming climate will affect important economic sectors such as winter tourism, hydropower, agriculture, and the insurance industry, which will be confronted with more frequent natural disasters. Climate-related health risks (allergies, pollution) are expected to increase, with consequent economic effects resulting from prolonged morbidity and absenteeism.

SEE ALSO: Climate Change, Effects; Drought; Floods; Kyoto Protocol.

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Syria

LOCATED IN THE Middle East, the Syrian Arab Republic has a land area of 71,479 sq. mi. (185,180 sq. km.), with a population of 19,929,000 (2006 est.) and a population density of 267 people per sq. mi. (103 people per sq. km.). Some 28 percent of Syria is arable land, with a further 43 percent used as meadows or pasture, much of it for low-intensity grazing of sheep. Only a very small part of the country is woodland.

In terms of its per capita carbon dioxide emissions, Syria ranks 93rd in the world, with emissions of 2.8 metric tons per person in 1990, gradually falling to 2.7 metric tons per person by 2003, after which emissions experienced a significant rise to 3.72 metric tons per person in 2004. Fossil fuels make up 64.5 percent of electricity generation in the country, and hydropower contributes to the remainder, with dams located on the Euphrates River. In 1973, the Syrian government built the Tabaqah Dam on the Euphrates to create a new reservoir called Lake Assad to help with the irrigation of the region, and there have been other, smaller projects in recent years.

About 70 percent of the country's carbon dioxide emissions come from liquid fuels, with 19 percent from gaseous fuels, 7 percent from gas flaring, and 4 percent from the manufacture of cement. Solid fuels are not used in the country. By sector, 42 percent of the carbon dioxide emissions come from the generating of electricity, with 32 percent from manufacturing and construction, and 12 percent from transportation. In terms of the effects of global warming and climate change, Syria has experienced a higher average temperature, which has resulted in some level of desertification and the widespread alienation of marginal arable land as the country draws heavily on its water reserves. One positive benefit, although short term, has been that in the Jabal and Nusariyah mountains, parallel to the coastal plain, there has been a rise in temperature, which has led to the melting of the snows, helping with the irrigation of the heavily populated eastern slopes of the mountain range.

The Syrian government of Hafez al-Assad took part in the United Nations Framework Convention on Climate Change, signed in Rio de Janeiro in May 1992. The government of his son Bashar al-Assad accepted the Kyoto Protocol to the UN Framework Convention on Climate Change on January 27, 2006, with it entering into force on April 27, 2006.

SEE ALSO: Carbon Dioxide; Climate Change, Effects; Deserts; Kyoto Protocol.

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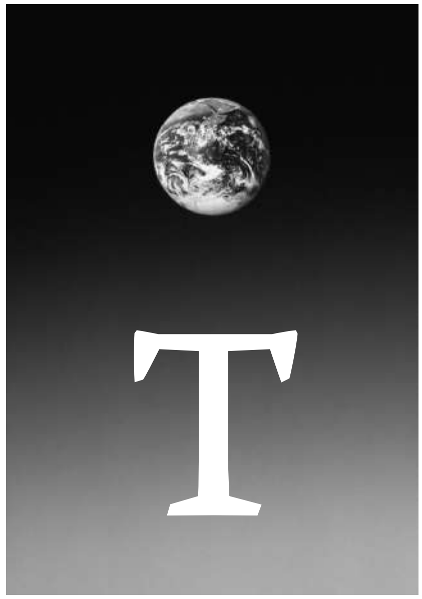

Tajikistan

TAJIKISTAN IS LOCATED in Central Asia, east of China. It is a landlocked country dominated by the Pamir and Alay mountain ranges, with the highest peak being over 7,200 m. (23,600 ft.) high. The valley floors are considered a continental climate zone, whereas the mountains range from semiarid to polar. Climate change has begun to affect the lives of many of the country's seven million residents, particularly those who live in the mountain zones.

According to modeling scenarios published by the government, Tajikistan should see an average temperature increase of 3.2–5.2 degrees F (1.8–2.9 degrees C) by the year 2050. Mean monthly temperature increases varied within the models, but at least one showed a sharp increase in February and March temperatures of 8.5–8.8 degrees F (4.7–4.9 degrees C) over historical averages. Precipitation should increase by 3–26 percent by 2050 in most regions, with several models showing an average increase of 14 percent in the mountains and 18 percent in the valleys. More frequent rainfall will increase soil erosion in the main agricultural sectors.

Six percent of Tajikistan is covered with glaciers, and they are receding at an increasingly worrisome pace. Several thousand small glaciers will vanish entirely by 2050, and the major glacier fields will shrink by 15–20 percent. Over the course of the 20th century, the massive Garmo glacier retreated by 4.3 mi. (7 km.) and shrunk in area by 2.3 mi. (6 sq. km.); the 43.5 mi.-long (70-km.) Fedchenko glacier has retreated 0.6 mi. (1 km.) in length and lost 0.85 mi. (2 sq. km.) of thickness in recent years.

Water flow in the major river basins is expected to decrease by an average of 7 percent by 2050. With increased snowfall in the mountains and the melting of glaciers, the spring floods are anticipated to increase in duration. At the same time, reduced water flow will have a severe effect on irrigation and hydroelectric power production. Mountain villages are already feeling the effects of the changing climate. Over the last few years, mountain communities have seen increased snowfall, which leads to the closure of mountain roads for longer and longer periods and causes severe flooding and landslides when the snows melt. New precipitation patterns, characterized by unusually heavy downpours, have led to flash flooding and crop loss as fields are washed away.

Tajikistan is not a major contributor to global emissions, expelling just 5.1 million metric tons of CO_2 in 1998. Of this, 67 percent came from liquid fuels, 29 percent from gaseous sources, and 4 percent from solid fuels. The government of Tajikistan has developed a national mitigation plan as part of their participation in the UN Framework Convention on Climate Change, pledging to support sustainable agricultural practices, the development of renewable energy sources, the reduction of greenhouse gas emissions, and the protection and development of carbon sinks for mitigation.

SEE ALSO: Climate Change, Effects; Floods; Rain.

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Tanzania

TANZANIA, SITUATED IN east Africa just south of the equator, is a country characterized by high environmental, ecosystem, and cultural diversity. Much of Tanzania is also characterized by low-lying plains extending in from the coastal area in addition to the low-lying island archipelagos dominated by the islands of Mafia, Pemba, and Zanzibar. Inland there is the Eastern Arc Mountain chain, which is formed from heavily metamorphosed pre-Cambrian basement rocks, periodically uplifted by faulting and weathering over millions of years.

The mountains rise to 8,350 ft. (2,600 m.) in altitude, although maximum altitudes of 2,200 to 2,500 m. are more typical and cover an area of 2,085 sq. mi. (5,400 sq. km.). Farther west there is a high plateau of gently undulating terrain commonly between 4,920 and 6,561 ft. (1,500 and 2,000 m.). To the north of Tanzania, the landscape is dominated by the quite recent (2 million years old) volcanic chain that includes Kilimanjaro and Mount Meru.

Rainfall patterns in Tanzania are associated with the passage of the Intertropical Convergence Zone (ITCZ), which migrates from approximately 10 degrees S during January to 10 degrees N during July. The southeast trade winds are driven by annual oscillation of the ITCZ, bringing monsoonal rainfall to the east of Tanzania. Wet and dry seasons are clearly defined: Northern Tanzania experiences a rainy season from March to May and from October to December, whereas southern areas have one long rainy season from November to May. The elevational gradient on the eastern slopes of the Eastern Arc Mountains is relatively steep, whereas the western sides are relatively gently sloping. It is estimated that forests and woodlands cover 45 percent of Tanzania. The widespread flora on mountain islands led to the view of a continent-wide, archipelago-like center termed Afromontane; however, the distinct flora of the Eastern Arc Mountains suggests that they are floristically different from other African mountains. The altitudinal distribution of forest types comprises three major vegetation categories: upper montane forest, upper montane herb and shrub, and montane forest. Much of the coastal area is characterized by a coastal forest ecosystem that has been fairly heavily degraded, and the central part of the country is dominated by savanna bordered to the west by the Eastern Arc Mountains; these make up one of the world's hot spots of biodiversity because of their great variety of plant and animal species and their unusually high number of endemic species.

Relatively few palaeoecological records have been generated from Tanzania, with those records that have been produced being largely associated with the Rift Valley lakes located in the west of the country—the Empaki Crater Lake and an interesting ice core from the permanent ice on Kilimanjaro. One record from the Eastern Arc Mountains indicates relatively little ecosystem change over the past 40,000 years; this is in marked contrast with those records from the lowland lakes, which show expansion of montane forest into present savannah environments under the cold dry climate of the last glacial period. The Holocene, similar to other places in East Africa, is marked by human effects from around 4,000 years ago, and particularly after around 2,000 years ago as the agricultural transformation took place. Superimposed on this era are numerous climate change events, such

Lions in Tanzania stay close to their water source. Lion attacks have increased in rural Tanzania, the increase mirroring the dramatic rise in population, which grew by nearly 50 percent between 1988 and 2002 and encroached on the lions' habitat.

as the shift to more arid condition centered around 4,000 years ago and detected as a rapid increase in dust from Mount Kilimanjaro. The complicated picture of human-induced effects within a background of changing climate is something to be explored by generating new records on environmental history in a much underresearched part of the world.

SEE ALSO: Climate Change, Effects; Deforestation.

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Tata Energy Research Institute (TERI)

THE ENERGY AND Resources Institute (TERI) began in 1974 as the Tata Energy Research Institute. Motivated by concerns about finite, nonrenewable energy resources and pollution, Darbari Seth, a chemical engineer working for Tata Chemicals, proposed a research institute dedicated to the collection and dissemination of information regarding energy production and utilization. R.J.D. Tata, then chairman of the Tata Group, actively supported the institute, and TERI was formally established in Delhi in 1974. By 1982, TERI had expanded to include research activities in the fields of energy, environment, and sustainable development. As the scope of activities continued to widen, TERI maintained its acronym, although it was renamed the Energy and Resources Institute in 2003. Now, TERI's staff of over 700 conducts research and provides professional support to governments, institutions, and corporations worldwide. TERI's global leadership in efforts to mitigate the threat of climate change has been further endorsed by the election of its director-general, Dr. Rajendra K. Pachauri, as chairman of the Intergovernmental Panel on Climate Change in April 2002.

Although spawned by the Tata Group, the largest conglomerate in India accounting for 96 companies operating in over 40 countries and exporting to 140 countries, TERI operates as a not-for-profit, nongovernmental organization. TERI's work is sponsored by over 900 organizations (Tata Group included), and more than 200 organizations from 43 countries serve as partners in TERI projects.

The Energy and Resources Institute currently operates through divisions that include energy–environment technology, environmental and industrial biotechnology, biotechnology and management of bioresources, regulatory studies and governance, resources and global security, action programs, information technology and services, sustainable development outreach, and policy analysis. Examples of TERI-led research projects vary widely and include microbial bioremediation of oil spills and oil sludge deposits; design and dissemination of biomass gasifiers; wasteland reclamation and biodiesel production through Jatropha Curcas, a nonedible, oil-bearing crop; e-waste recycling; green buildings; and ecovillages.

The Asian Development Bank declared TERI a clean energy knowledge hub in 2006. As evidence of its dedication to clean energy, TERI established the Green Rating for Integrated Habitat Assessment, the first of its kind in India. Other work in this area includes research and training initiatives to advance large-scale use of renewable and clean energy, energy efficiency, and response to climate change in Asia and the Pacific region. Although large-scale projects with international cooperation remain key to many of TERI's goals, TERI also promotes empowering disadvantaged populations and generating employment through small-scale entrepreneurial endeavors.

The institute established the TERI University in 1998. It became a deemed university in India in 1999. The TERI University offers degree programs only at the master's and Ph.D. levels, and faculty and students participate in research conducted by the institute.

TERI continues to collect, generate, and make available a wide range of publications on issues related to its areas of research and training. Given its long and successful history of publication, the institute established TERI Press.

During its relatively brief existence, TERI has expanded to include research, training, and support efforts throughout India, and it claims to be the only institution in a developing country to have established a significant presence in North America, Europe, the larger Asian continent, Japan, Malaysia, and the Middle East.

SEE ALSO: Biomass; Climate Change, Effects; Intergovernmental Panel on Climate Change (IPCC); Japan; Malaysia; Nongovernmental Organizations (NGOs).

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Technology

TECHNOLOGY IS DEFINED as applying science to manipulate or change the human environment. Although it is usually thought to involve some form of machinery or physical equipment, technology can just as effectively be intangible in form, such as with management technology, which provides different ways of understanding how resources, including people, may be organized for more efficient production or operation. Historically, technology changed and developed very slowly around the world. However in more recent years, the improvements in infrastructure—and particularly in communications—have meant that technological advances have increased at an ever-quicker rate. Meanwhile, the dissemination of that technology has spread around the world, although there are still many hundreds of millions of people too poor to benefit from it. Nevertheless, for most people, especially in the Western world, life and society have been transformed completely by the technologies that have emerged over the last two decades.

Because the rate of change of new technological innovation continues to accelerate, it seems likely that life and society in the future will be at least as difficult to predict now as it would have been a few decades in the past. Because of its prevalence in society, its ability to reduce the time needed for generally undesirable domestic tasks, and its ability to improve leisure opportunities, among other attributes, most people welcome technology and believe it to be beneficial to their lives. However there are still individuals and groups of people who may, perhaps for ideological or religious reasons, reject the use of technology. Because global climate change has come to be associated with the use of technology and the energy required to power so much of it, technology as a whole has come to be regarded by some people as an enemy that must be resisted and eradicated. In the extreme case, there are people who believe that only by returning to a form of society in which all forms of technology are rejected can humanity survive the forthcoming environmental crisis.

Philosophers such as Michael Foucault, meanwhile, consider technology to be a tool most commonly used by the powered elites of society to suppress the masses. They would point out that the introduction of technology is customarily followed by the imposition of restrictions that prevent the majority of people from accessing the benefits of that technology. For example, internet technology in China is regularly used to spy on the activities of ordinary people and keep their discussions heavily monitored. This is an instance of technology being used to suppress people and to maintain the existing architecture of power. In contrast, it is possible to argue that the very same technology actually represents a liberation of people because of the many new ways it enables people to communicate with each other and to share information.

Most people tend toward a more moderate position, recognizing the better lifestyle that some aspects of technology provide and being unwilling to abandon these forms, while accepting the need for greater efficiency in the use of resources. They would be unwilling to voluntarily choose to forego the use of that technology to cause some future effects to abate. In other words, people will not vote for significant reductions in the use of personal technologies to reduce future damage caused by climate change. To change their minds, some activists believe that it is necessary to startle or scare people into realizing what sort of changes are likely in the future. Those more skeptical of those future changes, meanwhile, accuse such activists of regularly committing this act and concluding, as a result, that all calls for changes in behavior are overstated and, possibly, politically motivated. This argument has been successfully deployed, in that it has muddied the waters of debate and, hence, reduced the likelihood of future changes in behavior.

THE ROLE OF TECHNOLOGY IN ABATING CLIMATE CHANGE

Technology can be employed to abate current and future climate change in a number of ways. At a large or macrolevel, there are plans to place enormous mirrors into orbit around the earth so that they reflect light energy from the sun back out into space, reducing atmospheric temperature. At a medium or mesolevel is the attempt to develop new and cleaner technologies in terms of energy production, which would reduce carbon emissions. At a microlevel, there are the efforts to reduce resource use inefficiencies by such means as recycling waste products, turning off unattended electronic devices, and generally developing technologies to mitigate future climate change. The extent to which it is possible to abate future climate change by action at the microlevel is not clear, and many estimates vary widely.

Clearly, turning off unused computers or televisions that are idle will save some energy and reduce carbon emissions, but many people believe that this amount of saved energy will be dwarfed by the increased amount of emissions resulting from the rapid and rather dirty industrialization occurring in India and

Concurrent with the rise of technology is the growth of cities, such as Hong Kong, China, above. One of the principal causes of increased atmospheric heat is the presence of cities, especially large cities, across most of the inhabited world.

China, in particular. Indeed, there is an argument that because the effects elsewhere are so great, there is no point trying to reduce emissions on a personal level. This argument does not bear rational examination: in the first place, the reduction of the rate of acceleration of global warming must of itself be a necessary and important thing; second, the people and governments of India and China (and most of the rest of the world) are also aware of the problems of global climate change and are willing to do what they can to bring about changes in their own lives.

Other arguments suggest that changes at the microlevel can have significant changes in the extent of future climate change. The noted skeptical environmentalist Björn Lomborg, for example, has argued that one of the principal causes of increased atmospheric heat is the presence of cities, especially large cities, across most of the inhabited world. Cities are built or have organically grown, in general terms, to maximize population density and, as such, are dry areas without much greenery or standing water. Further, many of the buildings or infrastructure within cities are dark in nature and, as a result, absorb a great deal of energy in a needless fashion. The result is that cities are several degrees F/C or more hotter than surrounding areas. This problem fuels increased use of air conditioning systems and other energy use (e.g., for refrigerators and other cooling devices), which leads to a vicious cycle. Lomborg argues that low-technology solutions can reduce the urban effect: paint buildings white, introduce more water areas, replace some tarmac with grass, and so forth. Taking these steps may reduce the temperature in the local city areas by several degrees. This would have a knock-on effect, too, as in many cases political priorities are determined by urban electorates. As a consequence, demonstrating that technology—even comparatively low-technology solutions—can lead to a measurable improvement in quality of life, which might then lead to more positive sentiment toward the use of technology to improve future lifestyles.

THE SEARCH FOR ALTERNATIVE ENERGY SOURCES

Because it is the use of hydrocarbon fuels that leads to carbon dioxide emissions and is the largest contributor to global climate change, it follows that finding alternative forms of energy that do not emit carbon to the same extent would represent the best means of abating future climate change. Further, the world's reserves of hydrocarbon fuels are finite, and there is a need to develop alternatives if current and projected lifestyles are to be maintained in the future. It is not clear exactly when the reserves of oil will be depleted under current trends of usage, as it is possible (although increasingly less likely) that areas of significant previously unexploited reserves will be found, and probably more importantly, improvements in technology have made it possible to extract profitably existing reserves that have to date been too difficult or expensive to obtain. In addition, as the price of oil increases in general—and continues to increase as demand increases—with respect to supply, more and more known but problematic reserves will become commercially viable. Already, using oil-soaked earth in parts of Canada that were previously prohibitively expensive to process has become viable because of the effect of supply and demand. Other difficult-to-access reserves will, likewise, become more viable.

Nevertheless, although the figures are controversial and contested, it seems likely that all oil reserves will be exhausted within about 120 years, based on current rates of consumption. It is possible, although far from certain, that peak oil production has already been reached. Although declining supply relative to demand will stimulate some increased efficiency of use of oil, it is nevertheless clear that new forms of energy will need to be developed within the next few decades. Clean technologies such as wind and wave power are expected to make up an increasing part of a portfolio of alternative sources of energy. They already contribute significantly to the energy production of some European countries, although there are problems with nimbyism—or not in my back yard-ism—as people complain that wind turbines are unsightly and noisy. Solar panels have been used with moderate success in many parts of the world, particularly those areas with high levels of sunshine. However improvements in this technology are still needed. Photovoltaic cells have been used to collect power from the sun, and water pipes have been heated by placing them in the sun, but there is a need for more integrated solutions to ensure that a higher level of efficiency is achieved and also to reduce initial start-up costs, which may be high. This is likely to come about through regulation rather than market influences.

Other technologies that might be developed include the tapping of geothermal energy, which has been used for thousands of years in a nonsystematic manner, in the form of hot springs. There remains considerable scope for the further development of the use of geothermal energy on a more systematic basis. Hydroelectricity is a further form of alternative energy and it has been used effectively on many rivers. Countries such as China plan a massive increase in the number of hydroelectric stations, with attendant dams, on the rivers passing through its territory. This includes plans for as many as 12 dams on the River Mekong, for example. However this form of energy is problematic because of the effect on people living downstream of reduced flow of water and because of the effect of building large dams on the populations living in the vicinity, many of whom must be resettled—some of them forcibly. The ownership of a river passing through the territory of more than one country is also a problematic issue.

The one means of producing energy that is available without the consideration of geography is that of nuclear power. The technology involved is to employ certain heavy elements such as plutonium and uranium, which undergo atomic decay on a largely predictable manner, releasing considerable amounts of energy at the same time. A more advanced approach is to employ nuclear fission, which involves causing atoms to collide with each other so as to release more subatomic particles such as neutrons and, hence, more power. The amount of power, which is converted to electricity, that may be released through these processes is limited only by the availability of the appropriate heavy elements. These elements are scarce, and the existing amounts are controlled, although not always effectively. There is a need for control because of the radioactive nature of the substances involved, which makes them very dangerous to life, as well as the possibility that they may be used to create highly destructive nuclear bombs.

Many governments are planning to increase, perhaps quite significantly, their reliance on nuclear power. This causes problems because of the threat of an accident releasing nuclear material, as happened at Chernobyl in the Ukraine, causing thousands of deaths. The use of power plants in known earthquake zones is of particular concern. In addition, depleted uranium or other material, which is no longer productive, remains dangerously radioactive for many thousands of years, and it is not clear where that waste may be safely stored over the long term. There is also the potential problem that nations that develop nuclear power plants might also employ this knowledge and technology to develop nuclear weapons. One consequence of this is that there is widespread public concern about the use of nuclear energy and opposition to it in democratic countries. Even so, improvements in the technology of safety suggest that more governments will wish to augment their nuclear power production capacity and begin building new plants, knowing that it takes several years or more between deciding to construct such a plant and when power from it is ready to enter the grid.

MACROLEVEL TECHNOLOGY APPROACHES TO CLIMATE CHANGE ABATEMENT

Various macrolevel technologies have been suggested as a means of reducing climate change. These are generally very expensive and time-consuming to create and maintain and, hence, tend to be regarded as something of a last-ditch attempt. These technologies include placing large mirrors or reflective dust in space to absorb or reflect away the sun's energy, or to use huge series of tubes leading to the ocean floor, through which excess heat energy may be circulated. Many of these ideas derive from the United States, which has a long tradition of optimism in terms of technology and also large firms and organizations possessing the kind of capital necessary to develop and, in time, implement such solutions. Because none of these solutions has, to date, been operationalized, it is not yet clear whether all or any of them will in fact be viable. Nevertheless, it is becoming clear that companies are starting to realize the market opportunities emerging for green or clean technologies. At the individual level, technology will be consumed by households to meet their own mandated requirements; for example, in terms of recycling or energy use reduction. At the state level, in contrast, public-sector support of megaprojects can provide sustained funding for a number of years sufficient to underwrite very large research and development operations. Because these technologies are not yet proven to be feasible and may be extremely expensive in practice, it would be much more cost-effective to make extensive use of micro- and mesolevel technologies immediately rather than waiting for a last-ditch attempt to maintain the planet as a place for human life. This will require some sacrifices in the short and medium terms.

TECHNOLOGY AND REGULATION

The Montreal Protocol of 1987, which helped to resolve the problem of atmospheric ozone depletion, demonstrated the ability of states to work together to solve transboundary environmental issues effectively. Market-based attempts to achieve similar goals, for example, through creating markets in tradable carbon emission permits, have foundered without a strong institutional shaping of the rules of the market and supervision of its activities. Technologists around the world have created numerous efficiencies that would help abate future climate change but that will only be implemented when state regulation requires it to be introduced. Just as the numbers of deaths from road traffic accidents was reduced (proportionate to the amount of traffic) after governments introduced legislation requiring safety belts to be worn, so too have buildings become more resistant to earthquakes after stricter building codes were introduced. In countries such as Germany, new regulations about energy production enable households under certain conditions to produce and sell their own power, such as that generated from solar power, online, for example. Good regulations provide appropriate incentives to encourage people to behave in the desired way and disincentives to dissuade people from behaving in undesired ways. The extent to which this can affect behavior and make measurable changes to energy use may be seen in California, where state-level legislation, transparently introduced over a sustained period, has ensured that energy use per capita has not increased in a number of years, despite the significant amount of electronic consumer goods owned per household.

SEE ALSO: Alternative Energy, Overview. Alternative Energy, Solar.

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Tennessee

TENNESSEE IS 42,143 sq. mi. (109,150 km.) in size with inland water making up 926 sq. mi. (2,398 sq. km.) Tennessee's average elevation is 900 ft. (274 m.) above sea level, with a range in elevation from 178 ft. above sea level on the Mississippi River to 6,643 ft. (2,025 m.) at Clingman's Dome. The variety of topographic features includes mountains, forested ridges, cultivated valleys, rugged plateau with valleys cut by streams, and the Highland Rim (an upland plain surrounds the Nashville Basin, and the Tennessee River separates the Highland Rim from the relatively flat coastal plain in the western part of Tennessee that extends almost to the low-lying area on the Mississippi River, which forms Tennessee's western border). The major rivers are the Mississippi, the Tennessee River, and the Cumberland River, along with many tributaries. Natural lakes and reservoirs store water.

Tennessee has hot summers, mild winters, and abundant precipitation, with variations based on region. West Tennessee (the Gulf Coastal plain), Middle Tennessee (Highland Rim and Nashville Basin is made up of the Highland Rim [mountains] and East Tennessee [mountainous high region]). Average July temperatures range from less than 70 degrees F (21 degrees C) in the Blue Ridge region to 80 degrees F (27 degrees C) in Nashville and Memphis, and even summer nights can be warm and muggy in central and western Tennessee, with cooler temperatures in the eastern mountains. Average January temperatures range from freezing in the eastern mountains to 42 degrees F (22 degrees C) in the southwestern region. The highest temperature recorded in the state is 113 degrees F (45 degrees C) on August 9, 1930, and the lowest temperature recorded in the state is 32 degrees F (0 degrees C) on December 30, 1917. The average annual precipitation is 52 in. or 132 cm. (ranging from 60 in. or 152 cm. in mountain areas to 45 in. or 114 cm. in protected ridges and valleys). Severe blizzards rarely hit Tennessee, but some snow falls every year. West Tennessee receives about 5 in. (13 cm.), and the east can expect twice as much. The precipitation is made up of a combination of rain, snow, and sleet. Heavy rain falls in March and April, causing rivers to overflow their banks.

Tobacco is grown in much of the state. Western Tennessee is the largest agriculture region, with crops of cotton, corn, soybeans, tobacco, and others. Livestock (cattle, sheep, hogs, and poultry) predominates in the Nashville Basin, as well as dairy farming. Crops grown in the region are used to feed the livestock, except tobacco, which is a cash crop. Tennessee's electricity is generated by coal-fired, nuclear power, and hydroelectric plants.

Although climate models vary on predicted temperature increase for Tennessee, estimates range from 1–5 degrees F (1.8–9 degrees C) in all seasons. Precipitation is estimated to increase only slightly in winter, perhaps 10–30 percent in spring and autumn and by 10–50 percent in summer. This increased rainfall could increase flooding (already a concern in the mountains in eastern Tennessee, in unregulated streams, and in growing urban areas near Chattanooga, Nashville, and Memphis).

With changes in climate, the extent of forested areas in Tennessee could change little or decline slightly, though the types of trees would be likely to change. Pine and scrub oaks would replace eastern hardwoods. The success of tree planting in environmental restoration areas (as in around mines) might decrease. Increased temperatures could pose a risk of wildfires. The agriculture may change little, however, with cotton yields unaffected and corn and hay yields possibly increasing.

If rainfall and runoff increase in the Tennessee region, then higher stream flows and lake levels could benefit hydropower production, enhance recreational opportunities, and improve water availability for water supplies. Increased water flow would dilute pollutants, though increased runoff including pesticides and fertilizers may shift levels of contamination higher, with the river basins in western Tennessee being especially susceptible.

Flooding increases the possibility of contamination of water supplies by sediment erosion, increased levels of pesticides and fertilizers, and runoff from grazing, mining, and urban areas.

Human health risks include, but are not limited to, contracting certain infectious diseases from water contamination or disease-carrying vectors such as mosquitoes, ticks, and rodents. Warmer temperatures would increase the incidence of heat-related illnesses and lead to higher concentrations of ground-level ozone pollution causing respiratory illnesses (diminished lung function, asthma, and respiratory inflammation).

On the basis of energy consumption data from the Energy Information Administration, State Energy Consumption, Price, and Expenditure Estimates, released June 1, 2007, indicate Tennessee's total CO_2 emissions from fossil fuel combustion for 2004 were 125.38 million metric tons CO_2, made up of contributions from: commercial sources (3.72 million metric tons CO_2), industrial sources (20.41 million metric tons CO_2), residential sources (4.41 million metric tons CO_2), transportation sources (44.93 million metric tons CO_2), and electric power sources (51.90 million metric tons CO_2).

Tennessee joined the Climate Registry, a voluntary national initiative to track, verify, and report greenhouse gas emissions, with acceptance of data from state agencies, corporations, and educational institutions beginning in January 2008. The Tennessee Environmental Council is including climate change strategy in their meetings.

Tennessee participates in a program called Rebuild America—an organization committed to assisting state and local government and school systems to implement energy-saving improvements. The Tennessee Valley Authority (TVA) has developed a program called Green Power Switch that enables customers to purchase 150-kilowatt-hour blocks of renewable energy (making up about 12 percent of a typical household's monthly energy consumption). In addition, TVA must meet federal and other environmental statutes and regulations for air and water quality as well as managing the disposal of wastes (including hazardous materials). These regulations are becoming more stringent with clean air requirements and reducing greenhouse gas emissions.

Federal and state agencies are responsible for conservation inducing forest management and environmental protection including protecting against soil erosion and water and air quality.

SEE ALSO: Carbon Dioxide; Carbon Emissions; Climate Change, Effects; Greenhouse Gases.

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Tertiary Climate

THE TERTIARY PERIOD (ca. 66.4 to 1.8 million years ago [Ma]) was an interval of enormous geologic, climatic, oceanographic, and biologic change. It spans the transition from a globally warm world of relatively high sea levels to a world of lower sea levels, polar glaciation, and sharply differentiated climate zones. Over the past decade, however, it has become increasingly clear that Tertiary climatic history was not a simple unidirectional cooling driven by a single cause but a much more complicated pattern of change controlled by a complex and dynamic linkage between changes in atmospheric CO_2 levels and ocean circulation, both probably ultimately driven by tectonic evolution of ocean-continent geometry. Although satisfactory explanations for many aspects of Tertiary climate history are available, many areas remain incompletely understood.

The early Tertiary (Paleocene and most of the Eocene epochs, ca. 66–50 Ma) was characterized by a continuation of Cretaceous warm equable climates extending from pole to pole. Global temperatures may have been as much as 18–22 degrees F (10–12 degrees C) higher than present, and pole-to-equator temperature gradients were about 9 degrees F (5 degrees C) during the Paleocene, as compared with about 45 degrees F (25 degrees C) today.

The Paleocene-Eocene boundary (about 54 Ma) was marked by a geologically brief episode of global warming known as the Paleocene-Eocene thermal maximum (PETM), characterized by an increase in sea surface temperatures of 9–11 degrees F (5–6 degrees C), in conjunction with ocean acidification, a decline in productivity, and a large and abrupt decrease in the proportion of isotopically heavy terrestrial sedimentary carbon in the oceans. The PETM is thought to have lasted only about 170,000 to 220,000 years, with most of the temperature and isotopic change occurring in the first 10,000 to 20,000 years. Its causes remain unclear, but it was probably associated with dissolution of methane hydrates on the ocean floor, which would then have caused greenhouse warming. Possible triggers for this hydrate release include an increase in volcanism, leading to an increase in atmospheric CO_2 and consequent sudden initiation of greenhouse warming; a change in ocean circulation; or massive regional submarine slope collapse.

Global temperatures warmed still further during the early Eocene, reaching their highest levels of the past 65 million years during an interval sometimes called the early Eocene climatic optimum (52–50 Ma). Global cooling began during the early middle Eocene (ca. 50 Ma) and accelerated rapidly across the Eocene-Oligocene boundary (ca. 34 Ma), at which time Antarctic continental glaciation began. This shift is frequently referred to as a change from a greenhouse to an icehouse climate regime, and it was one of the most fundamental reorganizations of global climate known in the geological record.

Initiation of Antarctic glaciation has long been attributed to the tectonic opening of Southern Ocean gateways, especially the Drake Passage between South America and the Antarctic Peninsula, which allowed establishment of the Antarctic Circumpolar Current and the consequent isolation of the southern continent from warmer low-latitude waters. This has been questioned recently, however, as a result of the redating of the formation of these gateways, as well as modeling results that point to a greater role for reduced atmospheric CO_2.

Most estimates of early Cenozoic atmospheric pCO_2 range between two and five times the present values in the middle to late Eocene and then decline rapidly during the Oligocene to reach approximately present levels in the latest Oligocene. This decline in CO_2 may, in turn, have been at least partly a result of the tectonic uplift of the Tibetan plateau, beginning around 40 Ma, leading to increased rates of chemical weathering. Levels of CO_2 remained relatively constant throughout the Miocene, suggesting that the substantial climate changes during this time were driven by other factors, including changes in weathering or ocean circulation.

Global temperatures warmed again in the late Oligocene, followed by a brief (ca. 200,000 years) but deep glacial interval at the Oligocene-Miocene boundary (ca. 24 Ma). Temperatures then stabilized or slightly increased (punctuated by several more brief glacials), leading to what is sometimes referred to as the mid-Miocene climatic optimum around 17 to 15 Ma, during which time deep water and high-latitude sea surface temperatures were 11–18 degrees F (6–10 degrees C) warmer than at present. The causes of this warming are not clear, but they may have been related to increased northward oceanic heat transport in the North Pacific brought via intensified currents primarily triggered by narrowing of the Indonesian Seaway in the western equatorial Pacific.

Another major cooling occurred between 14.2 and 13.7 Ma and is associated with increased production of cold Antarctic deep waters and a growth spurt of the East Antarctic Ice Sheet, leading to an increased latitudinal temperature gradient and drying in midlatitudes. A further episode of aridity occurred between 8 and 4 Ma. This cooling trend continued into the Quaternary period, with a short warming interval in the early to mid-Pliocene (ca. 5–3.2 Ma), characterized by warmer sea and air temperatures across at least much of the North Atlantic region.

Northern Hemisphere ice sheets first expanded about 3.5 Ma, with a major pulse of growth occurring 2.5 Ma, at which time the Earth is usually said to have passed over a thermal threshold initiating the latest so-called Ice Age, in which mode the planet is still today. The initiation of Northern Hemisphere glaciation has been attributed to completion of the formation of the Central American Isthmus at around 3.5 Ma, which deflected warm low-latitude currents flowing westward from Africa northward into the Gulf of Mexico and through the Florida Straits to join the Gulf Stream. This strengthened Gulf Stream then transported more moisture to high latitudes, where it supplied an increase in snowfall, leading to increased albedo and temperature decline.

SEE ALSO: Ice Ages; Paleoclimates.

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Texas

IN A POST–WORLD War II climate of mass consumption, urban disinvestment, and the emerging dominance of the automobile as the preferred mode of transportation, Texas and its economy grew dramatically. Fleeing postindustrial urban decay and the loss of manufacturing economies, millions of Americans and immigrants flocked to the wide-open and nonunionized spaces of the southwest United States. Home to almost 25 million residents, the State of Texas ranks second only to California in population and is experiencing the largest net population growth of any state in the nation.

Driven by this continuing growth in population, diversifying economic development, persistent low-density suburban development, almost exclusive reliance on the automobile for transportation, and a warming climate, the demand for cheap and plentiful energy—and attendant emissions of greenhouse gases—is growing rapidly. Texas leads the United States in greenhouse gas emissions—40 percent of the national total—largely because of its reliance on existing coal-burning power plants.

In a recent study analyzing urban sprawl, Fort Worth/Arlington and Dallas metro areas rated 10th and 13th on the list of the nation's 83 most sprawling urban areas. Having increased by 30 percent over the past 10 years, the 2000 Environmental Protection Agency ozone National Ambient Air Quality Standard report estimated that Texas vehicle miles traveled would increase between 2007 and 2030 by over 44 percent, and Dallas/Fort Worth, Houston, and San Antonio metropolitan regions would remain in nonattainment for ground-level ozone. These urban areas are experiencing significant population growth, continuing sprawl development, and increasingly severe highway congestion that contribute significantly to their climate change effect.

The consequences for Texas of impending climate change are serious, especially given the already extreme nature of much of its regional weather.

CONSEQUENCES OF CLIMATE CHANGE

Texas exhibits a wide variety of climates within its boundaries, from subtropical in the southeast to high desert in the north and west. Although all regions are likely to experience an increase in mean annual temperature (both daily maximums and minimums) and increasing shortages of freshwater, other challenges faced by the state from climate change differ as a function of geography. Texas's 370 mi. (595 km.) of coastline will experience higher sea levels and resulting beach erosion, saltwater infiltration, and subsidence. Increased water temperatures in the Gulf of Mexico may result in more frequent and widespread algal blooms toxic to indigenous fish and plant species. Warmer ocean and Gulf waters will also contribute to the intensity, if not the frequency, of coastal storms and hurricanes.

Climate change also will result in a redistribution of rainfall across the state, significantly affecting agricultural economies and freshwater supplies available to increasingly urban populations. As it continues to drain its aquifers, Texas increasingly relies on freshwater captured in surface reservoirs. A future that is markedly warmer and drier in many regions of the state will jeopardize these supplies (as demonstrated by the drought that gripped the state in recent years). Increasing temperatures will contribute to already pronounced urban heat islands, resulting in increased frequency of heat-related illnesses and deaths, as well as in increased severity of isolated weather events, especially thunderstorms bearing isolated, flooding rains.

Agricultural and forestation patterns and productivity, staples of regional and state economies, will be disrupted not only by the changes in rainfall, increased uncertainty in available irrigation water, and higher mean temperatures but also by a changing variety of natural weeds and pests that will migrate northward as the climate warms. Infestations of insects new to Texas crops will result in reduced crop productivity and, as farmers try to respond, a likely increase in the number and environmental toxicity of herbicides and pesticides.

RENEWABLE ENERGY SOURCES

Although it confronts serious climate challenges across the state, Texas is also blessed with sources of renewable energy that have only begun to be exploited. It is famous for its scorching summers and sunshine that will "peel the chrome off a trailer hitch." The largest portion of its electricity needs are generated by coal-fired and nuclear power plants. Recently, the state backed away from approving the construction of as many as 11 new coal-fired power plants and is in the process of redefining its energy policies. As technological advances reduce the price and increase the efficiency of solar energy-generation devices, Texas, especially in its western reaches, will be able to capitalize on the abundant radiant energy provided by the sun. In addition, wind-generated electricity is being produced in increasingly economical quantities by west Texas wind farms. Although a transmission infrastructure is evolving to supply the state's urban demand, Texas ranks first in wind power generation among U.S. states. It is also the country's leading producer of biodiesel transportation fuel. Its leadership role was highlighted by the success of country music icon Willie Nelson in promoting locally produced BioWillie biodiesel fuel, primarily marketed for the long-haul trucking industry.

LOCAL ACTION

In the absence of a meaningful climate protection policy at the federal or state levels, many Texas cities have joined municipalities in other states in a variety of nongovernmental organization–led initiatives to reduce their carbon footprints and to lobby for action on climate change and related environmental issues at both the state and federal levels. Among other actions taken by Texas municipalities, 17 Texas cities—including Austin, Dallas, and San Antonio—have signed the U.S. Conference of Mayors Climate Protection Agreement

The Dallas metro area is rated 13th on the list of the nation's 83 most sprawling urban areas. Texas is home to almost 25 million residents, and is experiencing the largest net population growth of any state in the United States.

committing their respective cities to carbon dioxide reductions similar to those contained in the Kyoto Protocol. Both Austin and San Antonio are also members of the Cities for Climate Protection, a global campaign of local and regional entities led by the International Council of Local Environmental Initiatives Local Governments for Sustainability. Through process implementation and performance monitoring, these cities are committed to a rigorous accounting and reduction of their greenhouse gas emissions.

SEE ALSO: Alternative Energy, Wind; Land Use.

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Thailand

LOCATED IN SOUTHEAST Asia, Thailand has a land area of 198,115 sq. mi. (513,115 sq. km.), with a population of 62,828,700 (December 2006) and a population density of 317 people per sq. mi. (122 people per sq. km.). Bangkok, the capital and the largest city, has a population of 6,593,000 and a population density of 9,418 per sq. mi. (3,630 per sq. km.). Traditionally, the economy of Thailand has been agricultural, and 34 percent of the land is arable, with an additional 2 percent used as meadows and pasture. With the increase in the tourist industry, as well as manufacturing, the importance of agriculture has declined, but it remains the country's major employer. Some 30 percent of the country is forested, with the timber industry being heavily regulated, although there are regular allegations of illegal logging.

Thailand has a relatively low per capita rate of carbon dioxide emissions—1.8 metric tons in 1990, rising steadily to 4.28 metric tons per person by 2004. Some 92.3 percent of the electricity in the country comes from fossil fuels, with most of the remainder drawn from hydropower. The heavy use of automobiles, and also private generators, has led to 56 percent of the carbon dioxide emissions from the country being from liquid fuels, with 15 percent from gaseous fuels and 21 percent from solid fuels. Some 8 percent of Thailand's carbon dioxide emissions come from the manufacture of cement.

In terms of the sector causing the carbon dioxide emissions, 38 percent comes from the generation of electricity, with air conditioning—especially for the tourist sector—being a very important part of the demand. Some 33 percent comes from transportation, with the traffic problems in Bangkok often leading to a pall of smog in the city. Some 25 percent of carbon dioxide emissions come from manufacturing and construction, with the remaining 3 percent from residential use.

Thailand can best be described as tropical and humid for the majority of the country during most of the year. The area of Thailand north of Bangkok has a climate determined by three seasons while the southern peninsular region of Thailand has only two. In northern Thailand the seasons are clearly defined. Between November and May the weather is mostly dry; however, this is broken up into the periods November to February and March to May. The later of these two periods has the higher relative temperatures, although the northeast monsoon does not directly affect the northern area of Thailand, it does cause cooling breezes from November to February. The other northern season is from May to November and is dominated by the southwest monsoon, during which time rainfall in the north is at its heaviest.

The southern region of Thailand really has only two seasons— the wet and the dry. These seasons do not run at the same time on both the east and west side of the peninsula. On the west coast the southwest monsoon brings rain and often heavy storms from April through October, while on the east coast the most rain falls between September and December.

Overall the southern parts of Thailand get by far the most rain with around 2,400 millimeters

Driving during a monsoon in Thailand. The Boxing Day tsunami in Thailand in 2004, which resulted in the deaths of an estimated 8,200 people, including many hundreds of foreign tourists, has been partially blamed by some experts on climate change.

every year, compared with the central and northern regions of Thailand, both of which get around 55 in. (1,400 mm.).

Thailand has been heavily affected by global warming and climate change. An increase in flooding in southern Thailand has resulted in a rise in the prevalence of insect-borne diseases such as malaria and dengue fever. The Boxing Day tsunami in 2004, which devastated the Phi Phi Islands and other islands along Thailand's Indian Ocean coastline, such as Ko Tapu, and resulted in the deaths of an estimated 8,200 people, including many hundreds of foreign tourists, has been partially blamed by some experts on climate change. The gradual bleaching of coral reefs in that region, and also in the Gulf of Thailand, is certainly attributable to global warming.

The Thai government took part in the United Nations Framework Convention on Climate Change, signed in Rio de Janeiro in May 1992. It signed the Kyoto Protocol to the UN Framework Convention on Climate Change on February 2, 1999, and it was ratified on August 28, 2002, entering into force on February 16, 2005.

SEE ALSO: Climate Change, Effects; Floods; Tsunamis.

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Thermocline

THE THERMOCLINE IS the region of the ocean where temperature decreases most rapidly with increasing depth. It separates the warm, well-mixed upper layer from the colder, deep water below. A thermocline is present throughout the year in the tropics and middle latitudes. It is more difficult to discern in high latitudes, where temperature is more uniform with depth. The presence of a very shallow thermocline in the eastern equatorial Pacific Ocean has important implications for global climate.

The thermocline exists because the ocean absorbs most of the sun's heat in a shallow layer near the surface. The heat absorbed from the sun increases the temperature of the surface relative to that of the deep ocean, maintaining the thermocline. This is in contrast to the atmosphere, where a much larger portion of incident solar radiation passes through to the Earth's surface.

Two important properties of the thermocline are its depth and its strength, or how rapidly temperature decreases with increasing depth. The thermocline's depth is influenced by the winds at the surface of the ocean. In the Atlantic and Pacific oceans, surface winds push warm surface water away from the equator toward the poles, bringing the thermocline close to the surface at the equator.

Water that diverges at the equator accumulates in the subtropics, increasing the depth of the thermocline there. The thermocline is generally (82 to 656 ft. (25 to 200 m.) deep in the equatorial regions and up to 3,281 ft. (1,000 m.) deep in the subtropics.

The thermocline is strongest in the tropics and weakest in high latitudes. This reflects the fact that the surface temperature of the ocean generally decreases from the tropics to the poles, whereas the temperature of the deep ocean is nearly the same at all latitudes. As a result, the temperature contrast between the upper ocean and the deep ocean is greatest in the tropics. The temperature can drop by as much as 18 degrees F (10 degrees C) in less than 164 ft. (50 m.) in the tropical thermocline.

In the extratropical oceans, the strength and depth of the thermocline vary from season to season. There is a main thermocline throughout the year between 656–3,281 ft. (200–1,000 m.). During summer, the sun heats the ocean's surface more strongly than in winter. Most of the additional heat is absorbed in a very shallow surface layer, generating a sharper "seasonal" thermocline above the main thermocline. The seasonal thermocline is similar to the tropical thermocline in terms of its strength and depth. It erodes in the winter as the surface cools relative to the temperature in the main thermocline.

TROPICAL OCEANS

The existence of a strong and shallow thermocline in the tropical oceans has important implications for climate. In the equatorial Pacific Ocean, westward surface winds lead to an accumulation of warm surface water in the west, depressing the thermocline there and raising it to near the surface in the east. The shallow thermocline in the east enables cold, nutrient-rich water to be mixed upward into the surface layer. Every few years the thermocline in the eastern equatorial Pacific deepens in association with an El Niño event. The mixing of cold, nutrient-rich thermocline water into the surface layer is reduced, the surface temperature of the eastern equatorial Pacific Ocean increases, and biological productivity decreases. The warmer surface temperatures associated with El Niño affect atmospheric circulation in the tropics and alter weather patterns throughout the world.

The depth of the eastern equatorial Pacific thermocline has varied significantly in association with changes in global climate. For example, during the early Pliocene period (between 4.5 and 3 million years ago; the most recent period with global temperatures significantly higher than today), the eastern Pacific thermocline was much deeper than it is today, much like it is during a modern El Niño event.

SEE ALSO: El Niño and La Niña; Mixed Layer; Wind-Driven Circulation.

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Thermodynamics

THE SCIENCE OF thermodynamics, a branch of physics, aims to describe transformations in energy. Thermodynamics comprises three laws. The first holds that energy can neither be created nor destroyed. Energy in various forms may be transformed into heat (thermal energy) and heat may be transformed into another form of energy so long as the total energy in the system remains constant. The second law states that entropy, a measure of the amount of energy dissipated as heat, increases over time in a closed system. The conversion of energy into heat increases the entropy of a system and the dissipation of heat likewise increases the entropy of a system. The third law states that as temperature approaches absolute zero, the theoretical minimum temperature in the universe, entropy approaches a maximum.

The first law of thermodynamics accounts for the relative constancy of the climate, averaged over long durations. Were Earth simply a reservoir nergy in the form of sunlight, it would heat up to a very high but finite temperature. Earth does not heat up to this magnitude because it radiates heat back into space. The dissipation of energy as heat, according to the second law of thermodynamics, describes the Earth's shedding of radiant energy received from the sun as heat. This law, functioning as a heat accountant, is at the heart of understanding the role of heat in determining the climate. The third law of thermodynamics does not operate as long as the Sun generates energy. Rather, the third law anticipates the end of the universe. The Sun will one day burn out. Bereft of its heat, Earth's climate will be eternally cold, as its temperature approaches absolute zero. Not only will the Sun be extinguished, but all stars in the universe will one day burn out. The heat from these stars will dissipate in all directions in the universe, bringing the temperature, uniform throughout the universe, near absolute zero.

The science of thermodynamics traces the origin of energy in the solar system to the Sun. Energy from the Sun is the basis of Earth's climate, but not all sunlight reaches Earth. The thermosphere lies 190 mi. (306 km.) above Earth's surface, and is the outermost layer of the atmosphere. It absorbs ultraviolet light so efficiently that its temperature rises as high as 570 degrees F (299 degrees C). This conversion of the sun's radiant energy into thermal energy obeys the second law of thermodynamics. The next layer of the atmosphere, the mesosphere, is 50 mi. (80 km.) above earth. Its temperature, cooler than the thermosphere, is 200 degrees F (93 degrees C). Carbon dioxide (CO_2) in the mesosphere absorbs infrared light as heat, and that light radiates from Earth back into space. CO_2 molecules absorb a portion of this light before it reaches space. The larger the number of CO_2 molecules, the more heat they will absorb. The heating of the atmosphere by the absorption of infrared light causes the Greenhouse Effect, the warming of Earth's climate. Beneath the mesosphere is the ozone rich stratosphere, roughly 15 mi. (24 km.) above Earth. The ozone in the stratosphere blocks some 90 percent of sunlight from reaching Earth. Ozone, like the thermosphere, absorbs ultraviolet light. Beneath the ozone layer is the troposphere, a variable layer 5 mi. (8 km.) thick at the poles and 20 mi. (32 km.) thick at the equator. The troposphere holds water vapor, which absorbs both infrared and ultraviolet light, heating the atmosphere. These layers of the atmosphere both absorb and radiate heat. The heat that they radiate either scatters into space or reaches Earth.

Earth absorbs sunlight, chiefly at the equator. This sunlight, in the form of heat, moves to the poles through the currents of the oceans and air. This distribution of heat from an area of greater concentration (the equator) to a region of lesser concentration (the poles) obeys the second law of thermodynamics. Heat supplies the energy for the movement of the oceanic and air currents, which in turn transform the potential energy of stasis into the kinetic energy of motion. On an idealized Earth on which the oceans and air distributed heat evenly throughout the planet, heat would reach thermodynamic equilibrium, the point at which entropy would be at a maximum. Earth is much less efficient than this idealized model. For all the motion of the oceanic and air currents, heat nevertheless concentrates at the equator, which is always warmer than the poles. The waters at the equator hold enormous amounts of heat. Because the oceans liberate their heat slowly, heat accumulates at the equator and is slowly transferred toward the poles.

In accord with the second law of thermodynamics, entropy would increase as heat moves from equator to poles, but the Sun continuously adds heat to Earth, keeping the equator warmer than the poles. Entropy does not increase because the equator remains warmer than the poles. Without the oceanic and air currents, heat would accumulate at the equator and would not circulate to cooler regions of Earth. The currents therefore perform an important function in carrying heat from the equator to temperate and cold latitudes.

Earth and the atmosphere reflect roughly one-third of the sunlight they receive and radiate the other two-thirds into space. Earth sheds the same amount of heat as it receives, keeping earth on average at 60 degrees F (16 degrees C). By contrast outer space, which has no atmosphere to absorb heat, is much colder at minus 454 degrees F (minus 270 degrees C). Earth absorbs sunlight as ultraviolet and visible light and continually radiates it back into space as infrared light.

Earth also reflects light back into space. The oceans reflect half the sunlight they receive, whereas ice and fresh snow reflect 90 percent. In accord with the second law of thermodynamics, entropy decreases when Earth absorbs heat, and increases when the oceanic and air currents diffuse heat to other regions of the planet. Similarly entropy increases when Earth reflects light back into space, thereby dissipating heat.

Entropy is least in equatorial waters because they retain heat and slowly liberate it to other regions of Earth. Heat is not evenly-distributed in equatorial waters, as thermodynamic equilibrium would suggest. In holding heat, the oceans at the equator moderate the climate, keeping lands near them warmer than inland stretches of territory.

The land warms four times faster than the oceans; the air warms faster still. Land and air also radiate heat faster than the oceans. The climate of a desert underscores the rapidity of heating and cooling on land. Temperatures in a desert rise rapidly during the day, often surpassing 100 degrees F (38 degrees C). At night a desert cools with equal speed, dipping as low as freezing. In accord with the second law of thermodynamics, entropy decreases as a desert absorbs heart and increases as it dissipates heat.

Warm climates hold heat not only in water and land, but also in air. Warm air holds more moisture than cool air in the form of water vapor, a greenhouse gas. Water vapor holds more heat than CO_2, methane, other greenhouse gases. Water in all three phases absorb and emit heat. Ice absorbs the least heat and reflects the most sunlight back into space. Liquid water and water vapor are efficient reservoirs of heat.

The laws of thermodynamics work because Earth and its atmosphere absorb and radiate heat. One might argue that the absorption and radiation of heat give Earth its distinctive characteristics and its ability to sustain life.

SEE ALSO: Climate; Greenhouse Effect.

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Thermohaline Circulation

THERMOHALINE CIRCULATION IS global oceanic circulation generated by buoyancy fluxes resulting from heat and freshwater exchange between the ocean, atmosphere, cryosphere, and land. External forcing leading to an increase in water density (i.e., cooling or salinity rise) causes the sinking of more dense water (so-called thermohaline convection) and compensating transport of more light shallower waters of the upper mixed layer and thermocline. This process forms thermohaline overturning, which is one of the principal mechanisms of meridional heat transport in the world's ocean and global coupled ocean-atmosphere system.

Thermohaline circulation is characterized by two regimes, as was first pointed out by Henry Stommel. They are caused by thermal and haline effects and, in turn, account for large-scale temperature and salinity distribution in the World Ocean and, hence, influence the global climate. In general, in recent climate conditions, just thermal overturning circulation prevails in the world oceans, because global thermohaline circulation is formed mostly by the sinking of cold high-latitude waters and the compensating transport of warm shallower water. In general, there are two principal sources of deep and bottom waters. They are in the North Atlantic and Antarctic regions, respectively. These sources produce North Atlantic deep water (NADW), the core of which is at 1.2 to 1.5 mi. (2 to 2.5 km.), and Antarctic bottom water (its core deepens below 2.5 mi. [4 km.]). Haline circulation prevails in some specific regions of the world oceans, such as in the semiclosed Black and Red seas. The effect of salinity changes on the density field is also enhanced in subtropical oceanic regions, especially in the subtropical Atlantic, which is close to the Sahara desert. There, the upper mixed layer depth is mostly controlled by thermohaline convection as a result of salinity effects.

Thermohaline and superimposed wind-driven forcing has caused recent large-scale general oceanic circulation. The relative importance of these two sources for integral volume transport of principal large-scale oceanic currents varies from one region to another. In the North Atlantic, for instance, thermohaline and wind-driven shares in the general circulation of the upper 1.5 mi. (2 km.) layer are discussed in a recent study by Alexander Polonsky.

Global warming may cause, in principle, a change in circulation regime as a result of ice/glacier melting and increased freshwater input into the polar zone of the North Atlantic. This may lead to surface water lightening and blocking of thermohaline overturning. The Gulf Stream should dramatically weaken as a result of that. Such a regime has been called thermohaline catastrophe because it should be accompanied by strong climate shift in the North America and Europe. It is expected that a new climate will be much more severe and will be accompanied by much more frequent and strong North Atlantic cyclones because even just eddy meridional heat transport prevails in the midlatitude atmosphere, and it must now compensate for the reduced meridional thermohaline heat transport in the ocean after thermohaline catastrophe. However, as follows from recent multimodel simulations published by Ronald Stouffer and coauthors, the likelihood of thermohaline catastrophe happening in the next 100 years is quite small, taking into account recent tendencies of ice/glacier melting.

As follows from the simulation results of Stefan Rahmstorf, during the Last Glacial Maximum (about 21,000 years ago), thermohaline circulation was characterized by more shallow meridional cell and reduced meridional heat transport in the North Atlantic. The core of NADW was at about 1 km. In general, this was the result of severe ice conditions in the North Atlantic, where NADW has being produced. Different paleodata analyzed recently by Jean Lynch-Stieglitz and coauthors (2007) confirm in part such a scenario.

There is some evidence that blocking thermohaline circulation in the North Atlantic occurred about 8,200 years ago, just after the last glacier period. Most likely, it was a result of a plume of freshwater from juvenile lakes that rose in the end of a glacier period. Another possibility is the relatively fast melting of an armada of icebergs spreading from a Greenland glacier. However, it has not been proven by the analysis of deep ocean sediments provided by Christopher Ellison and coauthors (2006).

SEE ALSO: Abrupt Climate Changes; Modeling of Ocean Circulation; Modeling of Paleoclimates; Mixed Layer; Thermocline.

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Thermosphere

THE EARTH IS surrounded by a blanket of air, called the atmosphere. The atmosphere is a thin layer of gases that envelope the Earth. The gases are held close to the earth by gravity and the thermal movement of air molecules. Life on Earth is supported by the atmosphere, solar energy, and the magnetic fields. Five layers have been identified in the atmosphere, using thermal characteristics, chemical composition, movement, and density. The atmosphere is divided into the troposphere, the stratosphere, the mesosphere, the thermosphere, and the exosphere. The thermosphere, from the Greek word (thermos) for heat, is the fourth atmospheric layer from Earth, separated from the mesosphere by the mesopause. It begins about 50 mi. (80 km.) above the Earth and is the layer of the atmosphere directly above the mesosphere and below the exosphere. The lower part of the thermosphere, from 50 to 342 mi. (80 to 550 km.) above the Earth's surface, contains the ionosphere, which is the region of the atmosphere that is filled with charged particles. Beyond the ionosphere, extending out to perhaps 6,214 mi. (10,000 km.), is the exosphere.

The Earth's thermosphere is the layer of the atmosphere that is first exposed to the sun's radiation and so is first heated by the sun; it is the hottest layer of the atmosphere. Within the thermosphere, temperatures rise continually to well beyond 1,832 degrees F (1,000 degrees C). In the thermosphere, ultraviolet radiation causes ionization. At these high altitudes, the residual atmospheric gases sort into strata according to their molecular mass. Thermospheric temperatures increase with altitude as a result of the absorption of highly energetic solar radiation by the small amount of residual oxygen present. Temperatures in the thermosphere are highly dependent on solar activity. Radiation causes the air particles in this layer to become electrically charged, enabling radio waves to bounce off and be received beyond the horizon.

The few molecules that are present in the thermosphere receive extraordinary amounts of energy from the sun, causing the layer to warm to high temperatures. Air temperature, however, is a measure of the kinetic energy of air molecules—not of the total energy stored by the air. The air is so thin that a small increase in energy can cause a large increase in temperature. Because the air is so thin within the thermosphere, such temperature values are not comparable to those of the troposphere or stratosphere. Again, because of the thin air in the thermosphere,

The Northern Lights occur in the thermosphere, which is the fourth atmospheric layer from Earth. It is the first layer of the atmosphere that is exposed to the sun's radiation, so it is the hottest layer of the atmosphere.

scientists cannot measure the temperature directly. Instead, they measure the density of the air by how much drag it puts on satellites and then use the density to determine the temperature.

Although the measured temperature is very hot, the thermosphere would actually feel very cold to humans because the total energy of the few air molecules residing there would not be enough to transfer any appreciable heat to our skin. In addition, it is so near vacuum that there is not enough contact with the few atoms of gas to transfer much heat. A normal thermometer would read significantly below 32 degrees F (0 degrees C). The dynamics of the lower thermosphere are dominated by the atmospheric tide, which is driven, in part, by the very significant diurnal heating.

The atmospheric tide dissipates above this level because molecular concentrations do not support the coherent motion needed for fluid flow. The International Space Station has a stable orbit within the upper part of the thermosphere, between 199–236 mi. (320–380 km.). The Northern Lights also occur in the thermosphere.

SEE ALSO: Atmospheric Composition; Atmospheric Vertical Structure; Climate Change, Effects.

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Worldwide, it is estimated that 50,000 thunderstorms occur every day, and over 18 million occur per year.

Thunderstorms

A THUNDERSTORM IS a localized storm that is produced by a cumulonimbus cloud and always contains thunder and lightning. Thunderstorms form in conditionally unstable environments, meaning there is cold, dry air aloft over warm, moist surface air. This causes the air to become buoyant and allows for rising air motion. A lifting mechanism is also needed to start the air moving. Such lifting mechanisms include surface heating, surface convergence, lifting caused by mountains, or lifting along frontal boundaries.

The heat and the humidity of the summertime can often produce what are called ordinary thunderstorms or air mass thunderstorms. These are the type of thunderstorms that seem to suddenly pop up, last less than an hour, and are rarely severe. A severe thunderstorm is defined by the National Weather Service as having three-quarter-inch diameter hail or surface winds exceeding 58 mi. (93 km.) per hour or producing a tornado. Ordinary thunderstorms also do not usually have excessive vertical wind shear, meaning that the wind speed or direction does not change greatly with height. They usually go through a series of stages from birth to decay. The first stage is known as the cumulus stage and is dominated by updrafts. The updrafts bring in warm, moist air, which then cools and condenses as it rises. When the clouds further develop and precipitation starts to fall, a downdraft is produced. This marks the beginning of the mature stage, which is the most intense stage. During this stage, the strong updraft is still present, supplying the warm, moist air, but the strong downdraft is also evident. The gust front is located at the boundary of the updraft and the downdraft. This is an area where the wind velocity changes rapidly. Eventually, the downdraft will cut off the supply of warm, moist air in the updraft. When this occurs, typically 15 to 30 minutes after the mature stage, the thunderstorm will start to weaken and enter the dissipating stage as a result of the deprivation of energy from the updraft.

If the vertical wind shear increases, this allows for the thunderstorm to tilt. Therefore, the downdraft is less likely to cut off the updraft, which allows the thunderstorm to persist longer. Sometimes the downdraft can slide underneath an updraft, which can produce multiple cell thunderstorms or simply multicell storms. If the vertical wind shear becomes extremely strong, the shear can produce a large rotational thunderstorm known as a supercell. Supercell thunderstorms are large storms that last longer than an hour and are often severe and can produce tornadoes. The strong wind shear creates horizontal spin, which can then rotate vertically when the updraft encounters the vortex.

Thunderstorms can occur as a line of multiple-cell thunderstorms known as squall-line thunderstorms. These usually form along or slightly ahead of a cold front. The line of thunderstorms can extend over 500 mi. (805 km.) and often exhibit severe characteristics. When thunderstorms occur in a large circular pattern, they are known as a mesoscale convective complex, or MCC. An MCC is a large, convectively driven system that usually lasts more than 12 hours and covers more than 38,610 sq. mi. (100,000 sq. km.) Many thunderstorms are embedded within the MCC and often form during the summer in the Great Plains. As warm, moist air is brought in from the Gulf of Mexico, the tops of the very high clouds cool rapidly by emitting radiation into space. This makes the atmosphere very unstable and allows for the MCCs to generate and persist. Because MCCs are usually located underneath weak upper-level winds, they tend to travel very slowly, which can cause locally heavy rains and flooding events.

All thunderstorms have lightning—the electrical discharge—and thunder—the resulting shockwave produced by the extreme heating. Lightning has a temperature of approximately 54,000 degrees F (29,982 degrees C), which is five times hotter than the surface of the sun. Lightning occurs during the mature stages of thunderstorms and can appear within a cloud and travel from one cloud to another or from cloud to ground. Most lightning strikes are within a cloud.

Worldwide, it is estimated that 50,000 thunderstorms occur every day, and over 18 million occur per year. Thunderstorm frequency is most common in the tropics, especially near the Intertropical Convergence Zone, which is an area of low pressure near the equator. Thunderstorms occur with lower frequency in drier regions near 30 degrees N/S, which is dominated by the subtropical high pressure, as well as in the polar regions. In the United States, thunderstorm activity is predominantly found in the southeast, with a maximum located over Florida. Florida has over 90 days of thunderstorms per year as a result of the convergence of wind from the Gulf of Mexico and the Atlantic.

Thunderstorms release a massive amount of latent heat energy through condensation. This is a major mechanism for the Earth to transfer heat from areas of energy surplus near the equator to areas of energy deficit toward the poles. It is generally agreed that increased greenhouse gas emissions are causing global temperatures to rise. With increased global surface temperatures, it is expected that more clouds will be produced with increased evaporation rates. However, the potential effects of increased cloud coverage and what it means for potential rainfall and thunderstorm activity is not fully understood.

The degree to which the increased aerosols and clouds will reflect solar energy back into space is the main discrepancy. Some scientists think that global warming will increase evaporation rates, thereby producing more precipitation. Others have speculated that with the increased clouds and aerosols in the atmosphere, this will greatly reduce the amount of radiation reaching the earth. As a result, this will make the lower and midlevels of the atmosphere warmer, therefore reducing evaporation rates. Because the thermal gradient, that is, the difference in temperature, will be reduced from the surface to the atmosphere, the reduced evaporation rates could then potentially make for drier conditions.

SEE ALSO: Climate Change, Effects; Rain; Rainfall Patterns.

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Togo

THIS WEST AFRICAN country, officially the Togolese Republic, is located between Ghana and Benin, with a northern border with Burkina Faso. It has a land area of 21,925 sq. mi. (56,790 sq. km.), with a population of 6,585,000 (2006 est.) and a population density of 280 people per sq. mi. (108 people per sq. km.). Some 38 percent of the country is arable, with a further 4 percent used for meadows and pasture and another 28 percent of the land forested.

For the electricity production in Togo, 97.9 percent comes from fossil fuels, with 2.1 percent coming from hydropower. These generate 102 million kilowatt-hours (kWh; in 2001), with 520 kWh, largely drawn from hydropower, more imported from Ghana. Although before World War I the Germans tried to establish Togoland (as it was then called, including part of what is now eastern Ghana) into a model colony, the country has remained relatively poor, with its carbon dioxide emissions being 0.2 metric tons per person in 1990, rising gradually to 0.38 metric tons per person in 2003. About 68 percent of the country's carbon emissions come from liquid fuels, with the remainder coming from the manufacture of cement. By sector, 37 percent comes from manufacturing and construction, with 35 percent from transportation and 14 percent from electricity and heat production. The high figure for transportation is because there is only one train line, going from the capital, Lomé, to Blitta, with very few other forms of public transport.

The coastal part of Togo, around Lomé, is low lying, and as such, it is at risk from global warming and climate change. The rising average temperatures are also likely to lead to increased desertification in the north of the country. The Togo government ratified the Vienna Convention in 1991 and took part in the United Nations Framework Convention on Climate Change, signed in Rio de Janeiro in May 1992. The government accepted the Kyoto Protocol to the UN Framework Convention on Climate Change on July 2, 2004, with it coming into force on February 16, 2005.

SEE ALSO: Climate Change, Effects; Deserts.

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Tonga

LOCATED IN THE South Pacific, the Kingdom of Tonga has a land area of 289 sq. mi. (748 sq. km.), with a population of 100,000 (2006 est.) and a population density of 396 people per sq. mi. (153 people per sq. km.). The country consists of 169 islands, but only 36 of these are permanently inhabited. With 24 percent of the country listed as arable, some 6 percent is used for meadows and pasture, with 12 percent of the country being forested; Tonga has a very restricted timber industry program.

Tonga also has a low per capita rate of carbon dioxide emissions, with 0.8 metric tons per person in 1990, rising to 1.12 metric tons by 2003, ranking Tonga 136th in the world in terms of emissions. Although the electricity production in the country is low, it is all generated from fossil fuels. With all the country's carbon dioxide emissions coming from liquid fuels, this accounts for not just electricity production but also the use of automobiles and small household or business generators.

Global warming and climate change are already having a major effect on Tonga, with the flooding of parts of the country, including a number of the uninhabited islands, and the very real risk of large parts of the country being lost as the water level rises. In addition, there is a problem over the alienation of arable land, deforestation leading to soil erosion, and off-shore coral reef bleaching and loss of marine life.

The Tonga government took part in the United Nations Framework Convention on Climate Change, signed in Rio de Janeiro in May 1992 and ratified in 1998, in the same year as the ratification of the Vienna Convention. The current Tonga government has not expressed a position on the Kyoto Protocol to the UN Framework Convention on Climate Change.

SEE ALSO: Climate Change, Effects; Floods.

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Toronto Conference

SCIENTISTS FROM VARIOUS international organizations, such as the World Meteorological Organization in Geneva, met with their peers in groups at various locations for three years. Following the signing of the United Nations Vienna Convention on the Protection of the Ozone Layer (1985) and the Villach Conference (1985), these meetings helped to develop the basis for further action. From the discussions at these meetings, a scientific accord on the main aspects of how much climate warming can be expected emerged. The confluence of this emerging consensus and other events led to the Toronto Conference in 1988.

The scientists' efforts gained the support of the United Nations, the World Meteorological Organization, the Canadian government, and other international organizations. The scientists then came together in Toronto, Canada, from June 27 to 30, 1988. In attracting national policymakers as well as 300 scientists from 46 countries and organizations, this conference became the first such international conference to combine science and policy.

Entitled the International Conference of the Changing Atmosphere: Implications for Global Security, the meeting highlighted atmospheric issues in a comprehensive way. The concern for the potential damage to the planet was compared with the consequences of nuclear war, and the scientific consensus at the conference astonished its chair, Stephen Lewis, who was then Canada's ambassador to the United Nations. Lewis also brokered the strongly worded final declaration. Identifying the existing situation as "an unintended, uncontrolled, globally pervasive experiment," the Conference Statement claimed that the consequences of this experiment would be second only those of a global nuclear war.

Recognizing that attempts to address issues affecting the atmosphere as a whole had been fragmentary to date, the Toronto Conference took a more global approach. The initiative was to integrate the existing Vienna Convention (1985) and the 1979 Geneva Convention on Long-Range Transboundary Air Pollution and to provide a basis for including issues that had not yet been addressed or recognized. Such an integrated approach to considering the atmosphere as a whole would conceivably permit a more complex approach to interrelated issues and solutions. As such, this initiative raised the possibility of a comprehensive Law of the Air.

RECOMMENDATIONS

The comprehensive approach and wide representation enabled attention to be paid to the scientific, economic, and social concerns. The attendees generated specific calls for action to governments, industry, and nongovernmental organizations. Working groups within the conference made specific recommendations to address a wide range of issues that were related and relevant to the health of the global atmosphere.

Issues that were recognized were those that arose both directly out of usage of the atmosphere and indirectly, through human effects on land and water. The atmospheric effects of the manner and form of human settlement—including the increasing urbanization of populations and acid rain—were directly relevant. Indirect atmospheric effects resulted from the full range of human activities including food production, industry, energy usage, trade, and investment.

Changing climate and human effects on coastal and marine resources were also pertinent. Human decision making involving forecasting, uncertainty, futures, and geopolitical issues—higher-order considerations resulting from the integration of programs and legal issues—were also addressed.

The precise form of a global pact was debated, with the Canadian government favoring the concept of an International Law of the Air. Canadian Prime Minister Brian Mulroney pointed out that the groundwork for such an approach exists in the Montreal Protocol to protect the ozone layer and in the impending international protocol on nitrogen oxide control. Norwegian Prime Minister Gro Brundtland recommended a global convention on protection of the climate.

The meeting recommended a global pact to protect the atmosphere and a world atmosphere fund to facilitate global solutions, which recognized differential issues in usage and effects. For instance, the different historical consumption of and contribution to the atmosphere of already industrialized nations and those in the process of industrializing would be balanced by having the fund financed in part by taxes on fossil fuels consumed in industrialized nations. The proposed atmosphere fund would then be used partly to provide economic assistance to developing countries pursuing environmentally friendly strategies such as reducing deforestation.

The delegates concluded that immediate action is imperative to address ozone depletion, global warming and sea-level rise, and acidification by atmospheric pollutants. The potential role of nuclear power as a clean energy source was debated, but no official recommendations emerged. Reduction of other greenhouse gases, substances that deplete the ozone layer, and acidifying emissions were recommended.

Specifically on the issue of global warming from greenhouse gases and climate change, the conference reached a consensus on the likelihood of a rise in the global mean temperature of between 2.7–8 degrees F (1.5–4.5 degrees C) by about 2050, but not on whether such warming has begun. The conference statement called for a 20 percent cut in present (1988) levels of global carbon dioxide emissions by the year 2005, about half of which could be achieved through conservation, leading to an eventual cut of 50 percent. This statement was possible as a result of the participation of governments that voluntarily committed to cutting carbon dioxide emissions by 20 percent by the year 2005. This became the so-called "Toronto target" for greenhouse gas emissions and went beyond the emissions targets recommended by most later international conferences, as well as the 1992 UN Framework Convention on Climate Change and the core goal of Kyoto.

The Toronto Conference was also influential in other developments. The Intergovernmental Panel on Climate Change (IPCC), an international grouping of over 300 of the world's best climate scientists, charged with peer reviewing and reporting on the latest international science, effects, and responses to climate change, had been formed just before the conference. The conference was instrumental in promoting the IPCC and in the eventual appointment of Swedish scientist Bert Bolin to head it.

PUBLIC AWARENESS

Discussions at the conference also led to the allocation of resources to the World Climate Programme and other global research institutions, to the support for technology transfer solutions, to the advocacy of reduction of deforestation, and to raising public awareness of issues related to the atmosphere.

As a follow-up to June's Toronto Conference, a smaller meeting of legal and policy experts was held in Ottawa, Canada, from February 20 to 22, 1989, to begin developing an international accord for the protection of the atmosphere. The 80 participants, acting in a personal capacity, constituted a broad spectrum of experts and officials from developed and developing countries, nongovernmental organizations, and academic institutions and discussed the legal and institutional framework for dealing with emerging atmospheric problems, agreed where possible on the basis of an umbrella convention framework, and identified areas of possible disagreement.

With the 1982 Law of the Sea as a precedent, the meeting recommended that one or more international conventions such as a Law of the Atmosphere and a narrower Climate Change Convention with appropriate protocols were urgently needed, especially to limit greenhouse warming. The statement from this meeting presented early drafts of the proposed documents.

The Law of the Atmosphere approach was criticized as being more unrealistic than the narrower Climate Change Convention and did not receive much attention from subsequent negotiators. In carrying the ideas from the Toronto Conference forward, the Ottawa meeting proposed broad terminology for atmosphere and atmospheric interference; discussed the obligation of nations to protect the atmosphere, recognizing the relationship between the atmosphere and other aspects of the environment; recognized the need to balancing of development internationally; and proposed an international notification process for harmful activities, liability, compensation, and dispute resolution mechanisms, as well as details of the Atmospheric Trust Fund.

Features that were eventually included in the 1992 Climate Convention included the approach of a framework treaty that deals with the central issues with protocols for particular details. This would be similar to the Vienna Convention with the Montreal Protocol. Two years after the Toronto Conference, the IPCC issued assessments that provided the basis for the United Nations Framework Convention on Climate Change in 1992, followed by the Kyoto Protocol in 1997.

SEE ALSO: Climate Change, Effects; Villach Conference; World Meteorological Organization.

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Tourism

THE RELATIONSHIP BETWEEN tourism and global warming is a paradoxical one: global warming has become a threat to tourism, yet tourism remains a major cause of global warming. This vicious circle is well known to all stakeholders of the tourism industry, but implementing meaningful change has proven difficult because of three types of resistance: politico-economic resistance (from policymakers in regions and countries that rely heavily on tourism as a source of income), commercial resistance (from the tourism industry itself), and sociocultural resistance (from tourists who are not ready to change their behavior).

Several factors account for the considerable development of tourism since World War II: growing affluence, longer holidays, cheaper transportation, the availability of preorganized packaged tours, and the development of an industry catering both to mass tourists and to independent travellers. The subsequent increase in demand has resulted in an exponential rise in visitor numbers, both domestically (within countries) and internationally (especially from developed countries to developing countries). Although domestic tourism is statistically much more important (e.g., it accounts for 99 percent of all U.S. tourism and for 85 percent of all Australian tourism), international tourism is easier to measure (through a simple head count at borders); in addition, international tourism corresponds much more to the mainstream imagery of tourism: an island-hopping cruise in the Caribbean, a romantic holiday in Paris, a big game safari in Kenya. According to the World Tourism Organization, the number of international tourists increased from a mere 25 million in 1950 to 800 million in 2005. This number is predicted to double and to reach 1.8 billion by 2020, as more and more people want to travel. They may well know that they contribute to global warming and climate change, and some may feel a pang of guilt and remorse, but their desire to travel is stronger.

Climate is a key resource for tourism: favorable climatic conditions are key attractions for tourists, be it to ski in the mountains, to relax on a beach, or to experience nature. As soon as climatic conditions fluctuate and become less predictable, the tourism demand is affected and tourist flows move elsewhere: tourism, as a geographic phenomenon, is fickle and versatile. The mass media occasionally run stories about tourism hot spots that are victims of climate change and see their tourism appeal decrease; examples abound from all across the world, from less snowfall and shorter skiing seasons in Aspen, Colorado, or in Chamonix in the French Alps, to damage to coral reefs and rising ocean

Warmer temperatures at ski resorts: As soon as climatic conditions fluctuate and become less predictable, the tourism demand is affected and tourist flows move elsewhere; tourism, as a geographic phenomenon, is fickle and versatile.

water in Australasia, not to mention hurricanes that affect island resorts and the cruising industry.

These media stories are not just anecdotes or isolated incidents: they are part of a wider concern already well documented in the tourism literature, both in the academic literature (with seriously researched case studies, a nascent modelization of the relationship between climate change and tourism, and an increasing number of specialists, such as the Canadian Daniel Scott, the Dutch Bas Amelung, and the French Jean-Paul Ceron) and in the professional literature (industry publications such as professional bodies' reports and newsletters, as well as travel guides for tourists).

ENVIRONMENTAL AWARENESS AND TOURISM

International tourism organizations endeavor to raise awareness, to harness energies, and to articulate realistic plans of action. In 2003, the World Tourism Organization held its first Summit on Climate Change and Tourism. This resulted in the so-called Djerba Declaration on Tourism and Climate Change, whose signatories encouraged all governments to act to control climate change. The Djerba Declaration also asked the travel industry to adjust its activities to minimize climate change, and it invited consumer associations and the media to further raise public awareness, both at destinations and in generating markets. Taking place in 2007 in Davos, Switzerland, the Second International Conference reviewed and emphasized the key aims and intentions of the Djerba Declaration, strengthening its urgency and exploring concrete ways for tourism to respond to climate change, while still ensuring tourism development as a tool of economic growth and sociocultural well-being. At another level, in 2007 the World Travel and Tourism Council launched an international campaign on the same topic, calling for an open and mature dialogue on issues of tourism, climate change, and the environment; the campaign ran full pages in major publications such as *The Daily Telegraph*, *Newsweek*, and *The Wall Street Journal*, as well as travel trade media around the world.

Tourism professionals are aware of their responsibilities with regard to the environment, but they also know how much tourism contributes to the world economy. In 2007, the tourism industry globally represented 231.2 million jobs, which corresponded to 8.3 percent of total employment; that is, one in every 12 jobs worldwide. By 2017, this figure is expected to rise to 262.6 million jobs. Through their statements and declarations, tourism policymakers at all levels (local, regional, national, and supranational) and from all sectors (public, private, and voluntary) show that they understand the seriousness of the situation with regard to global warming and climate change, but one cannot ignore the fact that tourism is one of the world's largest economic sectors.

Tourism is not just about holidays and recreation, it is a powerful economic force that cannot be obliterated; rather, it has to be managed by implementing ways to maximize its benefits and minimize its costs. Through the concept of sustainable tourism, sustainable development has now become a key agenda in tourism, covering a range of social, cultural, and environmental issues, including references to climate change and global warming, yet solutions and ways forward are difficult to find. Simply controlling the number of international flights and limiting the amount of international tourists may not be a viable alternative at all: such a short-term measure could have devastating effects on many regions and countries whose economies are dependent, if not overreliant, on tourism income; for instance, small island states such as the Maldives, the Netherlands Antilles, and the Seychelles.

In 2007, global tourism generated over $7 trillion, and this number is likely to double within the next decade. The ongoing democratization of tourism means that more and more people can afford to travel and readily do so, even when they are aware of the effect on climate change and global warming; their arguments are usually twofold: first, that their own individual contribution is minimal, and second, that tourism is only one cause of climate change and global warming, among others. Many factors account for the ongoing increase in tourists' numbers: technological developments (epitomized by the superjumbo A380, with its capacity of 850 passengers), market deregulation (leading to more competition, which keeps prices low, especially in the airline industry), and the multiplication of specialized niche markets (such as sports tourism, senior tourism, gay tourism, or industrial tourism, making the demand more fragmented but also easier to target and satisfy). Neither financial penalties (tourism ecotaxes, imposed on airlines or at the destination) nor ethical appeals (campaigns asking would-be tourists to reconsider because of their carbon footprint) are proving effective deterrents for what is increasingly regarded as a right and not a privilege. Even the most vocal critics of tourism like to travel to conferences (business tourism) and go away on holidays (leisure tourism), which weakens the arguments of the antitourism lobby.

THREATS TO TOURISM

Climate change poses several risks to tourism; not only direct risks (climate variability affecting immediate demand as well as tourists' comfort and safety in the short term) but also indirect risks (such as causing damage to ecosystems or reducing water supplies, which may jeopardize tourism in the long term). This is ironic, inasmuch as tourism as a whole is partly responsible: by definition, tourism relies on methods of travel that generate air pollution (greenhouse gas emissions from vehicles that transport tourists, especially aircraft), so by its very existence, tourism heavily contributes to climate change. Rather than attempting a difficult—if not impossible—balancing act, specialists have identified two strategies. The first strategy involves innovation (e.g., with regard to sources and production of energy) and disseminating best practice in terms of sustainable development (e.g., through benchmarks and rewards). This first approach takes tourism in its wider industrial context, applying to tourism some policies and measures from other sectors, such as building and manufacturing.

The second strategy involves analyzing how climate change affects tourism to proactively restructure the tourism industry itself, both in terms of tourism demand and tourism supply; for instance, extremely hot temperatures in summer in seaside destinations may lead to a decrease of the demand in summer but to higher rates in other warm times of the year, such as warmer winter periods. As seasonality has always been a plague of the tourism industry, this climate change may eventually prove beneficial, though it will require adapting and revisiting established patterns. This second approach considers tourism as a specific and idiosyncratic system, although some related sectors, such as agriculture, local transport, and the entertainment industry, are likely to be affected too (a phenomenon conceptualized as backward linkages). The two strategies are not mutually exclusive: they can be combined, as they are both underpinned by a mix of idealism and pragmatism (adaptation and mitigation are two concepts used by scholars and policymakers alike).

Because of the intrinsic diversity of the tourism industry (exemplified by differing tourists' needs and expectations, from a backpacking teenager touring Europe to jetsetters staying in exclusive resorts), there may not be a one-size-fits-all solution. Case studies of destinations ranging from the Fijian archipelago to Banff National Park in Canada show that each region needs to develop its own methodologies and planning scenarios to anticipate changes in tourism demand and distribution, while remembering that it is not only the complex tourism system that is affected by global warming and climate change but also the local communities. Collaboration between partners and agencies is always heralded as a necessary mechanism; a good illustration is the official cooperation between the World Tourism Organization and the World Meteorological Organization: in 2006, an Expert Team on Climate and Tourism was jointly set up by both agencies. Such meetings of experts can result in sharing intelligence to help with research projects, as there is a wide recognition that decisions need be evidence based. The tourism industry is aware of the problems posed by global warming and climate changes, and it wants to be part of the solution.

SEE ALSO: Economics, Cost of Affecting Climate Change; Transportation.

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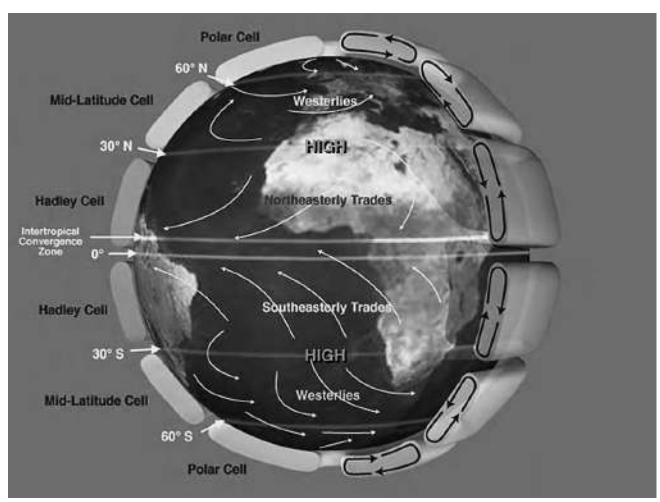
Trade Winds

THE TRADE WINDS are a large-scale component of Earth circulation, occupying most of the tropics straddling the equator between approximately latitude 30 degrees N and latitude 30 degrees S, with a seasonal shift of the entire trade wind belt system about 5 degrees of latitude northward during summer (July) and southward during winter (December).

In the Northern Hemisphere, warm equatorial air rises and flows north toward the pole, the Coriolis Effect (caused by the Earth's rotation) deflects the current, and as the air cools, it descends, blowing southwestward from the northeast. In the Southern Hemisphere, warm equatorial air rises and flows south toward the pole, the Coriolis effect deflects the current, and as the air cools, it descends, blowing northwestward from the southeast. The rising air is associated with deep atmospheric convection, heavy precipitation, and weak wind speeds, with an influence on global weather patterns Air heated by the sun rises and releases moisture through rain and thunderstorms. Once the air cools, it descends as drier air. In the equatorial low, the air rises and travels aloft to the subtropical highs, where it then sinks.

Mariners called these reliable wind currents for sailing the trade winds, or westerlies. The name trade winds comes from an old sailing term meaning that the winds could be counted on to blow steadily from the same direction at a constant speed. The trade



A NASA graphic of climatic zones and trade winds. In the tropics, the easterly trade winds dominate.

winds, or easterlies, carried air from east to west at low latitudes and are less regular over land areas than they are over the oceans. The trade winds meet at the Intertropical Convergence Zone. The doldrums (downward branch of the Hadley Cell, named for George Hadley, whose 1735 paper linked rising air and the Earth's rotation in causing the trade winds) are the calm winds at the Intertropical Convergence Zone in the area between latitude 5 degrees N and latitude 5 degrees S, where a sailing ship might not move because of the calm winds. In satellite imaging, the Intertropical Convergence Zone appears as a band of clouds. The strength and position of the Intertropical Convergence Zone influences tropical and global weather patterns.

Air temperature differences across the Earth's surface (both land and water) create winds, with warm air being lighter than cold air. Near the equator, the sun heats the sea surface, causing the warm air at the surface to rise and be replaced by the trade winds blowing from subtropical high pressure systems into equatorial low-pressure troughs. The trade winds blow steadily for days and are among the most consistent on earth. When trade winds move over warm tropical waters, they pick up moisture and bring heavy rainfall to the windward-facing slopes of mountainous areas, contrasting with the downward motion of dry air that creates desert areas on land. Because the area of Earth between the Tropic of Cancer and Tropic of Capricorn, lying at approximately 23 degrees latitude on either side of the equator, receives more solar heat than the rest of the earth, the warm air creates clouds and rain with thundershowers there almost every day.

The influence of the trade winds on weather and climate is seen with El Niño, La Niña, and the development of hurricanes/cyclones. The differences in pressure and temperature between the two sides of the Pacific are caused by the trade winds; air blowing from east to west pushes water, making the sea level higher in the western Pacific, and makes cold water rise toward the surface, making the eastern Pacific approximately 14 degrees F (7.7 degrees C) cooler than the western Pacific.

During El Niño years, the eastern Pacific sea surface is warmer, and the Intertropical Convergence Zone is closer to the equator, causing rainfall over the Pacific. The warm surface temperature is associated with reversed air pressure patterns and decreasing strength of trade winds, so more water stays in the eastern Pacific off the coast of South America. With the rain pattern shift eastward, the western Pacific can become drier over India and much of southeast Asia. A similar pattern sets up in the Atlantic, resulting in extreme drought in the eastern United States and reduced tropical storm development in the Atlantic Ocean.

During La Niña years, the trade winds are stronger than normal, causing more cold water to rise to the ocean surface. The cooler surface temperature is associated with a rain pattern shift westward. The eastern areas thus become drier, with an increased probability of flooding from monsoons in both India and much of southeast Asia.

Hurricanes (Atlantic) and cyclones (Indian Ocean) are tropical storms of low-pressure cells. Formation of hurricanes in the Atlantic comes from solar heating of water off the West African coast along the Intertropical Convergence Zone, with high cumulus cloud formation in the low-pressure area along the edge. These systems are pushed westward by the trade winds, and the rotation is set in motion by the Coriolis Effect. A similar pattern sets up in the Pacific, causing cyclones.

SEE ALSO: Coriolis Force; Doldrums; El Niño and La Niña; Winds, Westerlies.

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Transportation

TRANSPORTATION CAN BE simply defined as the movement of people, goods, and services from one place to another. Its system consists of the fixed facilities, flow entities, and control systems that permit the free flow and efficient movement of people and goods from place to place across geographical boundaries. Basically, there exist three forms of transportation: the road, water, and air transport.

The road transport systems are made up of the vehicular transport system and the rail transport system. The vehicular transport system comprises the different grades, sizes, and types of automobiles, and the rail transport system comprises the train systems of transportation. Water transportation also comprises the different shapes and sizes of water vehicles, known primarily as ships, boats, ferries, canoes, and so on. Air transport, in turn, comprises the different grades, shapes, and sizes of airplanes and helicopters.

FOSSIL FUELS

Each one of these means of transportation runs on fossil fuels of crude oil distillates and coal, apart from modern train systems in developed countries, which may run on automated power. These fuels are subjected to internal cycles of combustion, giving gaseous by-products of carbon dioxide (CO_2), carbon monoxide, and sulphur dioxide. Methane and nitrous oxide are also emitted by cars. World over, the greenhouse gas contribution of transportation is very high as a result of factors that include an increase in the number of vehicles, volume of passengers, and freight traffic. The percentage contribution of CO_2 from transportation alone varies from state to state and country to country. In 1990, Japan's contribution was put at about 19 percent, and that of the United States surprisingly doubled between 1960 and 2001. Specifically, it is reported that emissions of CO_2 in the United States jumped from 2 billion metric tons in 1960 to almost 5.7 billion metric tons in 2001, accounting for over a 100 percent increase, with over 20 percent of this emission linked to transportation. Transportation is also reported to account for 40 percent of volatile organic compounds, 77 percent of carbon monoxide, and 49 percent of nitrogen oxide emissions in the United States. In Canada, also, it is reported that transportation is the largest single anthropogenic source of outdoor air pollution. On average, each of the several million vehicles registered across the country emits approximately 5 tons of air pollutants and gases annually. This trend in record is the same for all industrialized nations and several developing nations, such as Nigeria in West Africa, because of an increased population and a rapid rate of economic growth, bringing about increased use of automobiles and other means of transportation. This increase has brought with it increasing emissions of air pollutants and greenhouse gases because of the type of engines in use and the nature of the fuels in place.

In general, it is reported that combustion engines emit nitrogen oxides (NO_x), carbon monoxide, and unburned hydrocarbons capable of chemical transformation in the atmosphere, creating other gaseous matter such as ozone. Ozone is a triatomic molecule consisting of three atoms of oxygen; it is an allotrope of oxygen but is much less stable. Its instability makes it a strong oxidizing agent, having the ability to decompose to oxygen in the atmosphere within 30 minutes. In its physical undiluted state, at standard temperature and pressure, it is a pale blue, odorless gas. In the troposphere, ozone acts as a greenhouse gas and has a radiative forcing of about 25 percent that of CO_2. Around the Earth's surface, it poses a regional air pollution problem damaging human health and agricultural crops.

More so, residual fuel oils, particularly the heavy oil used aboard ships, contain sulphur, which reacts with atmospheric water and oxygen to produce sulfate particles and sulphuric acids, also known as acid rain. It lowers soil and freshwater pH, resulting in damage to our natural environment, and also causes chemical weathering. Its ability to increase the reflection of part of the sunlight that should come into the Earth's surface creates a cooling effect. Road traffic on its own is a major contributor to environmental degradation and global warming. It clearly provides the largest net contribution to warming through its large emissions of CO_2 and significant emissions of ozone and soot. Soot particles emitted by diesel engines have the ability to absorb sunlight, thus heating up the climate. Total warming from road traffic is reported to be about 0.19 Watts per sq. m. (W/m^2), forming about 7 percent of the total climate forcing, as a result of an increased concentration of ozone, soot, and greenhouse gases.

Air traffic, as a sector in the transportation industry, also shows a trend toward increased environmentally unfriendly emissions. Airplanes fly in the upper edges of the atmosphere, where the air is rarefied and the planes release large quantities of greenhouse gases. CO_2, the main constituent in the exhaust gases, slowly descends into the lower altitude. However, the large number of planes flying across the sky has caused the average amount of these greenhouse gases to increase. CO_2 and other greenhouse gases get cut up in the stratosphere, where they become much more potent than at the Earth's surface, blocking radiant energy from reaching the planet. Thus, the global warming effect of air traffic pollution in the stratosphere is very high. In addition, the NO_x emitted have an especially large effect on ozone formation. A more recent research report on air traffic suggests that the occurrence of ice clouds, called cirrus clouds, at flying altitudes is increasing in areas with heavy air traffic because the trails of vapor left by aircraft at high altitude under certain meteorological conditions can expand. These clouds, found at altitudes of between 5 and 7.5 mi. (8 and 12 km.), have a warming effect on the climate because their greenhouse effect is stronger than their cooling effect through the reflection of light. This is a result of the low temperatures at this height.

Moreover, the various gases emitted by engines of transportation units pose serious challenges to the environment. CO_2, the most popular of the greenhouse gases, is a colorless, odorless gas with a covalent bond between its atomic constituents. It is the most potent greenhouse gas, being highly atmospherically stable and having a life of over a hundred years, with a strong ability to absorb radiations below the visible light spectrum, thus trapping heat attempting to escape from the Earth's surface and causing an increase in the temperature of the planet's surface. It has a radiative forcing of 1.5 W/m^2 and is regarded as the most powerful greenhouse gas because of its long atmospheric stability period.

The presence of a ton of CO_2 put into the atmosphere thus has a deleterious environmental warming effect for over a hundred years. With the increasing anthropogenic emission of this gas from transportation and other sources, the global warming effect of CO_2 on the environment has never been ignored. It is heavily concentrated in the atmosphere.

Methane (NH_4), in contrast, is a covalent compound, colorless and odorless. It is not as stable as CO_2 but has a stronger effect as a greenhouse gas than CO_2. Its stability period in the Earth's atmosphere is 10 years. It absorbs infrared radiation and affects tropospheric ozone. Methane may not be as popular a greenhouse gas as carbon dioxide, but its effects on the climate are stricter than it, and methane has been rated the second most potent greenhouse gas, after CO_2, with the exception of water vapor because of its short life and the quantity of it found in the Earth's atmosphere.

Another gas emitted from the burning of fossil fuels is nitrous oxide. It is a colorless, nonflammable, sweet-smelling gas having two nitrogen and one oxygen atoms covalently bonded together. When released into the atmosphere, nitrous oxide is the third largest greenhouse gas contributor to global warming, and has more effect than an equal amount of CO_2. It is reported that nitrous oxide is 296 times stronger a greenhouse gas than CO_2. It attacks ozone in the stratosphere, increasing the amount of ultraviolet light entering the Earth's surface. This ultraviolet light has deleterious effects on the human immune system, as well as the eye, and on the skin. It causes sunburn, inflammation, immunosuppression, tanning, and the accelerated aging of the skin.

GASEOUS POLLUTANTS

Other gaseous pollutants from transportation (mentioned earlier) are carbon monoxide and sulphur dioxide. Carbon monoxide is a colorless, odorless, and tasteless gas, formed by the thermal composition of excess carbon with oxygen. It is made up of a carbon atom covalently bonded to an oxygen atom. It is also released from the exhaust of motor vehicle engines, having gone through an incomplete internal combustion process of burning excess fossil fuels in the presence of oxygen. It is a toxic air pollutant. Its reaction in the atmosphere with some atmospheric constituents like the hydroxyl radical (OH^-) can increase the amounts of atmospheric methane and tropospheric ozone, thus causing an indirect forcing effect. It has the ability to combine with oxygen in the atmosphere to give CO_2, thereby contributing to greenhouse effects and global warming. Apart from this environmental degradation, CO has deleterious effects on human health.

Exposure to excess carbon monoxide can lead to heart and respiratory problems and has an effect on pregnancy, the central nervous system, and the heart—to mention a few adverse effects. Sulphur dioxide, in contrast, is a covalently bonded chemical compound made up of an atom of sulphur and two atoms of oxygen. It is anthropogenically produced from the combustion of coal and petroleum, which is commonly used by cars. It is a colorless gas with the smell of burning sulphur and is able to undergo serial combination to form sulphuric acid, which is an acid rain with corrosive tendencies found in the atmosphere. Sulphur dioxide is also toxic and has caused damage to humans in times past. However, its effects as a regulatory measure on the global warming effects of the greenhouse gases is limited by its lifespan on the Earth's surface, which is not more than a week.

With the present system of transportation still in use the world over, the rate of emissions of these harmful gases will continue to be on the increase, and their deleterious effects will become severe, as anthropogenic emissions of CO_2, methane, and nitrous oxide from industry and transportation are among the major causes of global warming. Gaseous pollutants of carbon monoxide and sulphur dioxide also contribute to dangerous effects on humans and the environment. However, various reports of the Intergovernmental Panel on Climate Change exist, each pointing to the damaging effects of such greenhouse gases as carbon dioxide, methane, and nitrous oxide. The contribution of transportation to the emission of these gases is high, and determining what must be done to reduce these emissions must be a global exercise that involves scientific contribution. Transportation effects on global warming and environmental pollution cannot be reduced without a redesign of the present system of engines vis-à-vis the available fuel systems. The emissions from modes of transportation can only increase as the numbers of vehicles, airplanes, ships, and other transport units migrating from one place to another increase.

SEE ALSO: Automobiles; Climate Change, Effects; Tourism.

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Trexler and Associates, Inc.

TREXLER CLIMATE AND Energy Services, Inc. (TC+ES) was founded as Trexler and Associates, Inc. (TAA) in the year 1991 by Dr. Mark C. Trexler, formerly of the World Resources Institute in Washington, D.C. TC+ES is based in Portland, Oregon. TC+ES was the company that wrote the first contracts for carbon offset, and designed the first methane carbon offset project for a coal mine.

Until 1997, the company was the only one serving the private sector in climate change mitigation services. That same year, TAA worked with Stonyfield Farm and its New Hampshire facility, helping the company to become the United States' first "greenhouse gas (GHG) neutral" facility. In 2000, TAA assisted Shaklee Corporation in its application to the Climate Neutral Network for the pilot certification of "Climate Neutral". The Climate Neutral Network awarded these certifications to companies who submitted worthy applications; it was to close down in 2007.

In 2002, TAA became partly run by Japan's Sumitomo Corporation. Sumitomo was established in 1919 as Osaka Hokko Kaisha Ltd., and adopted the English name Sumitomo Corporation in 1978.

Since its founding, TC+ES has worked with over 100 companies, large and small, in over 20 nations. Some of its better-known clients include the Chevron Research and Development Corporation, Fannie Mae, Nike Inc., Stonyfield Farm Inc., The Nature Conservancy, and the U.S. Department of Energy, and other institutions.

Services provided by TC+ES include achieving GHG neutrality, building ghg competitive advantage, customized price curve development, GHG inventory support, internal cost curve development, mitigation portfolio development, power plant siting and offset strategies, project design document (pdd) services, risk and opportunity assessment, and Sarbanes-Oxley compliance.

The company frequently publishes papers and reports regarding environmental strategizing and financial planning for companies interested in incorporating environmental responsibility.

SEE ALSO: Department of Energy, U.S.; Global Warming; Greenhouse Effect; Greenhouse Gases; Japan; Nongov-

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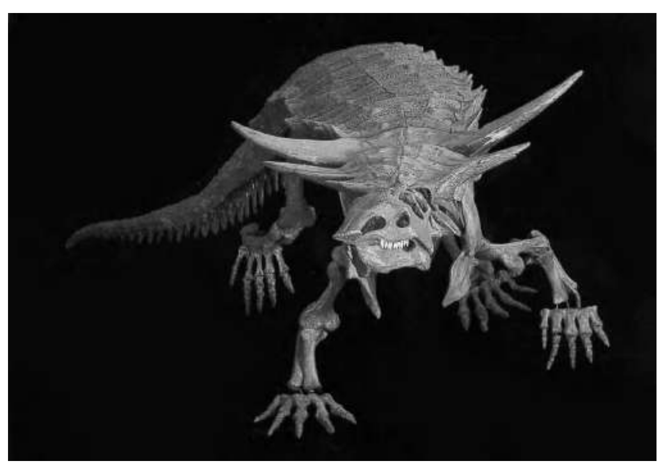
Triassic Period

THE TRIASSIC PERIOD is the geologic time period that extends from about 251 to 199 million years ago. This is the first period of the Mesozoic era, following the Permian and preceding the Jurassic period. Both the start and end of the Triassic are marked by major extinction events. During the Triassic period, both marine and continental life showed an adaptive radiation, beginning from the starkly impoverished biosphere that followed the Permian-Triassic extinction. The first flowering plants may have evolved during the Triassic, as did the first flying vertebrates, the pterosaurs. The Triassic period is further separated into Early, Middle, and Late Triassic epochs.

During the Triassic period, almost all the Earth's land mass was concentrated into a single supercontinent centered more or less on the equator, known as Pangaea. This supercontinent began to rift during the Triassic period but had not yet separated.

The Triassic climate was generally hot and dry, forming typical red bed sandstones and evaporites. There is no evidence of glaciation at or near either pole. The polar regions were moist and temperate—a climate suitable for reptile-like creatures. Pangaea's continental climate was highly seasonal, with very hot summers and cold winters. It probably had strong, cross-equatorial monsoons. The interior of Pangaea was hot and dry during the Triassic period. This may have been one of the hottest times in Earth history. Rapid global warming at the very end of the Permian may have created a super hothouse world that caused the great Permo-Triassic extinction.

The Permian-Triassic extinction event, also known as the Great Dying, was an extinction event that occurred 251.4 mya (million years ago). This was the Earth's most severe extinction event, with up to 96 percent of all marine species and 70 percent of all terrestrial vertebrate species becoming extinct. There are several proposed mechanisms for the extinction event, including both catastrophic and gradualistic processes, similar to those theorized for the Cretaceous extinction event. The former include large or multiple impact events, increased volcanism, or sudden release of methane hydrates from the seafloor. The latter include sea-level change, anoxia, and increasing aridity. Evidence that an impact event caused the Cretaceous-Tertiary extinction event has led naturally to speculation that impact may have been the cause of other extinction events, including the Permian-Triassic extinction. Several possible impact craters have been proposed as possible causes of this extinction event, including the Bedout structure off the northwest coast of Australia and the so-called Wilkes Land crater of east Antarctica. In each of these cases, the idea that an impact was responsible has not been proven and has been widely criticized. If impact was a major cause of this extinction event, it is possible or even likely that the crater no longer exists. Seventy percent of the Earth"s surface is



Aetosaur bones from the Triassic period in the Petrified Forest in Arizona. The Triassic climate was generally hot and dry.

sea, so an asteroid or comet fragment is over twice as likely to hit sea as to hit land. There is evidence that the oceans became anoxic toward the end of the Permian. There was a noticeable and rapid onset of anoxic deposition in marine sediments around east Greenland near the end of the Permian. The most likely causes of the global warming that drove the anoxic event were a severe anoxic event at the end of the Permian, causing sulphate-reducing bacteria to dominate the oceanic ecosystems and causing massive emissions of hydrogen sulfide, which poisoned plant and animal life on both land and sea. These massive emissions of hydrogen would have severely weakened the ozone layer, exposing much of the life that remained to fatal levels of ultraviolet radiation.

Pangaea's formation would also have altered both oceanic circulation and atmospheric weather patterns, creating seasonal monsoons near the coasts and an arid climate in the vast continental interior. Marine life suffered very high but not catastrophic rates of extinction after the formation of Pangaea—rates almost as high as in some of the Big Five mass extinctions. The formation of Pangaea seems not to have caused a significant rise in extinction levels on land, and in fact, most of the advance of Therapsids and the increase in their diversity seems to have occurred in the late Permian, after Pangaea was almost complete. Thus it seems likely that Pangaea initiated a long period of severe marine extinctions but was not directly responsible for the Great Dying and the end of the Permian.

The possible causes, which are supported by strong evidence, appear to describe a sequence of catastrophes, each one worse than the previous. The resultant global warming may have caused perhaps the most severe anoxic event in the oceans' history. The oceans became so anoxic that anaerobic sulphur-reducing organisms dominated their chemistry.

SEE ALSO: Global Warming; Paleoclimates.

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Trinidad and Tobago

THE ISLANDS OF Trinidad and Tobago, located in the Caribbean close to the South American coast, have a land area of 1,979 sq. mi. (5,128 sq. km.), with the island of Trinidad accounting for 1,864 sq. mi. (4,769 sq. km.), and Tobago the remaining 116 sq. mi. (300 sq. km.). The country has a population of 1,333,000 (2006 est.), of whom 96.3 percent live on the island of Trinidad, which has a population density of 660 people per sq. mi. (254 people per sq. km.). Some 69 percent of the population live in urban areas. With 15 percent of the land being arable, 9 percent is under permanent cultivation, with 2 percent being used as meadow or pasture. Some 44 percent of the country is forested, with efforts being made by the government to conserve the forests.

Much of the economy of Trinidad and Tobago comes from the petroleum industry, with petroleum and petroleum products making up the vast majority of the country's exports. The country also has coal deposits. The consumption of these deposits has led to an increase in greenhouse gases, with the result that Trinidad and Tobago has one of the highest carbon dioxide emissions per capita in the world. Although data published by the U.S. Department of Energy's Carbon Dioxide Information Analysis Center puts it at 9th in the world, Trinidad is the fifth highest independent country. Its emissions were 13.9 metric tons of carbon dioxide per capita in 1990, and with the exception of a low figure for 1993, emissions levels have risen significantly since then, reaching 22.1 metric tons per capita in 2003. The emissions are largely from gaseous fuels (72 percent), with 16 percent from liquid fuels, 10 percent from gas flaring, and 2 percent from the manufacture of cement. Not only is the heavy use of petroleum a major contributing factor but there is also poor public transport on Trinidad, resulting in widespread use of automobiles.

There is also extensive use of air conditioning for private houses and businesses. The effect of global warming can be seen by rising water temperatures detrimentally affecting the population of leatherback turtles, as well as affecting other Caribbean nations far more significantly. The government of Trinidad and Tobago has also been worried about the effects of global warming on the tourism industry, as well as the problems that might be posed to yachting and the cruise liners operating in the Caribbean.

The government of Patrick Manning took part in the United Nations Framework Convention on Climate Change, signed in Rio de Janeiro in May 1992, and 2 years later, Trinidad and Tobago was represented at the Global Conference on the Sustainable Development of Small Island Developing States held in Barbados. On January 7, 1999, the Trinidad government of Basdeo Panday signed the Kyoto Protocol to the UN Framework Convention on Climate Change, with it being ratified exactly 3 weeks later, but only entering into force on February 16, 2005.

SEE ALSO: Climate Change, Effects; Floods; Tourism; Transportation.

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Tropopause

THE TROPOPAUSE IS the boundary region dividing the troposphere, the lowest layer of the atmosphere, from the overlying stratosphere. Since the tropospheric and stratospheric air masses have rather distinct features, in correspondence to each surface location, the tropopause height is the level in the vertical where abrupt changes in the physical and chemical properties of the atmosphere are observed.

Three different definitions are typically adopted. The thermal tropopause is related to the change of the sign of the vertical derivative of the temperature (lapse rate), which is negative in the troposphere and positive in the stratosphere.

The World Meteorological Organization defines the tropopause as the lowest level where the absolute value of the temperature lapse rate decreases to 2K/km. or less, with the average lapse rate between this level and all higher levels within 1.2 mi. (2 km.) not exceeding 2K/km. The dynamical tropopause is defined in terms of sharp changes in the potential vorticity (much higher in the stratosphere), which measures stratification and rotation of the air masses. An abrupt increase (decrease) with height of the ozone (water vapor) mixing ratio indicates the presence of the chemical tropopause. In spite of the necessity of choosing phenomenological thresholds, the three definitions of the tropopause are quite consistent.

TROPICAL TROPOPAUSE

Typically, the tropopause height decreases with latitude, being around 3.7 mi. (6 km.) near the poles and 11 mi. (18 km.) near the equator. Whereas radiative and convective processes with time scale of the order of one week to one month basically determine the properties of the tropical tropopause, in the midlatitudes a relevant role is played also by baroclinic-fuelled extra-tropical cyclones, having a typical time scale of a few days, in such a way that the tropopause readjusts its height in such a way as to act effectively as a stabilizing mechanism limiting the growth of the weather perturbations. The tropopause is not a hard boundary: exchanges of tropospheric and stratospheric air occur through various mechanisms, including vigorous thunderstorms and midlatitude perturbations.

The globally averaged tropopause height tends to increase if the troposphere warms up and/or the stratosphere cools down, and the height change is approximately proportional to the difference between the tropospheric and stratospheric temperature changes. Therefore, the mean tropopause height can act as a robust indicator of climate change. Recent climate simulations have shown that the estimated increase after 1979 of about 492 ft. (150 m.) may be primarily explained by anthropogenic causes, namely the stratospheric cooling driven by ozone depletion and the tropospheric warming driven by increases in the greenhouse gases concentration. Considering natural processes, episodic, short-lived strong reductions of the globally averaged mean tropopause height are caused by large explosive volcanic eruptions, which warm the troposphere and cool the stratosphere.

SEE ALSO: Atmospheric General Circulation Models; Atmospheric Vertical Structure; Cyclones.

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Troposphere

ON THE BASIS of thermal characteristics, the atmosphere is normally subdivided into four major vertical layers: the troposphere, stratosphere, mesosphere, and thermosphere. The troposphere makes up the lowest of these layers, extending from the surface to a global average height of 7.5 mi. (12 km.). Coined in 1908 by French scientist Leon Philippe Teisserenc de Bort, the name troposphere is derived from the Greek word tropos, meaning to turn, mix, or change. The term aptly describes the extensive vertical mixing and stability changes of this layer, which generates clouds, precipitation, and other meteorological events. For this reason, the troposphere is commonly referred to as the weather sphere.

The depth of the troposphere is relatively thin, yet it contains approximately 80 percent of the atmosphere's mass. Because the atmosphere is compressible, air molecules are more compact closer to the surface, thereby increasing the density and pressure of the air at lower altitudes. The relationship between density and pressure with altitude is nonlinear, decreasing at a decreasing rate with increasing altitude. In the lower troposphere, the rate of pressure decrease is about 10 mbars. for every 330 ft. (100-m.) increase in elevation.

Temperature in the troposphere generally decreases with height, contrasting considerably between its lower and upper boundaries. Temperature in this layer is largely affected by the radiant energy exchanges from the underlying surface and insolation intensity. The global average temperature at the surface is 59 degrees F (15 degrees C) but decreases to around minus 82 degrees F (minus 63 degrees C) at the top of the troposphere. On the basis of mean tropospheric depth, the average rate of temperature decrease is 3.6 degrees F per 1,000 ft. (6.5 degrees C per km.), a measurement known as the normal lapse rate. This rate represents average global conditions, deviating substantially depending on latitude, time, and local modifications. The actual temperature change with height is the environmental lapse rate, which is measured remotely, using satellites, or directly, using Radiosondes (a balloon-borne instrument package). Eventually, temperature ceases to decline with height, transitioning into a zero lapse rate region (or isothermal layer), where temperature is neither increasing nor decreasing. This shift demarcates the boundary between the troposphere and the stratosphere, known as the tropopause.

The mean height of the tropopause can have considerable spatial and temporal variability. In the tropics, the depth of the troposphere is around 16 km. (10 mi.), but near the poles, the depth dwindles to about 8 km. (5 mi.) or less. The tropopause also varies seasonally, with higher heights occurring during the summer than the winter. Warm surface temperatures occurring at low latitudes and high sun periods encourage vertical thermal mixing, thereby extending the depth of the troposphere. Accordingly, the environmental lapse rate in these regions continues to remain positive (i.e., temperature decreases with height), and tropopause temperatures are typically lower in the tropics than for high latitudes. Occasionally the tropopause is difficult to discern because of extensive mixing between the upper troposphere and the lower stratosphere.

This situation is common in portions of the midlatitudes, usually defining the location of jet streams (a narrow belt of high-velocity winds often in excess of 185 km. per hour (115 mi. per hour) that steer midlatitude cyclones. Because the height of the tropopause is dependent on the average temperature of the troposphere, temperature changes in this layer can influence the location of extratropical storm tracks and cloud depth.

Embedded frequently within the troposphere are thin sublayers in which the temperature actually increases with height, known as temperature inversions. Radiation inversions result from nocturnal surface cooling. Under certain ambient conditions (e.g., cloudless nights), terrestrial radiation loss to space is enhanced and the ground (and air above) cool rapidly, thereby establishing a shallow inversion layer. Conversely, subsidence inversions occur from mid-upper tropospheric processes that produce areas of sinking air that are being warmed by compression; hence, lower tropospheric temperatures are actually colder than those aloft. This setting tends to stabilize the air, inhibiting vertical mixing and cloud growth.

A semipermanent sublayer of the troposphere is the planetary boundary layer (PBL), a section directly influenced by surface daily conditions. Comprising typically the lowest 1 km. (3,300 ft.) of the troposphere, the PBL is characterized by turbulence generated by frictional drag from the surface beneath and rising thermals (heated air parcels). The depth of the PBL amplifies and diminishes with the daily solar cycle, such that the greatest thickness is during the day when the atmosphere is most turbulent.

Evidence suggests that the troposphere has undergone a significant rate of warming during the past century. The tropospheric temperature trend in the latter half of the 20th century is estimated at a 0.18 degree F (0.10 degrees C) increase per decade, similar to the surface temperature rate change. Higher temperatures mean increased surface evaporation and tropospheric water vapor content. As a consequence, cloud cover has also shown an increase, and extratropical precipitation in the Northern Hemisphere has increased 5 to 10 percent since 1900.

Other climate-forcing agents (e.g., anthropogenic-induced greenhouse gas emissions) can alter the Earth's radiation balance and may also explain the upward temperature trend. For instance, tropospheric ozone (O_3), a greenhouse gas and surface pollutant, has increased by nearly 35 percent since the preindustrial era.

SEE ALSO: Atmospheric Boundary Layer; Atmospheric Vertical Structure; Tropopause.

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Tsunamis

TSUNAMIS (SOMETIMES CALLED seismic sea waves) are large sea waves that are created by underwater earthquakes, volcanic eruptions, or even nonseismic events such as landslides and meteorite impacts. Tsunamis are also known as tidal waves, even though this is a misnomer because the waves have nothing to do with tides. The word *tsunami* is a Japanese word meaning "harbor wave." Tsunamis are not easily seen on the open water, as they have extremely long wavelengths on the order of tens of kilometers. The speed of the wave is directly related to the depth of the water; therefore, as the water depth decreases, the tsunami moves slower. As the waves propagate toward the coast, the speed will decrease, but the amplitude or the height of the waves can achieve extraordinary levels. Tsunamis lose energy as they approach the coast, but they still have incredible amounts of energy, as they often cause beach erosion and undermine trees and other types of coastal vegetation. The fast-moving water is capable of flooding several hundreds of meters inland, well above normal flood levels, and destroying buildings and other structures. Tsunamis can extend to heights well above sea level, in extreme cases sometimes as high as 30 m. or 100 ft.

Volcanic activity and earthquakes are the prime causes of tsunamis. When the seafloor starts to buckle, the overlying water will begin to displace. As the seafloor rises and sinks, the displaced water will form waves because of the effects of gravity. Most of the major earthquakes occur at plate boundaries.

There are three different types of plate boundaries. A divergent boundary takes place where two plates move away from each other. At this type of boundary, volcanoes will form, out of which molten material will flow. Also, weaker, shallow-focus earthquakes can occur along these boundaries. Divergent boundaries are very common in the midocean such as at the Mid-Atlantic Ridge, the East Pacific Ridge, the Mid-Indian Ridge, and the Southeast-Indian Ridge. Convergent boundaries occur where two plates moving in opposite directions collide. One plate will be denser and will subduct underneath the other. These subduction zones are a very common location for earthquake activity. There are three different types of convergent boundaries: oceanic-continental convergence, oceanic-oceanic convergence,

The third and largest wave of the tsunami of December 26, 2004, invades the promenade on Ao Nang Beach, Thailand. Waves were reported as high as 30 m. or 100 ft., and it was the deadliest in recorded history, with an approximate 230,000 lives lost,

and continental-continental convergence. At an oceanic-continental convergent boundary, the oceanic crust is denser and will subduct underneath the continental crust. Volcanoes will form along the continental boundary, whereas deep trenches will form off the coast. Shallow-focus earthquakes often form along these subduction zones, such as along the west coast of South America. At an oceanic-oceanic convergent boundary, two ocean plates collide, forming a volcanic island arc on the ocean floor. Examples of this type of boundary include the Aleutian Islands, the Mariana Islands, and Japan. At a continental-continental convergent boundary, two continental plates collide, typically forming huge mountain ranges such as the Himalayas or the Alps. Under this type of convergence, volcanic activity is rare, but earthquake activity is very common. The final type of boundary is called a transform boundary, where two plates slide past each other. Transform boundaries occur along vertical fractures called faults, which are noted for great magnitudes of earthquake activity. Most faults are found near midoceanic ridges, but they can also extend through continents, as evidenced by the San Andreas Fault in California.

Tsunamis can be formed by anything that displaces a large volume of water from its equilibrium state. When earthquakes or volcanoes generate tsunamis, water is displaced as a result of the uplift or subsidence of the seafloor and water column. Sometimes submarine landslides, which are common with large earthquakes as well as volcanic collapses, can displace great volumes of water. However, these types of disturbances disturb the water from above, rather than from below. Tsunamis derived from these types of mechanisms usually do not last long and have minimal impacts on the coastlines.

The most recent deadly tsunami was the Asian tsunami that occurred after the 2004 Indian Ocean earthquake on December 26 of that year. The epicenter, which is the location at the Earth's surface directly above the focus of the earthquake, took place off the coast of Sumatra, Indonesia. The magnitude of this earthquake has been estimated to be between 9.1 and 9.3 on the Richter scale (the scale devised to estimate the amount of energy released in an earthquake). This made it the fourth most powerful recorded earthquake since 1900. The earthquake lasted almost 10 minutes and was the second most powerful ever recorded on a seismograph (an instrument that measures the seismic waves from an earthquake). Waves were reported as high as 30 m. or 100 ft., and it was the deadliest in recorded history, with an approximate 230,000 lives lost, mostly in the countries of Indonesia, India, Sri Lanka, and Thailand. Before this, the 1782 Pacific Ocean tsunami was the deadliest in recorded history, with an estimated 40,000 casualties in the South China Sea. Other powerful tsunamis include the 1883 tsunami following the eruption of Krakatoa, a volcanic island in Indonesia, and the 1908 tsunami that occurred in the Mediterranean Sea near Messina, Italy.

There has been speculation about possible effects of global warming after the 2004 tsunami, with proponents suggesting that the increase in average temperature allows the atmosphere and the oceans to gather energy, which may cause more earthquake activity. Critics, however, claim that if this were the case, there would be more of a correlation between El Niño and tsunamis, as El Niño warms the ocean over an active region with many plate boundaries. Therefore, links to global warming and tsunamis are unsubstantiated because it is difficult to associate what is happening at the surface of the ocean with the depth at which the focus of the earthquakes takes place.

SEE ALSO: Climate Change, Effects; Oceanic Changes.

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Tunisia

LOCATED IN NORTH Africa between Algeria and Libya, the Republic of Tunisia has a land area of 63,170 sq. mi. (163,610 sq. km.), with a population of 10,327,000 (2006 est.) and a population density of 161 people per sq. mi. (62 people per sq. km.). In spite of its having an arid climate, 19 percent of the land in Tunisia is arable, with 13 percent under permanent cultivation. There is also an additional 20 percent used as meadows or pasture, mainly for the raising of sheep, goats, and cattle. Only 4 percent of the country is forested.

Tunisia has its own supplies of crude oil and natural gas, and as a result, 99 percent of the country's electricity generation comes from the use of fossil fuels, with 1 percent coming from hydropower. In terms of its per capita rate of carbon dioxide emissions, they have risen from 1.6 metric tons per person in 1990 to 2.29 metric tons in 2004. Some 65 percent of Tunisia's carbon dioxide emissions come from liquid fuels, with 23 percent coming from gaseous fuels and 10 percent from the manufacture of cement. Heavy use of air conditioning, especially in the economically important tourist sector, results in electricity production making up 39 percent of the country's carbon dioxide emissions, with 25 percent coming from transportation, 24 percent from manufacturing and construction, and 11 percent from residential use.

The effect of global warming and climate change on Tunisia has seen the alienation of some arable land, with the rising temperature affecting the level of crop production. It has also led to gradual shortages of water in some inland parts of the country and in the increasing use of desalination, which in turn leads to increases in the amount of electricity that needs to be generated. The Tunisian government of Zine El Abidine Ben Ali took part in the United Nations Framework Convention on Climate Change, signed in Rio de Janeiro in May 1992. It accepted the Kyoto Protocol to the UN Framework Convention on Climate Change on January 22, 2003, with it entering into force on February 16, 2005.

SEE ALSO: Climate Change, Effects; Drought.

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Turkey

LOCATED MAINLY IN Asia, but with a small part of its land considered to be in Europe, the Republic of Turkey has a land area of 302,535 sq. mi. (779,452 sq. km.), with a population of 74,877,000 (2006 est.) and a population density of 240 people per sq. mi. (93 people per sq. km.). Istanbul, the former capital and the largest city, has a population density of 13,256 people per sq. mi. (5,137 per sq. km.). The present capital, Ankara, has a population of 3,641,900, with a population density of 13,328 per sq. mi. (1,424 per sq. km.). Some 32 percent of the land area of Turkey is arable, with 4 percent under permanent cultivation, and an additional 16 percent is used as meadows or pasture. Some 26 percent of the country remains forested, and there is only a small timber industry. In terms of its per capita rate of carbon dioxide emissions, it was 2.6 metric tons per person in 1990, rising to 3.14 metric tons per person by 2004.

Electricity generation in Turkey comes largely from fossil fuels (74.1 percent), with 25 percent being from hydropower. The use of hydropower has not been without controversy. Although it has generated much hydroelectricity, there have been environmental problems with the Illisu Dam in southeastern Turkey, as well as with some other projects. The production of electricity is responsible for 38 percent of Turkey's carbon dioxide emissions, with 8 percent coming from other energy industries, 25 percent being from manufacturing, 20 percent from transportation, and 13 percent from residential use. Heavy use of coal means that 44 percent of the emissions are the result of the use of solid fuels, with 37 percent being from liquid fuels, 10 percent from gaseous fuels, and 9 percent from the manufacture of cement.

Turkey has suffered some effects of global warming and climate change, with a rise in the average temperature in the country resulting in the snowmelt on some of the previously snow-covered peaks in the east of the country. More important, it has also led to the alienation of agricultural land throughout the country, with the need for water for irrigation and drinking leading to water shortages in some rural areas. There have also been problems in the agriculturally poor eastern part of Turkey, where there is already low productivity in farms and high levels of poverty.

The Turkish government took part in the United Nations Framework Convention on Climate Change, signed in Rio de Janeiro in May 1992. It has not expressed an opinion on the Kyoto Protocol to the UN Framework Convention on Climate Change.

SEE ALSO: Climate Change, Effects; Drought.

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Turkmenistan

LOCATED IN CENTRAL Asia, Turkmenistan is a country primarily made of desert. It lies between 35 degrees 08 minutes and 42 degrees 48 minutes N and between 52 degrees 27 minutes and 66 degrees 41 minutes E, north of the Kopet-Dag mountains, between the Caspian Sea to the west and the Amu-Darya River to the east. Turkmenistan covers 188,455 sq. mi. (488,096 sq. km.) and had a population of 5,097,028 in 2007.

Despite its extensive oil and gas resources, Turkmenistan remains a poor, predominantly rural country, with the majority of the population relying on intensive agriculture in irrigated oases, and it is extremely vulnerable to climate change.

Turkmenistan has a distinctive continental climate, with an average annual air temperature ranging from 54–62 degrees F (12–17 degrees C) in the north to 59–64 degrees F (15–18 degrees C) in the southeast and to the absolute maximum temperature of 118–122 degrees F (48–50 degrees C) in the Central and South-East Kara-Kum. The highest amount of annual rainfall is observed in the mountains (up to 398 mm. in Koyne-Kesir), as is the least rainfall (less than 95 mm. above the Kara-Bogaz-Gol Bay). Up to 80 percent of Turkmenistan's land consists of desert. Meteorological data reveal an increase of annual and winter temperatures in Turkmenistan dating from the beginning of the past century. Since 1931, the mean annual temperature has increased by 1 degree F (0.6 degrees C) in the northern part of the country and by 0.7 degrees F (0.4 degrees C)in the south.

At the same time the number of days with temperatures higher than 104 degrees F (40 degrees C) has increased since 1983. Climate Models predict temperature increases in Turkmenistan of 5–7 degrees F (3–4 degrees C) by the middle of the 21st century. Precipitation projections are highly uncertain, but given the existing aridity and high interannular and interseasonal variability of Turkmenistan's climate, even a slight temperature increase is likely to exacerbate the existing water stress in the region.

Turkmenistan signed and ratified the UN Framework Convention on Climate Change in 1995. In January 1999, Turkmenistan ratified the Kyoto Protocol and published the Initial Communication on Climate Change. Because Turkmenistan is covered under the Kyoto Protocol's Clean Development Mechanism, it can trade carbon credits with other countries that fall under the Joint Implementation Mechanism.

The major sources of carbon emissions in Turkmenistan include oil and gas extraction, petroleum refining, and the chemical industry, as well as motor transport concentrated mainly in Ashgabat, Turkmenbashi, Balkanabat, Mary, Turkmenabat, and Dashoguz.

Turkmenistan has taken some steps to reduce carbon emissions, such as a massive tree planting project throughout the country (Green Belt Project), modernization of Turkmenbashi and Seyidi refineries to conform to modern ecological standards, and relocation of the cement factories away from inhabited areas.

However, the nation's widespread poverty, recent decline in the educational system, misuse of hydrocarbon revenues, and high economic dependence on cotton production and exports leave Turkmenistan particularly vulnerable to high climatic variability, desertification, and droughts.

SEE ALSO: Climate Models; Deserts; Kyoto Mechanisms.

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Tuvalu

TUVALU HAS BEEN independent since 1978, joining the United Nations in 2000. The resident population has been estimated to be about 10,000 people in 2007, living on nine small, low-lying atoll islands. The total land area is only 9.4 sq. mi. (24.4 sq. km.); when the Exclusive Economic Zone is included, the total national area of Tuvalu is 289,576 sq. mi. (750,000 sq. km.). Tuvalu does not have substantial natural resources—the coral atoll soil is of poor quality, alkaline, shallow, and with low water-holding quality. Added to these environmental challenges are a lack of rainfall, lack of natural resources, the occurrence of cyclones, and the threat of sea-level rise. About 44 percent of the population lives on urban Funafuti, and the internal migration rate is expanding. The overcrowded urban situation has meant that having a sufficient freshwater supply is difficult.

As a small and fragmented Pacific Island nation, Tuvalu is increasingly vulnerable to cyclones, flooding, and sea-level rise, accompanied by environmental threats, such as land loss and coastal erosion, soil salinization, and intrusion of saltwater into the atolls' freshwater lenses and groundwater. Two incidences of flooding have been noted as being particularly severe for the urban island of Funafuti—one in 1977 and another one in 1993. Other climatic effects include coral bleaching in reef systems. Tuvalu's vulnerability, however, is also because of its impoverished economic situation, with large employment rates in the public sector, aid dependency, and a lack of natural resources for export; fragmentation and isolation of the islands; and a lack of capacity to support its population, which makes sea-level rise a problematic development issue. Current estimations of average sea-level rise in the South Pacific are 0.7 mm. per year. However, in relation to sea-level rise, the land of Funafuti island is sinking, which problem is accelerated by tectonic movement. As a consequence, and including indications of tide-gauge data, the sea-level rise in the Funafuti area has been estimated by scientists to be 2 + 1 mm. per year.

ENVIRONMENTAL REFUGEES

Tuvalu entered international negotiations on climate change in 2002, when Koloa Talake, the prime minister at the time, suggested pursuing legal actions against greenhouse gas emissions leading to global warming and the consequences of sea-level rise for Tuval, on the international level. The National Summit on Sustainable Development in Tuvalu in 2004 emphasized the need to promote awareness and strategies for adaptations on the national level. Migration as a final solution will be difficult for Tuvaluans and is also culturally contested. Existing migration schemes for Tuvalu are small.

Different from many other Pacific nations, Tuvalu, similarly to Kiribati, does not have the privilege of free access to the Pacific Rim countries. Current access allows 75 Tuvaluans to migrate each year to Australia and New Zealand. The strong relationship of Tuvaluans to their land, however, makes migration a last resort. Recent publications have suggested that Tuvalu and Tuvaluans are being publicly victimized when they are represented as potential places of disaster and as environmental refugees, respectively.

SEE ALSO: Climate Change, Effects; Floods.

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Tyndall, John (1820–93)

JOHN TYNDALL WAS born in Leighlinbridge, County Carlow, in Ireland on August 2, 1820. After working as a surveyor and a mathematics teacher, he attended the University of Marburg in Germany, where he received his Ph.D. In 1854, he became a professor of natural philosophy at the Royal Institution in London (a scientific research center founded in 1799). In 1867, he was made superintendent of the institution, taking over from Michael Faraday.

Tyndall's most well-known scientific studies included the nature of sound, light, and radiant heat and observations on the structure and movement of glaciers. Glaciers had become a scientific area of interest during that time because in the 1830s, Louis Agassiz (considered the father of glaciology) had discovered that a large portion of Europe and North America had once been covered with ice.

Tyndall developed an interest in meteorology as a result of his love for mountain climbing. He studied alpine glaciers and took meteorological

John Tyndall was a 19th-century physicist. He is renowned for his studies in the absorption of heat by atmospheric gases.

measurements on Mont Blanc in the Alps. Using a spectrophotometer he designed, Tyndall studied the absorption of infrared light (at the time called radiant heat) by atmospheric gases. Infrared light is felt as heat and has wavelengths of approximately 0.7 to 1.0 μm. Visible light for comparison has wavelengths of approximately 0.4 to 0.7 μm.

Some of the invisible gases (oxygen, nitrogen, and hydrogen) were transparent to radiant heat, whereas water vapor and carbonic acid (now known as carbon dioxide) absorbed and reemitted infrared light, thereby warming the atmosphere close to the earth. From these experiments, Tyndall realized that water vapor, carbon dioxide, and ozone—even in small quantities—were the best absorbers of heat radiation, and he later speculated on how changes in these gases could correlate to climate change.

GREENHOUSE GASES

Among the various atmospheric gases in the troposphere, Tyndall discovered the importance of water vapor and carbon dioxide as greenhouse gases that trap heat on the surface of the earth. Without these atmospheric gases to trap heat, the heat would rapidly radiate back into space, and the Earth would be much colder. During cold nights, there is an enhanced chance of fog or dew in the mornings because the moisture in the air (water vapor) condenses into droplet as the air cools. In deserts—hot and dry climates—there is a lack of water vapor in the air, and the sand radiates heat easily into space. Changes in the atmospheric levels of gases produce changes in the climate as well.

In the 1860s, Tyndall began to suggest that slight changes in the atmospheric composition could bring about climatic variations. Tyndall was the first scientist to explain the Ice Ages as being caused by greenhouse effect. In particular, he noted that variations in water vapor resulted in a change in the climate and realized the importance of the greenhouse effect in maintaining ecosystems necessary for life. He thought changes in the composition of the atmosphere may have produced all changes in the climate.

Using the laws of thermodynamics, Tyndall proposed that changes in carbon dioxide cause an initial change in temperature, and when the humidity changes accordingly, the change in humidity leads to a second change in the temperature.

During the Victorian era, he was the contemporary and friend of other important scientists. In addition to his scientific research, he promoted scientific education of the public with scientific demonstrations and advocated using hands-on laboratory experimentation to teach science. In 1874, Tyndall used his address before the British Association for the Advancement of Science to proclaim rational thought and skepticism as the aim and superiority of science.

In the 1870s, he made a lecture tour of the United States and included his lab demonstrations. Over the course of his professional life, he was the recipient of numerous scientific awards and recognition. In addition to his dynamic public speeches using laboratory experimentation, he published a wide range of papers, treatises, and books. Digital versions of John Tyndall's books can be found at http://books.google.com and include *Lectures on Light Delivered in the United States in 1872–1873*, first published in 1873; *Hours of Exercise in the Alps*, first published in 1871; and *The Glaciers of the Alps*, first published in 1861.

John Tyndall died on December 4, 1893, from an overdose of chloral hydrate. At the inquest, his wife testified she mistakenly gave him chloral hydrate instead of his normal medication, leading to his death.

TYNDALL EFFECT

The Tyndall effect, a scientific principle on the dispersion of light beams through colloidal suspensions or emulsions, was named for him. The importance of his research continues, as his work continues to shape scientific research on climate change.

The Tyndall Centre, with headquarters at the School of Environmental Sciences at the University of East Anglia, founded in 2000, is named after John Tyndall, in honor of his being one of the first scientists to recognize the Earth's natural greenhouse effect and observing, identifying, and proposing the climate effects of the radiative properties of atmospheric gases. The mission of the Tyndall Centre is to research and educate policymakers on climate change, to develop and apply research methods for climate change, and to promote international dialogue on managing future climate change.

In support of this goal, research at the Tyndall Centre includes action to provide information through data collection and interpretation and modeling to assess possible scenarios of the effect of human and natural causes on climate change and to disseminate this information by encouraging international discussion and policymaking. By using empirical research, the Tyndall Centre proposes protection of coastline ecosystems, city-scale emissions testing, and accountability for contributions to climate change. The Tyndall Centre focuses on this objective, with a strategy to investigate and identify behavior modification and education opportunities to promote sustainable approaches to limiting human-induced climate change.

SEE ALSO: Carbon Dioxide; Greenhouse Effect; Greenhouse Gases.

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Uganda

UGANDA IS SITUATED in the interlacustrine highlands of central Africa; these highlands are generally characterized by a high plateau that is associated with the Great Rift Valley that dominates Uganda. The plateau generally lies between 3,280 to 6,562 ft. (1,000–2,000 m.). One characteristic feature of the Great Rift Valley is the development of numerous lakes; these include Tanganyika and Kivu, while in the Albertine Rift region in the north, the lakes include George, Edward, and Albert. Uplift along the shoulders of the Western Rift Valley resulted in the reversal of the previously west-flowing rivers and the creation of the basin now occupied by Lake Victoria. The Nile River, which forms the eastern boundary of the interlacustrine highlands, is the major outlet of Lake Victoria, flowing northward from Lake Victoria. Farther to the west, Uganda is dominated by the Ruwenzori mountain range—the infamous mountains of the moon—that straddle the border with the Democratic Republic of Congo.

The climate of Uganda varies from humid through seasonally arid conditions. Precipitation is dependent largely on the Intertropical Convergence Zone (ITCZ); the movement of the ITCZ follows the position of maximum surface heating associated with the overhead position of the sun. Climate is further modified by topography and by the proximity of the large lakes. The distribution of vegetation is mainly dependent on altitude, levels of precipitation, and human activities. Because of human pressure, cultivated and grazed land occupies much of Uganda. Much of the interlacustrine highlands lie within a phytogeographical zone known as the Lake Victoria Regional Mosaic, where five distinct floras meet; namely, the Afromontane, Guineo-Congolian, Somalia-Masai, Sudanian, and Zambazian Regional Centers of Endemism. Above 6,562 ft. (2,000 m.) there are three distinct vegetation belts; namely, Afroalpine, Ericaceous, and Montane forest belts. The Afroalpine Belt occurs mainly above 11,810 ft. (3,600 m.) in the high mountains of the region, which include Mount Elgon, the Virunga volcanic mountains, and the Rwenzori.

Environmental histories of Uganda have been reconstructed via a long history of palaeoecological research from the numerous lakes and swamps. Recent interest in other proxy records, such as archaeology, historical linguistics, oral traditions, and meteorological data have provided a detailed understanding of the environmental history of Uganda and the associations between environmental and human histories in the region. Under the cool and dry climate conditions of the last glacial maximum, vegetation from higher altitudes extended to lower elevations. From around 15,000 years before present (yr. BP), as global climates warmed, montane forest types retreated back to mountainous areas, reaching the minimal extent around 6,000 yr. BP under the warm and wet conditions of the mid-Holocene.

The climate history from 5,000 yr. BP to the present is more complex, as ecosystems have been increasingly influenced by human activity. A period of relatively drier climate between 5,000 and 2,000 yr. BP is marked by relatively low lake water levels. Vegetation also reflected this climate change, experiencing a marked transition to drier forest types from about 3,500 yr. BP. Uganda experienced a return to relatively moist environmental conditions after about 2,000 yr. BP; during this same period, areas around Lake Victoria experienced a decrease in evergreen forest, with it being replaced by semideciduous forest. The introduction of agriculture to Uganda is commonly associated with Bantu-speaking people, who are reported to have spread throughout much of central Africa after about 3,000 yr. BP.

SEE ALSO: Climate Change, Effects; Food Production.

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Ukraine

UKRAINE IS A republic in east Europe, part of the former Soviet Union. Its capital and largest city is Kiev (50 degrees 27 minutes N, 30 degrees 30 minutes E, population of 2.6 million in 2007, estimation by the Department of Ukrainian State Statistics). The total area of Ukraine is 233,090 sq. mi. (or 603,700 sq. km., the 44th country in size and second in Europe after European Russia). The total population is around 46.6 billion (in 2007, estimation by the Department of Ukrainian State Statistics). The word Ukraine originally meant "near the border" (of Russia and Poland).

The country has a mostly temperate continental climate, though a more Mediterranean climate is found on the southern Crimean coast. Precipitation is disproportionately distributed, being highest in the west and north (up to 31–39 in., or 800–1,000 mm. per year) and lesser in the east and southeast (around 16–18 in., or 400–450 mm. per year). Winters vary from cool along the Black Sea to cold farther inland. Summers are warm across the greater part of the country but are generally hot in the south. The average temperature in January is 18–19 degrees F (minus 7 to minus 8 degrees C) in the northern Ukraine, while it is 37–39 degrees F (3–4 degrees C) in the southern Crimea. The absolute January minimum/maximum temperature minus 43 degrees F to 67 degrees F (minus 42 degrees C to 19.5 degrees C) was observed in the northeast/Crimea. January precipitations vary from 1–2.5 in. (35–65 mm.) per month. The average temperature in July is around 64–75 degrees F (18–24 degrees C). The absolute July maximum/minimum temperature 106/36 degrees F (41.0/2.4 degrees C) was observed in the northeast. July precipitations vary from 1–7 in. (30–185 mm.) per month.

The linear temperature trend varies from around 1.8–3.6 degrees F (1–2 degrees C) per 100 years for the northern Ukraine in winter/spring to 30 degrees F (minus 1 degree C) per 100 years for the southern Ukraine in summer/fall. The linear trend of precipitation varies from around 4 in. (100 mm.) a year per 100 years for drier regions to minus 4 in. (100 mm.) a year per 100 years for wetter regions. So, the continental climate of Ukraine is becoming more mild. The interannular climate variability of Ukraine (especially its northern part) is under the strong control of the North Atlantic Oscillation.

The Ukrainian landscape consists mostly of fertile plains, or steppes, and plateaus, crossed by rivers such as the Dnieper, Seversky Donets, Dniester, and Southern Buh as they flow south into the Black Sea and the smaller Sea of Azov. To the southwest, the delta of the Danube forms the nation's border with Romania. The Danube is the largest European river, which rises in the Alpine region. Its average discharge from 1947–2001 was about 6,350 cu. m. per second. The maximum/minimum discharge (9,180/4,420 cu. m. per second) is observed in May/October. There is a positive linear trend of mean annual Danube discharge, which is about 200 cu. m. per second per 50 years. The country's only mountains are the Carpathian Mountains in the west, of which the highest is Mount Hoverla at 6,762 ft. (2,061 m.), and those in the Crimean peninsula in the extreme south, along the Black Sea coast.

The Black Sea is the southern border of Ukraine and is the largest natural reservoir of sulfate dioxide in any sea in the world. As a result of cyclonic general circulation in the Black Sea, the upper boundary of the sulfate dioxide zone is situated at a typical depth of about 262–328 ft. (80–100 m.) in the internal parts of the sea, and it deepens to up to 492–590 ft. (150–180 m.) along the shelf slope. The intensity of the principal element of the Black Sea general circulation (the so-called Rim current) varies from one decade to another as a result of quasi-periodic low-frequency changes of external forcing (such as wind stress, fresh/heat balance, and Mediterranean water inflow). The upper boundary of the sulfate dioxide zone moves up and down because of such quasi-periodical variability. There is also small negative trend of depth of sulfate dioxide zone (around minus 10 m. per 50 years), which points to its shoaling in the internal part of the sea in recent decades. This is the result of Rim current intensification caused by stronger external forcing.

The Black Sea, bordering the south of the Ukraine, is the largest natural reservoir of sulfate dioxide.

SEE ALSO: Climate Change, Effects; Oceanic Changes.

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UN Conference on Trade and Development/Earth Council Institute: Carbon Market Program

THE UNITED NATIONS Conference on Trade and Development (UNCTAD)/Earth Council Carbon Market Program (CMP) started in 1991 as the UNCTAD Emissions Trading Project and has opened the way for a collaboration between governments and the private sector in the development of a global carbon market. The program aims to reduce greenhouse gas emissions and is targeted primarily to economies in transition and third world countries. An emission trading system aims to control pollution by providing economic incentives for the reduction of polluting emissions. A central authority establishes a limit on the amount of a pollutant that can be emitted. Companies or other groups that release polluting emissions have to hold an equivalent number of credits or allowances, which represent the right to emit a specific amount. The total amount of credits cannot exceed the limit, so that total emissions cannot go beyond that level. Groups that need to increase their emissions must buy credits from those who pollute less. The transfer of allowances is described as a trade, although the buyer is actually being fined for polluting, while the seller is being compensated for their reduction of the emissions.

The starting point of the program is the recognition that future economies will be carbon constrained. UNCTAD and the Earth Council conceive their function as preparing developing countries for the likely changes in relative prices and relative production costs that the introduction of climate policies and measures will cause. They are also trying to facilitate a smoother transition to a postunregulated carbon economy.

The CMP aims to reduce the effect of climate change by contributing to the development of an integrated global emissions trading system in which all participant countries accept the principle of common but differentiated responsibilities. The United Nations Secretariat issued a major report on the subject in May 1992, as a contribution to the work of the Earth Summit held in Rio de Janeiro in June 1992. Since then, UNCTAD and the Earth Council have stimulated and encouraged research and capacity building in the area of greenhouse gas emissions trading. As one of their primary activities, UNCTAD and the Earth Council have lent their support to interested governments, corporations, and nongovernmental organizations for the development of a multilateral market for trading in greenhouse gas emission allowance and certified emission reduction credits, in accordance with the Kyoto Protocol and the decisions of the Conference of the Parties. The program also includes an annual Carbon Market Policy Forum, which brings together buyers, sellers, and market makers from the public and private sectors in both developed and developing countries.

A significant element of CMP is its work with economies in transition in developing their capacity to implement the Kyoto Protocol. CMP has devised a wide range of capacity-building activities and materials to assist accession countries, which form the Central Group 11 (CG11), in their development of national Kyoto strategies. CMP also has developed stocktaking reports of the current situation in relation to emissions trading and the Kyoto Protocol in accession countries. In addition, it has discussed a policy framework that identifies the various policy options and practical steps that CG11 countries may take, as well as the identification of specific capacity-building needs. In addition, UNCTAD and Earth Council have launched the Carbon Market E-learning Centre (CMEC), which contains modules related to emissions trading. The CMEC supplies learning opportunities for global audiences on the use of emissions trading as an economic resource to implement the UN Framework Conventions on Climate Change and the Kyoto Protocol. The center offers online courses and, more important, virtual workshops. These help other institutions to develop their own courses through the e-learning facilities of the CMEC.

UNCTAD and Earth Council Institute support the efforts of developing and transitional countries to participate effectively in the emerging trade and investments in allowances and credits for carbon emissions. As part of the CMP, UNCTAD and Earth Council Institute have also encouraged investments from the private sector for the Clean Development Mechanism (CDM) of the Kyoto Protocol, particularly in Least Developed Countries. The program has supported the creation of public-private bodies for the implementation of the CDM and has attempted to develop the CDM through capacity building, starting from the needs of local communities. The CMP has lent its support particularly to Brazil, as well as to African countries such as Tanzania, Uganda, Mozambique, Zambia, and Malawi.

SEE ALSO: Climate Change, Effects; Greenhouse Effect; Greenhouse Gases; Kyoto Protocol; United Nations; United Nations Environment Programme (UNEP).

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United Arab Emirates

LOCATED IN THE Persian Gulf, the United Arab Emirates (U.A.E., formerly the Trucial States) has a land area of 32,278 sq. mi. (83,600 sq. km.), with a population of 4,380,000 (2006 est.) and a population density of 139 people per sq. mi. (64 people per sq. km.). Its economy is heavily dependent on petroleum and natural gas, with the country enjoying a very high standard of living. With little natural freshwater and regular sand and dust storms, the U.A.E. has little arable land, with most of the food in the country being imported.

With a dry desert climate and great wealth, widespread use of private automobiles and air conditioning has resulted in heavy use of electricity, all of which comes from fossil fuels. This has resulted in the country having the third highest rate of per capita carbon dioxide emissions in the world—29.3 metric tons in 1990, falling to 16.9 metric tons in 1996, and then rising steadily to 37.8 metric tons per person by 2004. Some 67 percent of the carbon dioxide emissions have come from gaseous fuels, with 27 percent from liquid fuels, and 3 percent from gas flaring. In terms of the sector generating the carbon dioxide emissions, 43 percent comes from electricity production, 45 percent from manufacturing and construction, and 8 percent from transportation.

An effect of global warming and climate change in the U.A.E. has been the raising of the average temperature in the country, making the establishment of arable land even harder. It has also forced the country to invest heavily in desalination plants to provide the country with enough freshwater. There has been large-scale use of water to transform Dubai, and some environmentalists have been critical of the use of water for the maintenance of gardens and golf courses in the country. The rise in the temperature of the water in the Persian Gulf has also led to the bleaching of coral reefs and further depletion of fish stock.

The U.A.E. government took part in the United Nations Framework Convention on Climate Change, signed in Rio de Janeiro in May 1992. The government accepted the Kyoto Protocol to the UN Framework Convention on Climate Change on January 26, 2005, with it entering into force on April 26, 2005.

SEE ALSO: Carbon Dioxide; Climate Change, Effects; Global Warming; Kyoto Protocol.

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United Kingdom

THE UNITED KINGDOM of Great Britain and Northern Ireland has a land area of 94,526 sq. mi. (244,100 sq. km.), with a population of 60,587,300 (July 2006) and a population density of 637 people per sq. mi. (246 people per sq. km.). London, the capital and the 16th largest city in the world, has a population density of 11,927 per sq. mi. (4,597 per sq. km.). Some 25 percent of the land of the United Kingdom is devoted to agriculture, with a further 46 percent used for meadow or pasture, and 10 percent of the land being forested.

Traditionally, most of the electricity generation in the United Kingdom has come from coal, which has been mined in parts of Scotland, Yorkshire, Nottinghamshire, and South Wales. The continued use of coal, and also of oil, Britain having made use of the North Sea oil fields since the 1970s, has meant that 73.2 percent of Britain's electricity generation was, in 2001, still coming from fossil fuels—coal, oil, and natural gas—with 23 percent coming from nuclear fuel and only 1.5 percent from hydropower. Although recent governments have tried to use nuclear power more extensively, this move has been widely opposed by many people, who are concerned about the safety of nuclear power, with political pressure over the location of the various nuclear power stations.

The United Kingdom ranks 37th in terms of its carbon dioxide emissions per capita, with 10.0 metric tons in 1990, falling steadily to 9.2 metric tons by 1998, and then rising to 9.79 metric tons by 2004. A third of all carbon dioxide emissions in the country are from the generation of electricity, with 27 percent from transportation, through heavy use of private automobiles, and large traffic jams and tailbacks in London and many other major cities, some 17 percent generated for residential use, and 15 percent from manufacturing and construction. In terms of the source of these emissions, 27 percent is from solid fuels, with 36 percent from liquid fuels and 35 percent from gaseous fuels, and 1 percent from gas flaring.

There have been many effects on Britain of global warming and climate change. Because statistics have been collected there since the 18th century, it has been easier to study the changes. The number of cold days has steadily decreased, with an average of 4 days per year above 68 degrees F (20 degrees C) for most of the period since 1772, but 26 days above 68 degrees F (20 degrees C) in 1995. Indeed, October 2001 was the warmest October in central England, with four of the five warmest years in the previous three and a half centuries being in the 1990s and early 2000s. One study has shown that oak trees have experienced earlier leafing as the climate gets warmer.

As well as rises in temperature, there have also been widespread floods, with that in October and November 2000 resulting in the flooding of some 10,000 houses at a cost of about $1.5 billion. This was the worst flooding in Britain since those in March to June of 1947, with the melting of a six-week snowpack, although some war damage to locks on canals leading into the River Thames made the floods worse than normal. Since then, there had been floods in 1968, 1993, and 1998, with those in 2000 following the wettest autumn since records were first collected in the late 1660s. Although floods have not been unknown in Britain—and the River Thames flooded again in 2003 and 2006—in June and July 2007 there were much more serious floods. These caused damage estimated at $3 billion, with Northern Ireland experiencing floods on June 12 and East Yorkshire and the Midlands being hit three days later.

Over the next five weeks, large parts of Berkshire, Gloucestershire, Oxfordshire, and South Wales were also inundated, with rainfall in June 2007 being twice the June average. Indeed, some areas of the country received the average monthly precipitation in one day. The worry has been that the floods, which took place twice a century on average, are now taking place every three to five years. The flooding would be much worse without the construction of the Thames Barrier in the 1970s, which has prevented any serious floods from happening in London since those in January 1928, March 1947, and 1968.

During the 1990s, a detailed survey of plant species in the country showed that the date of the first flowering of 385 British plant species had advanced by an average of 4.5 days when compared with the previous four decades. Flowering is particularly sensitive to the temperature in the month before the plant flowers, indicating that plants have become sensitive to the changes in temperature, with those that flower in spring being the most responsive. In terms of fauna, British birds have steadily expanded their ranges northward, with more birds that had previously only been found in the south of the country being spotted in northern England and Scotland. Over the last 25 years, some birds have expanded the northern margins of their ranges by about 12 mi. (19 km.). Another study of birds has shown that between the years 1971 and 1995, some 32 percent of the 65 species in the study have started laying eggs earlier—on average 8.8 days earlier—each year. In addition, frogs, toads, and newts have started spawning

Floods causing an estimated $3 billion in damages hit the United Kingdom in 2007, including this flooding in Sheffield.

between 9 and 10 days earlier than had been the case 20 years earlier.

The British government of John Major took part in the United Nations Framework Convention on Climate Change, signed in Rio de Janeiro in May 1992. The next government, that of Tony Blair, signed the Kyoto Protocol to the UN Framework Convention on Climate Change on April 29, 1998, ratifying it on May 31, 2002, with it entering into force on February 16, 2005.

The United Kingdom Climate Strategy introduced in 1994 had the objective of keeping greenhouse gas emissions of carbon dioxide, methane, and nitrous oxide at 1990 rates—carbon dioxide by incentives to business and home users to conserve energy; methane by reducing landfill through a landfill levy and a greater regulatory environment, as well as limiting methane emissions from coal production; and nitrous oxide through technological innovations in the manufacture of nylon. The introduction of three-way catalytic converters was planned to reduce carbon monoxide, especially from car exhausts, by up to 50 percent, and the reorganization of large power stations was expected to reduce nitrogen oxides by 35 percent.

In November 2000, the United Kingdom's Climate Change Policy, which was formulated following the United Nations Conference on Environment and Development, was formally launched. The United Kingdom was, in 2004, the eighth largest producer of carbon emissions, with the country being responsible for about 2.3 percent of the world's total coming from fossil fuels. The plan drawn up by the Blair government was not just to cut the emissions back to 12.5 percent less than the 1990 rate during the period from 2008 until 2012, as agreed by the Kyoto Protocol, but also to reduce them to 20 percent lower than the 1990 rate by 2010. The methods used by the British government to reduce carbon emissions largely hinged on encouraging business to improve its use of energy, to cut back on emissions from cars by providing better public transport, to promote energy efficiency in homes, and to get agriculture to reduce emissions.

As worry about the effects of global warming and climate change received much publicity in the British press, the Campaign against Climate Change was founded in 2001 to oppose the rejection of the Kyoto Protocol by U.S. president George W. Bush. Although it had small beginnings, on December 3, 2005, it did organize a large rally in London, and another took place on November 4, 2005. By this time, there were also a number of other pressure groups, including Stop Climate Chaos. Formed as a coalition of a number of other groups, including the Campaign against Climate Change, in September 2005, Stop Climate Chaos was also organizing protests. This was to lead to the I Count Campaign to try to get governments around the world to introduce measures to prevent world temperatures from rising more than 3.6 degrees F (2 degrees C).

On June 21, 2006, royal assent was given to a parliamentary bill that became the Climate Change and Sustainable Energy Act 2006, which, introduced to the British Parliament by Mark Lazarowicz, a Scottish Labour member of parliament, encourages microgeneration installations to reduce the use of large power stations and, as a result, reduce carbon dioxide emissions and fuel poverty, whereby some poor people had been unable to afford to heat their residences. The impetus from this led to the drafting of the Climate Change Bill, which was published on March 13, 2007, based heavily on the measures suggested in the I Count campaign. It aimed to reduce the United Kingdom's carbon emissions for 2050 to 60 percent of the level for 1990, with an intermediate target range of 26 to 32 percent by 2020. The bill was initially criticized for failing to include international aviation and shipping but quickly gained cross-party support, although it has not been passed into law. The British government has also been very keen on establishing a system of having a greenhouse gas allowance trading regime, although plans for this are still being drawn up.

SEE ALSO: Carbon Dioxide; Climate Change, Effects; Global Warming; Kyoto Protocol.

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United Nations

GLOBAL CLIMATE CHANGE is one of the most pressing issues of the 21st century. Because of the use of coal, oil, and gas for energy and the loss and degradation of forests, our planet is warming faster than at any time in the last several thousand years. We have already experienced warming temperatures, changing rainfall patterns, and sea-level rise. These disruptive forces have severe effects on economies, environment, and society of humankind. Nonetheless, the climate challenge may at the same time be viewed as an enormous opportunity for a significant economic change. It is quite evident that the United Nations (UN), by implementing a number of notable conventions and treaties, assumes a key role to play in a wide range of activities concerned with understanding, mitigating, and adapting to climate change. In a nutshell, the past few decades have seen a growing recognition of the importance of involvement of the UN with the complex scientific and technical issues related to global warming, climate change, and sustainable development.

Although it is rightly perceived that it is just a kind of global challenge the UN is uniquely positioned to address, it is also recognized that this is not a challenge for this world body alone. To handle the dilemma, it requires a truly concerted global effort—an initiative that draws together national governments, private sector, and civil society in one sustained push for change. This policy-relevant piece concludes by asserting the following forward-looking reflections that the UN, with its sensitivity and imagination, will be able to more successfully convey the urgency of the situation and send the following message to all of us: we should unite at any cost to save our beloved planet.

THE UN CONVENTIONS ON CLIMATE CHANGE

Regardless of the fact that the international scientists have drawn attention to the threats posed by global warming in the 1960s and 1970s, it took some years before the global community responded. In 1988, an Intergovernmental Panel on Climate Change (IPCC), an authoritative UN network of 2000 scientists, was created by the UN Environment Programme (UNEP) and the World Meteorological Organization. In 1990, this group presented a first assessment report that reflected the views of 400 scientists. The report indicated that global warming was real and urged that something be done about it. The findings of the panel prompted governments to create an international treaty, the UN Framework Convention on Climate Change (UNFCCC). By the standards of international agreements, the negotiation of the convention was rapid. It was ready for signature at the UN Conference on Environment and Development, more popularly known as the Earth Summit, held in Rio de Janeiro in 1992.

More comprehensively, the Convention on Climate Change, which entered into effect on March 21, 1994, sets an overall framework for intergovernmental efforts to tackle the challenge posed by climate change. It recognizes that the climate system is a shared resource, the stability of which can be affected by industrial and other emissions of carbon dioxide and other greenhouse gases (GHGs). Under this convention, which enjoys near universal membership, with 191 countries having ratified it, governments gather and share information on GHG emissions, national policies, and best practices; launch national strategies for addressing GHG emissions and adapting to expected effects, including the provision of financial and technological support to developing countries; and cooperate in preparing for adaptation to the effects of climate change. Notwithstanding, the recent UNFCCC report underscores the principal changes to patterns of investment and financial flows required to tackle climate change in the next quarter century. A major accomplishment of the convention, which is general and flexible in character, is that it admits that there is a problem.

A number of nations have recently approved an addition to the UNFCCC, the Kyoto Protocol, a second, more far-reaching international treaty on climate change that entered into force on February 16, 2005. The Kyoto Protocol has more powerful and legally binding measures that call for industrialized countries to collectively reduce emissions to 5 percent below 1990 levels between 2008 and 2012. In fact, these trends have been projected to accelerate over the recent years, including the Conference of the Parties of the UNFCCC, held in Bali (Indonesia) in December 2007, although the Vienna Climate Change Talks 2007 were attended by nearly 1,000 representatives from over 150 governments, business and industry, environmental organizations, journalists, and research institutions.

THE UN RESPONSE TO CLIMATE CHANGE ACTION

In 2007, climate change has indeed become one of the highly prioritized concerns for the UN, because there is now an overall understanding that the phenomenon will seriously affect the way the world operates in toady's challenging era of globalization, from healthcare and water issues to economic activity, humanitarian assistance, and the peace-building and security aspects. The UN has already demonstrated a long-standing commitment and responsibility toward resolving the cardinal environmental hazards encompassing reducing GHG emissions to limit future climate change and improving the capacity of the world's biodiversity and poorest communities to adapt to its inevitable effects. This universal organization has played a pivotal role in generating the scientific consensus, elevating the issue to the cover pages of the global media, and placing it on the in-tray of heads of state and government, as well as the chief executive officers of businesses and industries.

The UN, through the UNFCCC, helps to accelerate the take-up of clean and renewable energies to counter the climate change challenge. To be more specific, the Clean Development Mechanism (CDM) of the Kyoto Protocol permits developed countries to offset some of their emissions through clean and renewable energy projects and certain forestry schemes in developing countries. The CDM funds flowing from north to south will reach up to US$100 billion over the coming years. The high-technology industries and job opportunities are emerging in both developed and developing nations. China and India are currently homes to two of the biggest wind turbine and power companies. The foreign direct investment in renewable energy, driven in part by the UN-brokered climate treaties, is anticipated to top US$80 billion in 2007. The UN system is further endeavoring to nourish this process. For instance, the UNEP, in partnership with the UN Foundation and Asian Development Bank, piloted a project that has brought solar power to 100,000 people in India.

This sort of progress actually echoes the Millennium Development Goals adopted by the UN, as they relate to such areas as poverty alleviation, public health, basic education, and so on. Furthermore, the UN assists in harnessing the power of the carbon markets and evaluates the potential for forests to cope with challenge emanated from the climate change. The UN's Food and Agriculture Organization, for example, estimates that 13 million hectares of the world's forests are lost annually and that deforestation accounts for approximately 20 percent of the global GHG emissions.

The issue of climate change, along with such steps as the UN Global Compact, assists the restoration of nexus between the UN and other segments of society making up business and industry. Although an intriguing feature of recent months is a call by the private sector for international regulation across the globe, businesses appear eager to do their part if the ground rules are clear and comprehensive. In addition, many other welcoming initiatives are already being undertaken. The European Union, for instance, has agreed to a 20 percent emission reduction target, which will rise to 30 percent if other countries follow suit. The Group of Eight Summit in Germany has also affirmed the ongoing UN climate change process. It is demanding that governments and the UN deliver an international agreement to address this issue. Developing countries are also acting at the same time. In Brazil, efforts to counter deforestation in the Amazon have shown positive results, whereas China has recommitted itself to reduce its energy intensity by 20 percent.

In addition, the prime minister of India has recently ordered a review of his nation's GHG emissions.

The UN is looking at its own backyard as well. The Capital Master Plan for the refurbishment of the UN headquarters in New York is assessing how to factor green measures into the project, looking to make the structure a striking example of an ecofriendly building. This is part of a wider evaluation of how UN operations, from building to procurement of goods and services, can respond to the sustainability challenge. It is redundant to say that the UN World Tourism Organization (UNWTO) has developed an information-gathering Web resource consisting of data, studies, policy papers, videos, and other materials, as part of its effort to combat climate change. Although the tourism sector is expected to mitigate and adapt in the face of global warming and to explore and put in place more climate-friendly and climate-proof alternatives, the UNWTO service is a contribution to fostering the knowledge base and search for solutions to meet the climate challenge.

Finally, the UN is the only forum in which an agreement striving to reduce GHG emissions beyond 2012 could practically be brokered among the 190-plus countries with diverse outlooks and economies, but of a common atmosphere. Despite the fact that the warming of the Earth's atmosphere has by this time adversely affected fragile ecosystems and the livelihoods of poor people, this protest at the same time offers manifold alluring prospects for all of its member states.

FUTURE DIRECTIONS

The most recent findings of the IPCC have emphasized that the science on climate change is very clear. The panel report, issued in May 2007, has also unequivocally confirmed the warming of the climate system and linked it directly to human activities. The IPCC has outlined the likely effects of climate change in the near future if the international community fails to act. Although this grave threat is now beginning to receive the high attention it merits, it brings up an underpinning question about how the UN itself will meet this ultimatum, carrying serious implications for our planet and our future generations.

UN Secretary-General Ban Ki-moon, who has identified climate change as one of his top priorities since his

A moment of silence was observed for the victims of the Algiers bombing during the United Nations Climate Change Conference in Bali, Indonesia, December 3–14, 2007. The gathering brought together representatives of over 180 countries.

very first days in office, intends to take a leadership role in supporting efforts by the international community to address the problem by bringing world leaders together and ensuring that all parts of the UN system will contribute to the solution. The UN, as a global forum with broader participation, is best suited to forging a common approach to responding to climate change. Observing the imminence and severity of the problems posed by the accelerating changes in the global climate, the secretary-general has warned that we cannot go on this way for long, and that we cannot continue with business as usual. He also urged us to take joint action on a global scale to address climate change. It is true that there are numerous policy and technological options available to face this impending crisis, but we should have the political will to seize them.

Both developed and developing countries have to be able to reassess the big picture of what is required by identifying the key building blocks for an effective response to climate change. There is a consensus that the response needs to be global, with the involvement of all countries, and that it needs to give equal weight to adaptation and mitigation. The industrialized nations can do much more to reduce GHG emissions and encourage energy efficiency, and they can also support clean development in fast-growing economies and adaptation measures in countries facing the greatest hardships from climate change. In contrast, the developing countries need to be more engaged in addressing climate change while safeguarding their socioeconomic growth and poverty eradication. As for the UN as a whole, it should help the developing economies to finance and deploy energy efficient technologies and incorporate adaptation into the UNFCCC and related environmental organizations.

As an expert scientific panel has recently reported to the UN, to head off the worst of climate change, the governments must pour tens of billions of dollars more than they are into clean-energy research and enforce sharp rollbacks in fossil-fuel emissions. The UN itself must better prepare to help tens of millions of environmental refugees, and authorities everywhere should discourage new building on land less than 1 m. (39 in.) above sea level. The construction of climate-resilient cities may also be championed. The climate-resilient cities are identified as cities that produce low per capita emissions and that can manage weather-related events. Moreover, a climate-resilient city has a reliable supply of potable water, given that water will likely become scarcer as weather patterns change.

The UN is an intergovernmental organization, but it collects its strength and inspiration from the support of civil society worldwide. In fact, there are a number of wonderful illustrations of cohesive ties binding the UN to global civil society. Although these relationships date back to the earliest days of this global forum, they have truly come of age just recently. In spite of the truth that this has been possible because of a deliberate and sustained outreach effort on both parts, it also reflects the substantially expanded role of civil society organizations on the world stage. That is why today's UN relies on its partnership with the nongovernmental organization (NGO) community in virtually everything it does. Some research findings show that the nonstate actor can contribute effectively and efficiently, if it fosters awareness in developing inventive initiatives at the grassroots level, which inspire people to work toward a solution. Thus, one area in which the cooperative partnership between the UN and civil society is increasingly essential relates to the global challenge posed by climate change. Conceding that the NGOs have historically been at the forefront of the struggle to draw attention to the environment, and to push for action to protect it, they may be stimulated to shoulder their redoubled responsibility toward building grassroots support for a breakthrough, as well as common ground for fighting climate change.

Climate change is not just an environmental issue but one that has serious socioeconomic implications as well. Because this advanced issue requires the attention of many sectors such as finance, energy, transport, agriculture, and health, climate change should firmly be positioned in the broader sustainable development agenda. Climate change impinges on all countries, because its aftermaths know no boundaries. Hence, this issue must be addressed in the context of the international development agenda. To be more concrete, the actions on climate change must be integrated into development efforts and scientific research led by various parts of the UN family. This may include work to address investment flows and finance schemes relevant to the development of an effective and appropriate international response to climate change and increased support for adaptation and for involving industry leaders to encourage support from the private sector. In other words, multilateral and bilateral donors, regional development banks, and international investment flows into the developing countries ought to reflect adaptation in their investment decisions.

It is expected that the Bali summit, by building a climate of trust among all governments in that spirit, will determine future action on mitigation, adaptation, the global carbon market, and financing responses to climate change for the period after the expiry of the 166-member Kyoto Protocol, the current global framework for reducing GHG emissions, in 2012.

CONCLUSION

Combating climate change presents a remarkable opportunity to break with the past and to look anew at the way we operate, the way we do business, and the path we use to relate to each other, now and in the future. Nevertheless, as climate change is a global problem, it needs a long-term global solution. The UN's ultimate goal is to make a comprehensive agreement under the UNFCCC process. Such an agreement must tackle climate change on all fronts, including climate adaptation, disaster mitigation, clean technologies, global deforestation, and resource mobilization. The UN should be at the center of brokering a fair, equitable, and decisive climate change regime for the new millennium. Toward confronting the climate change challenge, the UN needs an international collaborative stride made by governments, the private sector, and civil society. If this comprehensive organization succeeds, it will not only change the world but will save humanity. The UN must lead the world to a universal consensus discussion and enroot a strategic policy guideline to be realized over the coming years; the faster we get at it, the easier it is going to be to adapt.

SEE ALSO: Adaptation; Clean Development Mechanism; Deforestation; Developing Countries; Energy Efficiency; European Union; Greenhouse Gases; Kyoto Protocol; Nongovernmental Organizations (NGOs); Refugees, Environmental; Tourism; United Nations Environment Programme (UNEP).

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United Nations Development Programme (UNDP)

THE UNITED NATIONS Development Programme (UNDP) is the United Nations' (UN's) global development network that assists developing countries in managing and funding sustainable environmentally sensitive global and national development and, as such, is the world's largest multilateral development source. The UNDP was created (1965–71) by merging the Expanded Programme of Technical Assistance with the UN Special Fund. The UNDP currently works in 166 countries, with the UNDP Resident Representative in each generally serving as the resident coordinator of the UN development activities. The UNDP is an executive board within the UN General Assembly. The UNDP administrator is the third-ranking position in the UN, following the secretary-general and deputy secretary-general. Headquartered in New York City, the UNDP is funded entirely by voluntary contributions from member nations. The UNDP annually publishes local, regional, national, and global Human Development Reports. The UNDP concentrates on five development challenges: democratic governance, poverty reduction, crisis prevention and recovery, energy and environment, and HIV/AIDS.

UNDP GOALS AND INITIATIVES

The umbrella goal of the UNDP is to cut world poverty in half by 2015; that goal is supported by seeking to achieve in the same year eight subsidiary Millennium Development Goals (MDGs), so named because they were derived from the September 2000 UN Millennium Summit. The MDGs are to eradicate extreme poverty and hunger; achieve universal primary education; promote gender equality and empower women; reduce child mortality; improve maternal health; combat HIV/AIDS, malaria, and other diseases; ensure environmental sustainability; and develop the Global Partnership for Development endorsed at the March 2002 International Conference on Financing for Development in Monterrey, Mexico, and reaffirmed in August 2002 at the Johannesburg World Summit on Sustainable Development.

The goal of achieving environmental sustainability is rooted in the idea that developing and impoverished countries are those countries that are most damaged by environmental degradation and by the use of expensive polluting energy sources. The UNDP's goal of ensuring environmental sustainability concentrates on effective water governance, access to sustainable energy services, sustainable land management targeting desertification and land degradation, the conservation and sustainable use of biodiversity, and national/sectoral policies controlling emissions of ozone-depleting substances (ODSs) and persistent organic pollutant (POP) emissions. The UNDP seeks to accomplish these objectives by linking its developing country client states with environmentally sensitive development projects that produce long-term jobs. The UNDP also helps these same countries develop and adopt policies that encourage and sustain these projects and assists in developing other governmental policies and action plans that might positively affect environmental sustainability. The UNDP also helps these countries develop the capacity to manage their environment, energy resource use, and sustainability while reducing poverty, sustaining their advancing development, and integrating the local communities and women into this management.

The UNDP promotes the effective use of the client state's water resources by developing policies and programs integrating the sustainable use of marine, coastal, and freshwater resources; adequate and accessible clean water sources; and the sanitation services necessary to sustain and improve these water resources. The UNDP supports these integrated water resources management programs by initiating and then requiring transboundary waters management within a water governance framework uniting local, national, and regional governmental entities.

The UNDP promotes access to sustainable clean energy services by supporting sustainable and integrated transboundary energy resource development and energy use targeted at reducing the poverty in the client state. The UNDP promotes the use of energy technologies that are climate change neutral or abating. The UNDP facilitates these programs by providing access to funding sources that include, but are not limited to, the Kyoto Protocol's Clean Development Mechanism and the Global Environment Facility (GEF) program. All of the funding sources accessible through the UNDP support projects that mitigate climate change and support indigenous sustainable livelihoods.

The UNDP promotes sustainable land management, contending that land degradation and desertification are two of the major causes of rural poverty in developing countries. The UNDP concentrates on educating and helping its client states and their composite communities maintain the integrity of the indigenous land-based ecosystems by developing or revising land governance policies that protect the land, sustain livelihoods, and mitigate or adapt to climate change. The UNDP also supports the creation of infrastructure projects that prevent or retard land degradation and desertification. These projects are funded for the most part by integrated multistakeholder relationships symbiotically uniting local, national, regional, and global entities.

The UNDP promotes conservation and sustainable biodiversity by helping client states and their composite communities maintain and develop the capacity to manage their indigenous biodiversity and ecosystems. This process not only seeks to sustain the indigenous biodiversity and ecosystems but also seeks to manage them so as to provide more food, fuel, sustainable livelihoods, and medicines in addition to better security and shelter. This process sometimes entails the development of clean water systems, improved disease control, and better preparedness for and reduced vulnerability to natural disasters. The UNDP helps these countries develop and then manage their agriculture, fisheries, forests, and other resources in a pro-poor approach oriented to developing marketable self-sustaining biotechnology.

The UNDP's Montreal Protocol and GEF programs are designed to support the reduction and elimination of ODSs and POP emissions on the national and sectoral levels while maintaining the economic competitiveness of the client states through alternative technologies and increasing indigenous capacity.

SEE ALSO: Clean Development Mechanism; Intergovernmental Panel on Climate Change (IPCC); Kyoto Protocol; Sustainability; United Nations.

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United Nations Environment Programme (UNEP)

THE UN ENVIRONMENT Programme (UNEP) coordinates all United Nations (UN) global and regional environmental activities, assists developing countries in implementing environmentally sound policies, encourages sustainable development through sound environmental practices, reviews the status of the global environment, seeks consensus in environmental policy, and alerts the global community and governments of new and emerging threats to the biosphere. The UNEP officially divides its responsibilities into seven divisions: Early Warning and Assessment; Environmental Policy Implementation; Technology, Industry, and Economics; Regional Cooperation; Environmental Law and Conventions; Global Environment Facility Coordination; and Communications and Public Information.

The UNEP grew out of the June 1972 UN Conference on the Human Environment, but its mandates and objectives are derived from UN General Assembly resolution 2997 (27) (December 15, 1972), as amended at the UN's 1992 Conference on Environment and Development, the 1997 Nairobi Declaration on the Role and Mandate of UNEP, and the Malmö Ministerial Declaration of May 31, 2000. The UNEP is headquartered in Gigiri, Nairobi, Kenya, and has six regional offices and a number of country offices all under the governance of UNEP's Governing Council. Fifty-eight member states allocated according to geographical regions and serving three-year terms make up the council. The council has the primary responsibility for the developing UN policies and programs on environmental issues. The council attempts to mediate differences and promote cooperation between UN member states. The UNEP secretariat employs 890 global staff members and is funded by UN member states. The UNEP's executive director, as of June 2006, was Achim Steiner. Steiner was preceded in the position by Dr. Klaus Töpfer, who followed Dr. Mostafa Kamal Tolba, who held the position from 1975 to 1992.

GOALS AND ACTIVITIES OF UNEP

UNEP activities span the spectrum of global environmental issues concerning the atmospheric, marine, and terrestrial ecosystems. The UNEP develops international and regional meetings on environmental issues, promotes a synergy of science and policy on environmental issues, funds and implements development projects related to the environment, works with environmental nongovernmental organizations (NGOs), and is responsible for coordinating and implementing responses to climate change, especially when those changes relate to undeveloped countries with little funding. The UNEP cosponsors and coorganizes regional workshops on the common problems of climate change and possible response strategies in Africa, Latin America, the Caribbean, the Asian-Pacific Basin, and the former Soviet Union.

UNEP also sponsors the development of member state solar loan programs and plays a pivotal role in restoring the Shatt al Arab marshlands that were virtually destroyed by Iraq's Saddam Hussein when the Marsh Arabs sided with Iran in the Iran-Iraq War. The UNEP estimated in 2001 that the marshes were reduced to no more than 386 sq. mi. (1,000 sq. km.). Restoration of the marshlands began in 2003, following the end of organized Iraqi military resistance to the 2003 Anglo-American invasion of Iraq to oust Hussein, and by 2007, the marsh was restored to approximately 50 percent of the area it made up before the Iran-Iraq War. In a similar vein, the UNEP helped/helps create guidelines and treaties relating to transboundary air and water pollution and international trade in harmful chemicals.

The UNEP plays an integral role in creating criteria and indicators for assessing ecological and economic vulnerabilities to climate change and developing regional responses and adaptation. The UNEP is creating a handbook on economical agricultural adaptive strategies to climate change and has published a handbook on climate change communications. The UNEP also plans and implements the Climate Change Outreach Programme, promoting climate change awareness at the national level and assisting governments in developing adaptive response strategies. Its Assessment of Impacts of and Adaptation to Climate Change in Multiple Regions and Sectors project, funded by the Global Environment Facility, seeks to create the scientific and technical capacity in over 45 mostly African countries to respond to climate change.

The discovery of a hole in the ozone layer of the atmosphere in 1985, coupled with the earlier detection of the warming of the Earth (1980), gave impetus to the idea that one of the causes is human-induced climate change (anthropogenic climate change) from man-made, ozone-depleting gases. The United Nations and the World Meteorological Organization (WMO) responded by creating in 1988 the Intergovernmental Panel on Climate Change (IPCC) and tasking it with studying the hypothesized phenomenon on a comprehensive, objective, open, and transparent basis. The IPCC determined that the Earth had warmed over the last 150-year period and that that warming was in part caused by human activity. The executive summary of the report concluded that most of the observed global warming experienced in the last 50 years is a result of the increase in greenhouse gas concentrations. The IPCC and former U.S. vice president Al Gore were jointly awarded the Nobel Peace Prize on October 12, 2007, for their work on global warming.

The UNEP and the WMO provide the joint secretariat support to IPCC. The IPCC does not engage in research. Its assessments are based on peer-reviewed and published scientific/technical literature under guidelines set forth in the Principles Governing IPCC Work. The IPCC has three Working Groups and a Task Force. Working Group I assesses the scientific aspects of the climate system and climate change. Working Group II assesses the vulnerability of socio-economic and natural systems to climate change, negative and positive consequences of climate change, and adaptive strategies. Working Group III assesses options for limiting greenhouse gas emissions and ways of mitigating climate change. The Task Force on National Greenhouse Gas Inventories is responsible for the IPCC National Greenhouse Gas Inventories Programme and developed the methodology for calculating national greenhouse gas inventories.

After the IPCCs Fourth Assessment Report was issued in February 2007, 46 nations, led by France, signed the Paris Call for Action seeking the replacement of the UNEP with a new and more powerful United Nations Environment Organization. The top four greenhouse gas emitters, the United States, China, Russia, and India, did not sign.

SEE ALSO: Climate; Global Environment Facility (GEF); Greenhouse Gases; Intergovernmental Panel on Climate Change (IPCC); United Nations; World Meteorological Organization.

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United States of America

THE UNITED STATES of America is the world's largest industrialized country and emitter of carbon dioxide. It is therefore widely regarded as the most significant contributor to global warming and climate change. U.S. climate change policies have never remained consistent, as they have tended to shift in accordance with the presidential administration in office. The current administration, led by George W. Bush, has come under particular scrutiny from the media, the scientific community, the general public, and other countries for its climate change policies.

The focus on climate change in the United States became particularly acute in the late 1980s and evolved out of concern about the growing damage to the ozone layer. For two decades, that problem had occupied the attention of scientists and policymakers. In the early 1970s, scientific researchers at the University of California in Irvine established clear evidence that chlorofluorocarbons (CFCs)—chemical compounds made up of fluorine, chlorine, and carbon—were damaging the ozone layer, the thin protective layer above the Earth's atmosphere. The increased solar radiation entering the atmosphere as a result of this damage had the potential to cause health problems such as skin cancers and cataracts. At the time, CFCs were widely used as refrigerants, cleaning solvents, and the basis for aerosol products.

In October 1976, the U.S. Environmental Protection Agency (EPA) prohibited companies from manufacturing CFC-based products unless they were essential and threatened to cancel the product registration of companies that failed to comply. The following year, the agency ordered a gradual phase-out of CFCs from household products such as deodorants, hairsprays, and cleaners. In 1985, the United Nations Environment Programme (UNEP) created a framework convention for the protection of the ozone layer. It encouraged governments to adopt relevant measures to that end, devised a Conference of the Parties composed of governments that had ratified the convention, and appointed a UN secretariat to monitor and frame the actions of the Conference of the Parties. The creation of the framework convention paved the way for international negotiations over the regulation of CFCs. These negotiations, although initially hindered by energy interests in both the European Union (EU) and the United States, ultimately led to the Montreal Protocol of 1988, a worldwide treaty that mandated a staged reduction in the production and consumption of fully halogenated CFCs. The treaty was more lenient toward developing countries, as it gave them a 10-year grace period for the phase-out of CFCs and promised them technological assistance from industrialized nations in return for switching to CFC alternatives. The United States ratified the Montreal Protocol on April 21, 1988, and brought it into effect at the beginning of the following year.

During the next 18 months, the signatories of the Montreal Protocol realized that the original draft of the protocol did not go far enough in controlling CFC emissions. At the second Conference of the Parties in June 1990, delegates placed further restrictions on the production and use of CFCs and further reduced the acceptable level for CFCs in the atmosphere. The fourth Conference of the Parties, which took place two years later, led to further changes. For example, the United States had to limit its production of ozone-depleting substances in accordance with its own Clean Air Act. Over time, the Montreal Protocol virtually eliminated CFC emissions and significantly reduced the threat to the ozone layer. Ultimately, it was the model on which future environmental regulations were based.

INTERNATIONAL FOCUS ON CLIMATE CHANGE

At the same time as ozone depletion was occupying the attention of international policymakers, the issue of planetary climate change was also gaining ascendancy on the world stage. As a phenomenon, climate change was by no means new, having been identified by scientists in the late 1950s. However, in the 1980s, it became the focus of widespread public and political attention. In the summer of 1988, the United States experienced its hottest and driest summer since records began. Fire destroyed millions of acres of forest in western regions of the country, and in the south, barges and small boats became stranded as the Mississippi River began to recede. The Midwest experienced prolonged periods of drought, and across the country crop yields declined severely. On June 23, the temperature in Washington, D.C., reached a record 101 degrees F (38 degrees C).

In response to the extreme weather conditions, Senator Timothy Wirth (D-CO) convened a U.S. Senate hearing on the issue of climate change. Paul Revere, a scientist for NASA, confirmed at the hearing that extra carbon was building in the atmosphere and heating the Earth. His colleague James E. Hansen similarly asserted that the planet was experiencing its highest temperatures of the 20th century. Both men used the phrase "the greenhouse effect" to describe global warming. They also claimed that global warming was occurring as a result of human activity, especially the combustion of fossil fuels such as coal and oil.

Just days after the Senate hearing ended, politicians, officials, and scientists gathered in Toronto, Canada, for an environmental conference. The delegates proposed a 20 percent reduction in global carbon dioxide emissions by 2005, although they based this proposal less on firm economic and scientific analysis than on a desire to show their commitment to solving the climate change problem. Later that year, in December, the UNEP and the World Meteorological Organization jointly created the Intergovernmental Panel on Climate Change (IPCC), an organization designed to bring together climate information from around the world.

THE DIVISIVE ISSUE OF GLOBAL WARMING

At a 1989 summit meeting of the world's seven largest industrial democracies, it was apparent that the EU and United States were becoming increasingly divided over global warming. West European countries thought that the evidence about climate change was irrefutable, whereas George H.W. Bush, the American president, argued that the matter required further research. A number of factors accounted for the disparity between the two sides, particularly the fact that the United States was experiencing higher and faster population growth than Europe, and thus would be more adversely affected by limitations on carbon emissions and fuel consumption. In 1990, the IPCC released its first report, which reflected the general consensus of scientists that global warming was a serious issue.

The 1992 UN Conference on Environment and Development, at Rio de Janeiro in Brazil, represented the first step toward international regulation of climate change. Attended by governments from around the world, the conference resulted in a treaty called the Framework Convention on Climate Change (FCCC), which sought to limit greenhouse gases at a level that would not interfere with the planet's natural climate system. It also established a new Conference of the Parties, a forum in which nations would meet and establish environmental standards. The United States, still under the leadership of George H.W. Bush, promptly ratified and implemented the treaty, as did the majority of governments at the conference. Industrialized countries also used the conference as an opportunity to adopt a program called Agenda 21, which promised development assistance to developing countries on the condition they took steps to adopt more environmentally sound policies.

In January 1993, recently elected U.S. president William J. Clinton assumed control of the White House. The vice president in the new administration, Albert Gore, had published a book the previous year called *Earth in the Balance*, which he hoped would alert the general public to the fragility of the natural environment. On Earth Day in April of that year, Clinton, in adherence with the stipulations laid down in the FCCC, publicly announced that he aimed to reduce carbon dioxide emissions to their 1990 level by the year 2000. He also called for a tax on energy consumption, although strong opposition from the Democratic-controlled Congress thwarted this proposal.

The IPCC released its second report in 1996. The report stated that human activities were having a clear effect on climate change. Although some scientists were still skeptical about the findings, the majority agreed that global warming had become a major problem. In light of the evidence presented in the report, Conference of the Parties delegates sought further preventative measures. At the Second Conference of the Parties in Geneva that year, Timothy Wirth, now undersecretary for global affairs in the Clinton Administration, announced that the United States was willing to limit its greenhouse gas emissions if other countries were prepared to do the same. Delegates at the conference began to draw up a protocol for the framework convention that they could sign at the next Conference of the Parties, scheduled for Kyoto, Japan, in 1997. The most important aspect of the draft protocol was its proposal to reduce carbon emissions to a set level between 2008 and 2012.

As part of his ongoing efforts to underline his commitment to solving the global climate crisis, Clinton gave a speech at a special meeting of the UN in New York in June 1997. He proposed the development of new technology, the introduction of strategies such as emissions trading, and the adoption of measures that would protect the environment without impeding economic growth. He followed up this speech by holding a press conference with Gore at the White House the following month. At the conference, he reiterated his government's commitment to tacking climate change. The U.S. Senate, which had come under Republican control in the midterm elections, was becoming increasingly uneasy at Clinton's rhetoric, and in late July it adopted a resolution that warned the president to exercise caution at the forthcoming Kyoto conference. Known as the Byrd-Hagel Resolution, after its two main sponsors, the resolution advised Clinton not to accept terms that would jeopardize the American economy or place less responsibility for climate change on developing nations. Although opposition in Congress was mounting, Clinton stated at a meeting of the National Geographic Society in October that he supported reducing U.S. emissions to their 1990 level between 2008 and 2012. He neglected to explain, however, that the plan might have negative economic consequences for the United States.

INTERNATIONAL RESPONSES

The third Conference of the Parties took place in Kyoto, Japan, in November 1997 and was attended by 10,000 government officials from across the globe, as well as scores of lobbyists, observers, and media representatives. During the proceedings, the United States reiterated Clinton's plan to reduce carbon dioxide emissions to their 1990 level during the first commitment period, between 2008 and 2012. Most of the European countries felt that this measure was inadequate, and they demanded more substantial action. The dissension between Europe and America thwarted an agreement over emissions policy, and only a last-minute trip to Japan by Gore resulted in a compromise between the two sides. Gore said that the United States would reduce its carbon dioxide emissions to 7 percent below the 1990 level during the first commitment period, scheduled for 2008 to 2012, and the Europeans agreed to cut their emissions to 8 percent below the 1990 level during the same time frame. Overall, the Kyoto text only committed the 38 industrialized countries in attendance at the conference to reducing their emissions. It placed no obligation on developing nations, who argued that a binding emissions treaty would hinder their path to full industrialization.

The treaty, although open for signatures at the end of the conference, was by no means complete. A number of issues remained unresolved, including emissions trading and carbon dioxide sinks. Emissions trading, a policy strongly favored by the United States, would allow countries that had improved on their emissions targets to sell the difference to countries at risk of not meeting their targets. Many European countries were unfamiliar with this policy and were reluctant to adhere to it without full knowledge of its consequences. Australia, Japan, and the United States also advocated that carbon dioxide sinks—reservoirs such as forests and oceans that absorb carbon and prevent it from escaping into the atmosphere—should be included as part of countries' emissions targets. Clinton signed the treaty in 1998 but did not present it to the Senate for ratification.

The sixth Conference of the Parties opened at The Hague in the Netherlands in late November 2000. It was somewhat overshadowed by events in the United States, where the result of the November 7 presidential election was still in dispute because of ongoing recounts in the state of Florida. The key purpose of the conference was to establish the regulations for the implementation of the Kyoto Protocol. For the previous three years, dissension and conflicting interests had prevented the protocol from coming into force. The Umbrella Group—a federation composed of the United States, Australia, Canada, and Japan and supported by energy companies and oil-rich countries such as Kuwait—argued that carbon sinks should be allowed to count as part of countries' reduction targets. The Umbrella Group also hoped to include a provision for emissions trading in the Kyoto regulations.

In its *Third Assessment Report*, published at the beginning of 2001, the IPCC further emphasized the role of humans in the climate change process. Discrediting the idea that global warming stemmed from natural phenomena such as volcanic activity and changes in the sun's radiation, the IPCC argued that the combustion of fossil fuels such as coal, oil, and natural gas was the only reasonable cause of climate change. Moreover, it attributed global warming to an average temperature increase of just 1 degree over the previous century and warned that if fossil fuel consumption continued without restraint, the planet would experience an additional 3 degrees to 10 degrees of warming by the year 2100. The panel was confident, though, that there was still enough time to halt the process of climate change.

U.S. WITHDRAWL FROM THE KYOTO PROTOCOL

The same month the IPCC report was published, George W. Bush entered the White House, and he moved quickly to limit his country's responsibility for reducing carbon dioxide emissions. On March 28, he announced that he was going to withdraw the United States from the Kyoto Protocol. He justified his decision by arguing that the protocol would have a harmful effect on the American economy and that it unfairly placed most of the burden for reducing carbon dioxide emissions on industrialized nations. Dick Cheney, the vice president in the Bush Administration, openly repudiated the protocol. As an alternative, Bush proposed an extensive program of scientific research and technological innovation. To that end, he instructed the National Academy of Sciences (NAS) to carry out an extensive study on the impact of the greenhouse effect. Bush's actions prompted outrage among the signatories of the Kyoto Protocol. Many of the EU member countries said that the United States had no right to reject the validity of the protocol.

The NAS released its findings in May 2001. The report reiterated that climate change was a very real phenomenon, caused predominantly by human actions.

The Intergovernmental Panel on Climate Change warned that if fossil fuel consumption continued without restraint, the planet would experience an additional 3 to 10 degrees of warming by the year 2100.

It concurred that there had been an average temperature increase of 1 degree F during the 20th century, and estimated that temperatures would increase between 2.5–10 degrees F (1.4–5.5 degrees C) during the 21st century. It further predicted that sea levels could rise as much as 3 ft. (1 m.) by 2100, resulting in adverse social consequences such as homelessness, starvation, and growing numbers of environmental refugees. Even in light of clear evidence about the harmful consequences of carbon emissions, the Bush Administration continued to circumvent the issue of climate change.

A NEW U.S. PLAN

The same month as the NAS published its report, Vice President Dick Cheney's energy task force announced a national plan to develop new sources of energy. Cheney publicly announced that the plan would secure America's energy needs for the long-term future, but the plan did not place any emphasis on conserving energy or making energy consumption more efficient. An environmental group later discovered that representatives from the energy industry had exerted a large degree of influence over the task force. A few weeks later, Bush revealed his plans for a U.S. Climate Change Initiative, which would support climate change research and manage the distribution of funding for such research.

An American delegation was present at the seventh Conference of the Parties in Bonn in July 2001, despite the United States' repudiation of the Kyoto treaty. Paula Dobriansky, the head of the delegation, agreed that it would not participate in any discussions pertaining to the treaty. However, the United States still made its presence felt at the conference. Dobriansky announced to a bemused audience that Bush was committed to halting the process of climate change and then went on to reiterate the administration's opposition to the Kyoto Protocol. She said that the United States would only stop other countries from adhering to the protocol if such actions harmed the country's interests. The conference was also notable for the fact that the EU finally consented to the idea of carbon sinks, agreeing to let countries include sinks as part of their carbon reductions. The EU also agreed that there should be no limit on emissions trading. Both provisions were included in the Bonn Agreement, which also stipulated that countries would be responsible for additional emission reductions in the second commitment period if they missed their initial targets.

In 2002, Bush announced that he aimed for an 18 percent reduction in the intensity of greenhouse gas emissions by 2012. He proposed to achieve this through measures such as consumer information campaigns, new mandatory regulations, and partnerships with energy firms. He argued that his plan demonstrated his government's commitment to meet the terms of the United Nations Framework Convention on Climate Change. However, many scientists and politicians pointed out that Bush's plan only sought to reduce the intensity, and not the quantity, of greenhouse gas emissions. The scientific community predicted that if the United States continued to follow the same plan in the coming decades, it could potentially cause greenhouse gas emissions to increase 30 percent above their 1990 level by the year 2030. In addition to that plan, the Bush Administration and the energy industry established a new energy project called FutureGen in 2003. The purpose of the project was to build an advanced facility for generating power through the gasification of coal and the sequestering of carbon emissions. The facility, which is currently under construction, is scheduled to open in 2012.

Although Bush began to acknowledge in 2003 that climate change stemmed from human actions, his initiatives did not extend much beyond those that were already in force. He was reelected in 2004, and by the following year the United States was still heavily reliant on coal-burning power plants for its energy. In 2005, coal-generated energy represented 32 percent of all the energy generated across the country. Around 23 percent of the nation's energy came from natural gas, 18 percent from natural gas and petroleum, and 10 percent from nuclear generation. According to figures compiled by the UN Statistics Division, the United States had the highest level of carbon dioxide emissions in the world in 2004. It emitted the equivalent of 7 billion tons of carbon dioxide, by far the highest rate of any country in the world, and the same amount of greenhouse gases as 2.6 billion people living in 151 developing nations. China, the world's fastest-growing economy, was in second place, having emitted the equivalent of just over 4 billion tons of carbon dioxide. However, the difference in carbon emissions between the two countries was far greater when broken down to an average figure for each member of the population. American emissions amounted to an average of 23.92 tons of emissions per person, whereas China's emissions only averaged out to 3.36 tons of emissions for every member of the population.

Many prominent American environmental groups continued to campaign vigorously for the United States to join the Kyoto Protocol but were hindered by a powerful industrial lobby. However, more than half of the states in the union had started their own initiatives to reduce greenhouse gas emissions. In California in 2003, then-governor Gray Davis stipulated that car manufacturers had to reduce the emissions level of all vehicles sold in the state. The California Air Resources Board established new emissions standards for cars that came into effect at the end of 2005. Davis's successor, Arnold Schwarzenegger, also took a firm stance on the environment.

Despite the Bush Administration's claims that the United States cannot adhere to the Kyoto Protocol, scientific evidence has proven that more restrictive policies on carbon emissions will not have a detrimental effect on American economic growth. During the energy crisis of 1973 to 1986, the country actually improved its energy efficiency: its economy grew by 35 percent, and its energy output remained at a consistent level. Robert Ayers, an ecological pioneer, estimates that 19 of every 20 units of energy in the United States are wasted and advocates capturing those wasted units to cut America's energy consumption.

In recent years, there have been clear indicators about how global warming has been affecting the United States. Eighteen of the warmest years on record occurred between 1980 and 2006; 2005 was officially the hottest year ever recorded. Ten of the 12 strongest hurricanes on record occurred in 2005. Many of those hurricanes had a direct effect on the United States, particularly Hurricane Katrina, which devastated the city of New Orleans and parts of Louisiana and killed hundreds of people. In Montana, the number of glaciers at Glacier National Park is rapidly falling. In 1910, the park had 150 glaciers, and that number is now less than 30.

Evidence about how climate change will affect the United States in the future has been growing. Peer-reviewed data show that the country could lose up to 14,000 sq. mi. (36,260 sq. km.) of territory as a result of global warming. The NAS predicts a 3-ft. (1 m.) rise in sea levels by 2100, and the Environmental Protection Agency estimates that the acreage available for cultivation in Maryland and Pennsylvania could drop as much as 43 percent in the coming decades. Scientists estimate that Glacier National Park's glaciers will have disappeared by 2030. They are also predicting a major reduction in winter snowpack in the Pacific Northwest and Rocky Mountain regions, which would not only harm the economy of those regions by eradicating the conditions necessary for winter sports such as skiing and snowboarding but would also threaten the drinking water supplies, drawn from melting snow, of millions of people. Other possible consequences of global warming for America include higher levels of aridity in the Southwest and Great Plains, increased flooding along major river basins, more wildfires, and the spread of disease and illness. In the past few years, the effect of climate change has become a prominent issue in popular American culture. Both the fictional disaster movie *The Day After Tomorrow* and Gore's documentary *An Inconvenient Truth* graphically depict what will happen to the United States, and other parts of the world, if temperatures continue to rise unabated.

SEE ALSO: Bush (George H.W.) Administration; Bush (George W.) Administration; California; Carbon Emissions; Carbon Footprint; Carbon Sinks; Carter Administration; Climate Action Network (CAN); Clinton Administration; Department of Defense, U.S.; Department of Energy, U.S.; Department of State, U.S.; Emissions Trading; Framework Convention on Climate Change; Global Warming; Gore, Albert Jr.; Greenhouse Effect; Greenhouse Gases; Intergovernmental Panel on Climate Change (IPCC); Kyoto Mechanisms; Kyoto Protocol; Louisiana; Montreal Protocol; Refugees, Environmental; Toronto Conference; United Nations Environment Programme (UNEP); World Meteorological Organization.

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University Corporation for Atmospheric Research

THE UNIVERSITY CORPORATION for Atmospheric Research (UCAR) is a nonprofit institution that has a mission to "support, enhance, and extend the capabilities of the university community, nationally and internationally; understand the behavior of the atmosphere and related systems and the global environment; and foster the transfer of knowledge and technology for the betterment of life on Earth." It was founded in the year 1960 and is based in Boulder, Colorado. The UCAR research lab maintains an affiliated nature preserve.

UCAR collaborates with universities to manage the National Center for Atmospheric Research (NCAR) and the UCAR Office of Programs. The goal of these three organizations is "Understanding our changing Earth system, Educating about the atmosphere and related sciences, Supporting a global community of researchers, and Benefiting society through science and technology."

The establishment of UCAR began in the 1950s, when faculty representatives from 14 universities met to discuss the need for supporting the atmospheric sciences, as well as enhancing the study of these sciences. These faculty members realized the research potential in an institution that could foster collaborations and maintain personnel that one university on its own would not have the resources to do. Thus, the NCAR was founded with support from the U.S. National Science Foundation. UCAR was formally established in 1960 to manage NCAR and foster Earth systems science. Earth systems science investigates not only the atmosphere as an entity but also its relations with the Earth's oceans and lands, as well as with the sun.

The universities and institutions that work with UCAR are member universities, international affiliates, or academic affiliates. Member universities must be North American universities offering doctoral degrees in the atmospheric and related sciences. International affiliates are international universities that grant equivalent degrees, and academic affiliates are North American universities that award predoctoral degrees in similar fields. Some of the member universities include the University of Alaska, Columbia University, Drexel University, the University of Illinois at Urbana-Champaign, the University of Missouri, Old Dominion University, Saint Louis University, and the University of Wyoming. In addition, there are private-sector members who participate in UCAR by funding projects, assisting with technology, collaborating with UCAR research, or acting on UCAR governance boards.

NCAR researchers and technical staff frequently collaborate with the UN Intergovernmental Panel on Climate Change (IPCC) to write or review reports of the latter institution. On October 11, 2007, the Nobel Peace Prize was awarded to former U.S. vice president Al Gore and the IPCC for their work evidencing the human effect on global warming.

Earlier that year, the IPCC had published its fourth periodic assessment of climate change; these assessments began in the year 1991. Assessments take into account numerous pieces of climatological data, analyze past climate patterns, and predict future patterns for local and global environments.

UCAR also manages an Office of Education and Outreach (EO), which communicates with the public, and especially youths, about the necessity and intrigues of working in Earth systems science.

SEE ALSO: Clinton Administration; Colorado; Columbia University; National Center for Atmospheric Research;

United Nations; University of Alaska; University of Illinois.

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University Corporation for Atmospheric Research Joint Office for Science Support

THE JOINT OFFICE for Science Support (JOSS) of the University Corporation for Atmospheric Research (UCAR) is a group of professional and skilled technical and administrative specialists whose mission is to serve and support the scientific community. JOSS headquarters is located in Boulder, Colorado. The office receives funding from the National Science Foundation and the National Oceanic and Atmospheric Administration (NOAA), as well as from other U.S. agencies, private sources, and international organizations. Before 2005, JOSS was divided into two groups: the Field Operations and Data Management (FODM) group and the Program Support Operations (PSO) group. In 2005, the FODM staff moved to NCAR's Earth Observing Laboratory, and PSO/JOSS remained in UCAR UOP (Office of Programs) and retained the name JOSS. Many of the events sponsored by JOSS have to do with climate change and its effect on human existence. JOSS also collaborated closely with the Global Atmospheric Research Program (GARP) for its alpine (1979) and monsoon (1982) experiments in Switzerland and India, respectively.

JOSS collaborates with scientists and research managers to plan and conduct scientific programs in the most productive and cost-effective ways. JOSS supports planning efforts, research programs, field experiments, and data management activities worldwide. The office offers a wide range of services. It can be a consultant both for individual investigators and for research managers and funding agency officials planning extensive geophysical field experiments and monitoring projects.

JOSS also helps researchers to establish their own network of professional relationships with key people in other institutions and agencies, the U.S. Department of State, and other governments. JOSS aids researchers in planning and conducting meetings, workshops, and conferences. The office has an extensive breadth of knowledge and many years of experience in most regions of the world and advises others about research activities in the United States and elsewhere.

The office team organizes field trips through detailed budgeting, site surveys, and logistical and operational support. It takes care of establishing staff and operations centers for the field project and directs daily operations. JOSS supplies ground support for aircraft, ships, radar, and other observing platforms and systems and hires and trains local workers. On average, JOSS provides various support services for over 475 scientific events and more than 2,500 travelers every year. Supported meeting size has ranged from 12 to 1,200 participants. These international and domestic meetings are relevant to scientists and governmental agencies because they are the initial planning stages of future research or the sharing of information and opinions within the scientific community and government. JOSS-supported meetings have also provided a wide range of topics related to climate change.

For example, JOSS supported a large meeting of Native Americans from across the United States. Representatives from various tribes came together to share their opinions about how climate affects their own lives and how they are adapting their old ways into the modern world with regard to climate issues. JOSS has also supported several large, politically significant meetings in Washington, D.C., designed to help atmospheric scientists share their knowledge, research findings, and predictions with agencies that have the power to influence government decisions.

From 1995 to 2001, JOSS took an active part in the Indian Ocean Experiment (INDOEX). The experiment started from the assumption that regional consequences of global warming depend critically on the potentially large cooling effect of another pollutant, known as aerosols. These aerosols scatter sunlight back to space and cause a regional cooling effect, thus causing uncertainty in predicting future climate. The Indian Ocean Experiment attempted to address the complex influence of aerosol cooling on global warming by collecting in situ data on the regional cooling effect of sulfate and other aerosols.

The project's goal was to study natural and anthropogenic climate forcing by aerosols and feedbacks on regional and global climate. International Global Change Research Program considered this issue to be of critical importance. INDOEX measured long-range transport of air pollution from south and southeast Asia toward the Indian Ocean during the dry monsoon season from January to March 1999. Surprisingly high pollution levels were observed over the entire northern Indian Ocean toward the Intertropical Convergence Zone at about 6 degrees S.

Agricultural burning and especially biofuel use were shown to enhance carbon monoxide concentrations. Fossil fuel combustion and biomass burning caused a high aerosol loading. The growing pollution in the region gave rise to extensive air quality degradation, which, the experiment pointed out, had local, regional, and global implications, including a reduction of the oxidizing power of the atmosphere. JOSS was also involved in GARP experiments, as well as in the establishment of the international research institute on El Niño and its consequences.

JOSS provides administrative, travel, and logistical support for several institutions that operate in the field of climate change and global warming, such as the Intergovernmental Panel on Climate Change, the International Research Institute for Climate and Society, the Office of the U.S. Global Change Research Program, the NOAA Climate Program Office, and the Inter-American Institute for Global Climate Change Studies. It also produces Reports to the Nation on Our Changing Planet, a series of general interest monographs that provide science-based information on issues regarding climate and global change for the general public.

SEE ALSO: Aerosols; Global Warming; Greenhouse Effect; Greenhouse Gases; Kyoto Protocol.

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University of Alaska

THE UNIVERSITY OF Alaska system has three main campuses (University of Alaska Fairbanks (UAF), University of Alaska Anchorage, and University of Southeast) and 15 satellite campuses. However, beyond individual researchers at various campuses, all four global warming or climate change research centers, institutes, and groups are found at the UAF campus. The four centers are the Alaska Climate Research Center (ACRC), the International Arctic Research Center (IARC), Center for Global Change and Arctic System Research, and the Alaska Center for Climate Assessment and Policy (ACCAP).

Under the direction of the Geophysical Institute, the ACRC conducts secondary data gathering, storage, and report analysis. The ACRC is funded by the State of Alaska under Title 14, Chapter 40, Section 085. The IARC is a joint venture between Japan and the United States. It is an international focused research center that includes 20 research groups and over 60 international scientists. The IARC mission is to determine whether climate change is manmade or natural, what the data points are needed to make this determination, and what the possible effects of climate change are.

In 2007, a national and international controversy sprang out of the IARC when Director Syun-Ichi Akasofu claimed the 2005 peer-review Internatioal Panel on Climate Change (IPCC) report was methodologically flawed. Dr. Akasofu claimed the IPCC did not have an anthropogenic (natural) greenhouse gases control to account for their assertion of a 0.6 degrees man-made climate change over the past 100 years. Professor Akasofu also claimed that CO_2 and other greenhouse gases are not responsible for climate change the researchers would have included anthropogenic greenhouse gases. In a public response to criticism from the academic community, Akasofu noted that, "Since I am not a climatologist, all the data presented in my note are found in papers and books published in the past; that is why I do not want to publish my note as a paper in a professional journal." Although not a climatologist, Akasofu learned speculation on climatology has widely circulated among antiglobal warming groups.

The Center for Global Change and Arctic System Research was founded in 1990 with the goal of fostering interdisciplinary Arctic and sub-Arctic research in Arctic biology, atmospheric chemistry, climatology, engineering, geophysics, hydrology, natural resources management, social sciences, and marine sciences to better understand global change in the Arctic. There are two subgroups and a 1,042-page Arctic research study by the Center for Global Change and Arctic System Research affiliates. One subgroup is the Globe Learning and Observations to Benefit the Environment (GLOBE), founded in 1997. GLOBE is an international group that develops hands-on environmental science curriculum for K–12 students, teachers, and scientists. Another subgroup, founded in 1994, is the University of Alaska-National Oceanic and Atmospheric Administration (UA-NOAA) Cooperative Institute for Arctic Research (CIFAR). CIFAR is one of 13 national university-based NOAA institutes.

It focuses on atmospheric and climate research/modeling. The UA-NOAA studies focus on arctic haze, marine science, fisheries, and sea ice research. The last subgroup is a research study called the Arctic Climate Impact Assessment (ACIA). The ACIA report was prepared for the Fourth Arctic Council Meeting in Reykjavik, Iceland, in November 2004. Some of the findings from the report note that over the past 50 years, the mean surface air temperature has increased 3.6–5.4 degrees F (2–3 degrees C) and late summer ice decreased by 15–20 percent over the past 30 years; in addition, between 1961 and 1998, North American glaciers lost 108 cu. mi. of ice.

The ACCAP was founded in 2006. The ACCAP mission is to determine the biophysical and socioeconomic effect of climate change within Alaska and to improve regional, local, and Alaskan ability to create policies that address the changing climate. The ACCAP works in affiliation with NOAA-Regional Integrated Sciences and Assessments, Institute of Northern Engineering, International Arctic Research Center, the Institute for Socioeconomic Research at the University of Alaska Anchorage, and the Alaska Climate Research Center.

SEE ALSO: Alaska; Climate Change, Effects; Education.

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University of Arizona

THE UNIVERSITY OF Arizona (UA or U of A) is a land-grant and space-grant public institution of higher education and research located in Tucson. The University of Arizona was the first university in the state of Arizona, founded in 1885, when Arizona was still a territory. UA includes Arizona's only allopathic medical school. In 2006, total enrollment was 36,805 students. UA embraces its threefold mission of excellence in teaching, research, and public service. Now in its second century of service to the state, UA has become one of the nation's top 20 public research institutions.

The UA graduate school offers several programs of study in atmospheric and environmental science. The Department of Atmospheric Sciences offers programs leading to the master of science and doctoral degrees. Research is conducted through the Institute of Atmospheric Physics in areas such as climate and global change, land-atmosphere interaction, convective processes, atmospheric dynamics, radiative transfer, remote sensing, atmospheric aerosols, atmospheric chemistry, cloud and precipitation physics, lightning, atmospheric electricity, weather forecasting, and numerical weather prediction. The Department of Soil, Water, and Environmental Science (SWES) offers graduate work leading to M.S. and Ph.D. degrees in soil, water, and environmental science. Two tracks are offered, environmental science and soil and water science. In addition to the major, each Ph.D. student must complete a minor, which can be intra- or interdepartmental. Many, if not most, SWES graduate students enroll in several non-SWES courses as part of their program. This reflects the multidisciplinary characteristics of the SWES program in general, and also that a minor is required for all Ph.D. students.

The most frequently studied outside courses are in chemistry, chemical and environmental engineering, hydrology and water resources, and microbiology. With an M.S. or Ph.D. in environmental science, students will be prepared for careers in business and industry, governmental agencies, educational institutions, and private consulting firms. Many Ph.D. students obtain faculty positions at colleges and universities. The Environmental Studies Laboratory was created in 1999 to provide facilities and equipment for the research of past, present, and future environmental variability and change. Current research encompasses paleoclimate studies across the globe, wildfire studies in southwestern North America, and relationships between climate and society across multiple spatial and temporal scales. The laboratory is just one of several complementary investigative groups of environmental and earth system sciences in the Department of Geosciences and at UA. The laboratory is involved in a number of efforts aimed at improving the quality of and participation in K–12 education.

Research carried out by staff and students at the Environmental Studies Laboratory and their forerunners at the University of Colorado and Columbia University has centered around two broad themes. The oldest concentrates on paleoenvironmental science and its application toward understanding the full range of environmental variability, with a focus on climate and ecology. More recently, the laboratory has worked on improving connections between environmental sciences and society, with the specific goal of increasing the scientific basis of environmental decision making. Both themes involve a conscious effort to work across broad temporal scales and over spatial scales that extend from local to global. By working on projects in many key systems around the world, the hope is to craft a better understanding of the global system.

SEE ALSO: Arizona; Climate Change, Effects; Weather; Soils.

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University of Birmingham

THE UNIVERSITY OF Birmingham is an English university in the city of Birmingham. Founded in 1900 as a successor to Mason Science College, with origins dating back to the 1825 Birmingham Medical School, the University of Birmingham was arguably the first so-called red brick university. It currently has over 18,000 undergraduate and over 11,000 postgraduate students. The University of Birmingham has an international reputation for excellence in research and teaching in environmental science, engineering, and policy. There are currently around 150 academic staff actively investigating scientific, technical, and socioeconomic aspects across a broad range of environmental disciplines, including the management of freshwater resources, environmental restoration, sustainable use of natural materials, pollution control, waste management, management of natural hazards, and human health.

The Center for Environmental Research and Training plays a key role in providing a focus for the university's environmental expertise. It acts as a gateway for external organizations, enabling this expertise to be made more widely accessible, and provides a mechanism for the promotion and management of interdisciplinary research within the university. The Institute for Energy Research and Policy, founded in 2005, focuses on research into the economics of energy policy, energy efficiency, wind power, and hydrogen-based energy systems. The Centre for Environmental Research and Training and the School of Geography Earth and Environmental Sciences are internationally recognized in many areas of climate change research. The center seeks to enhance the university's international reputation for environmental research and teaching by advancing partnerships with institutions overseas, such as in Poland, Malaysia, Thailand, and the West Indies.

In October 2006, as part of an ongoing series of initiatives to reduce greenhouse gas emissions from university activities, a new climate change website was launched. The website's purpose was to provide advice and information on the solutions that the university as a whole can provide to the challenge of climate change. In addition, extra effort has been made to implement more energy-efficient practices.

The University of Birmingham is also one of a select group of universities that are committed to carbon management with the Carbon Trust to actively cut their carbon emissions and so minimize the long-term effects of climate change. The Carbon Trust has designed a university-focused program, which will provide technical and change management support to help the sector realize carbon emissions savings. The primary focus of the work is to reduce emissions under the control of the university, such as academic, accommodation, and leisure buildings and vehicle fleets. Practical support will be given in areas such as identifying carbon-saving opportunities, developing an emissions reduction implementation plan, providing analysis software, and offering workshop support for staff and senior management training.

SEE ALSO: Carbon Trust; Energy Research; Environmental Policy.

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University of California, Berkeley

THE UNIVERSITY OF California, Berkeley, is the premier public research university in the United States, with 97 percent of its academic programs being among the top 10 in the country. Commonly referred to as UC Berkeley, Berkeley, and Cal, the university's academic excellence is sustained by a $2.46 billion endowment. Berkeley was founded in 1868 and is the oldest of the 10 University of California campuses. During the 1930s, the leadership of university president Robert Sproul helped Berkeley to establish itself as a leading research university, and by 1942 the American Council on Education ranked Berkeley second only to Harvard in the number of distinguished academic departments. A reorganization of the University of California system in 1952 resulted in the naming of Clark Kerr as the first chancellor for the Berkeley campus. Since then, there have been nine other chancellors; the current chancellor is Robert Birgeneau, who has filled this role since 2004.

Berkeley is a comprehensive university offering over 7,000 courses in 130-plus academic departments organized into 14 colleges and schools, offering nearly 300 degree programs. The university awards over 5,500 bachelor's degrees, 2,000 master's degrees, 900 doctorates, and 200 law degrees each year. With 33,558 students and 1,950 faculty, the student-faculty ratio is 17 to 1—among the lowest of any major university. Berkeley is the most selective school in the UC system and is one of the most selective universities in the country. For the 2006–07 academic year, 4,157 freshmen matriculated at Berkeley, from an applicant pool of just under 41,750 applicants. Graduate admissions vary by department, although in 2006 the university's doctoral programs admitted 1,058 students from a pool of 14,263 applicants.

Collectively, Berkeley's 32 libraries tie with University of Illinois for the fourth largest academic library system in the United States, surpassed only by the U.S. Library of Congress, Harvard, and Yale. In 2003, the Association of Research Libraries ranked Berkeley as the top public university library in North America and third among all universities. As of 2006, Berkeley's library system contains over 10 million volumes and maintains over 70,000 serial titles.

The scholarly achievements and excellence of the faculty and alumni have helped to build and maintain

Berkeley's excellent reputation. Berkeley scientists invented the cyclotron, discovered the antiproton, isolated the polio virus, created the Unix computer operating system, and discovered numerous transuranic elements including seaborgium, plutonium, berkelium, lawrencium, and californium. During World War II, Ernest Orlando Lawrence's Radiation Laboratory at Berkeley contracted with the U.S. Army to develop the atomic bomb, and Berkeley physics professor J. Robert Oppenheimer was named scientific head of the Manhattan Project in 1942. Berkeley faculty have a no less distinguished record in fields outside the physical sciences: they include 221 American Academy of Arts and Sciences Fellows, 83 Fulbright Scholars, 28 MacArthur Fellowships, 384 Guggenheim Fellows, 87 members of the National Academy of Engineering, 132 members of the National Academy of Sciences, 3 Pulitzer Prize winners, and 92 Sloan Fellows. Berkeley counts 61 Nobel laureates among its faculty, researchers, and alumni—the sixth most of any university in the world; 20 have served on its faculty.

Berkeley's reputation for student activism was forged in the 1960s. With the end of World War II and the subsequent rise of student activism, the California Board of Regents succumbed to pressure from the student government and ended compulsory military training at Berkeley in 1962. Then, in 1964, an impromptu response by students to the university's ban on campus political activity led to the beginning of the Free Speech Movement and, ultimately, the freedom of expression by students. This movement grew during the protests against U.S. involvement in the Vietnam War during the 1960s and early 1970s. Today Berkeley has over 700 established student groups, nearly 100 of which are political. There is also a strong sense of public service among Berkeley graduates. For example, Berkeley sends the most students to the U.S. Peace Corps of any university in the nation.

As part of its academic excellence, Berkeley is also a leader in environmental research. There are over 100 individual undergraduate and graduate programs at Berkeley that focus on the environment, in addition to dozens of top research centers. The university is also active in research concerning global warming and climate change, with several centers involved in research and advocacy on these and related issues. For example, the University of California Climate Change Center was established in 2003 by the California Energy Commission to undertake a broad program of scientific and economic research on climate change in California. The center has sites at both the Berkeley and San Diego campuses of UC. The Berkeley center, based at the Goldman School of Public Policy, focuses on economic and policy analysis, whereas the site in San Diego (at the Scripps Institute of Oceanography) focuses on physical climate modeling. Several other departments on the Berkeley campus are involved in the work of the center including the Department of Agricultural and Resource Economics, the Department of City and Regional Planning, the Department of Civil and Environmental Engineering, the Graduate Group in Energy and Resources (ERG), and the Environmental Energy Technologies Division of the Lawrence Berkeley National Laboratory.

The ERG is an interdisciplinary academic unit of the Berkeley campus that was created in 1973 to develop, transmit, and apply critical knowledge to enable a future in which human material needs and a healthy environment are mutually and sustainably satisfied. ERG conducts programs that include graduate teaching and research on issues of energy, resources, development, human and biological diversity, environmental justice, governance, global climate change, and new approaches to thinking about economics and consumption. The University of California Energy Institute (UCEI) is a multicampus research unit of the University of California system begun in 1980, whose mission has been to foster research and educate students and policymakers on energy issues. The Center for Global Metropolitan Studies (GMS) is a campus initiative to foster interdisciplinary collaboration to investigate and address problems and opportunities posed by global metropolitan growth and change through research. The Berkeley Institute of the Environment (BIE) was established in 2005 and brings together and helps enhance diverse campus programs and research units by making research tools and understanding accessible across disciplinary lines to address complex environmental problems, while fostering collaboration and thinking about critical environmental problems. The Institute of Transportation Studies (ITS) is one of the world's leading centers for transportation research, education, and scholarship. Research areas include transportation sustainability, future urban transit systems, and environmental effects. The UC Berkeley Transportation Sustainability Research Center (TSRC) was formed in 2006 to combine the research forces of the five aforementioned centers, institutes, and groups (ERG, UCEI, GMS, BIE, and ITS). The TSRC is a multicampus unit that supports research, education, and outreach.

Other campus activities related to global warming include the research and advocacy work of the College of Engineering. For example, on August 2, 2007, the college released a blueprint for fighting global warming by reducing the amount of carbon emitted when transportation fuels are used in California. This low-carbon fuel standard is designed to stimulate improvements in transportation fuel technologies and is expected to become the foundation for similar initiatives in other states, as well as nationally and internationally.

There is also a Chancellor's Advisory Committee on Sustainability that promotes environmental management and sustainable development on the Berkeley campus. The mission of the committee is to engage the campus in an ongoing dialogue about reaching environmental sustainability and to integrate environmental sustainability with existing campus programs in education, research, operations, and public service. The committee is charged with advising the chancellor on matters pertaining to the environment and sustainability as it directly relates to the university.

Berkeley's tradition of student political action has also merged with global climatic change issues. For example, in March 2007, students organized the California Campus Climate Challenge Summit to learn about global warming, climate change, and methods for influencing policy change via student activism. Such activities also highlight the social justice aspects of issues concerning global warming and the desire by some to create an environmental and social movement to help raise awareness about this issue. Also, Berkeley alumna Sissel Waage has just coedited a book to address issues of climate change and global warming. The book features a wide array of authors ranging from activists to scholars to students, who each discuss what the average person can do to turn their private concerns into public action.

SEE ALSO: Carbon Footprint; Climate Change; Education.

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University of Cambridge

THE UNIVERSITY OF Cambridge (Cambridge University), located in Cambridge, England, is the second-oldest university in the English-speaking world and has a reputation as one of the world's most prestigious universities. The university grew out of an association of scholars in the city of Cambridge that was formed in 1209 by scholars leaving Oxford after a dispute with the townsfolk there. The universities of Oxford and Cambridge are often jointly referred to as Oxbridge. In addition to their cultural and practical associations as a historic part of English society, the two universities also have a long history of rivalry with each other. The University of Cambridge currently has 31 colleges, of which three admit only women (New Hall, Newnham, and Lucy Cavendish). The remaining 28 are mixed, with Magdalene being the last all-male college to begin admitting women, in 1988. Two colleges admit only postgraduates (Clare Hall and Darwin), and four more admit mainly mature students or graduate students (Hughes Hall, Lucy Cavendish, St. Edmund's, and Wolfson).

The other 25 colleges admit mainly undergraduate students but also allow postgraduates following courses of study or research. Although various colleges are traditionally strong in a particular subject, for example, Churchill has a formalized bias toward the sciences and engineering, the colleges all admit students from just about the whole range of subjects, although some colleges do not take students for a handful of subjects such as architecture or history of art. It is noteworthy that costs to students (accommodation and food prices) vary considerably from college to college. This may be of increasing significance to potential applicants as government grants decline in the next few years.

The Department of Land Economy offers a three-year honors undergraduate degree program, as well as postgraduate studies in environmental policy. The main focus of the program is land and environmental protection. Up to 40 students are admitted each year. The University of Cambridge offers a variety of taught courses relating to the environment, whether as part of an undergraduate degree course or a postgraduate course. Climate change research at the University of Cambridge ranges from long-term climate modeling using geological data to in situ measurements of the present composition of the Earth's atmosphere, at all scales from global climate models to study of the dynamic chemical processes controlling the present state of the atmosphere. Significant expertise in atmospheric sciences and earth sciences provides a strong foundation for research into limiting the effects of human activity on the Earth's climate, mitigating the effects of climate change, assessing the effects of climate change on human health, and designing economic policies and technologies for climate change mitigation.

The Cambridge Environmental Initiative was launched in December 2004. The primary mission of this initiative is to facilitate and support interdisciplinary environmental research within the University of Cambridge, promote the university's external profile in environmental research, and encourage new environmental research initiatives within the university.

The Cambridge Center for Climate Change Mitigation Research is an interdisciplinary research center, focusing on climate change mitigation at the local and global levels. The main objective of this collaboration is to foresee strategies, policies, and processes to mitigate human-induced climate change, which are effective, efficient, and equitable, including understanding and modeling transitions to low-carbon energy-environment-economy systems. The center houses global, European, and U.K. research teams adopting a common set of conventions and protocols that are networked with multidisciplinary teams working in different countries.

In March 2007, former U.S. vice president Al Gore delivered a climate change training program to 200 of the United Kingdom's top leaders from business, government, media, education, and civil society. The program brought together leaders committed to communicating and taking action on climate change across the United Kingdom and internationally. The program, hosted by the University of Cambridge, was designed to help trainees understand the issues and think critically about solutions and actions required to address climate change issues.

SEE ALSO: Cambridge Environmental Initiative; Oxford University.

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Fernando Herrera
University of California, San Diego

University of Colorado

THE UNIVERSITY OF Colorado at Boulder (CU) is the flagship university of the University of Colorado system. CU has produced a number of astronauts, Nobel laureates, Pulitzer Prize winners, and other notable individuals in their fields.

The Department of Atmospheric and Oceanic Sciences (ATOC) is an interdisciplinary program that provides an educational and research environment to examine the dynamic, physical, and chemical processes that occur in the atmosphere and the ocean. A major theme is the establishment of a physical basis for understanding, observing, and modeling climate and global change. At the undergraduate level, approximately 2,000 students are pursuing baccalaureate degrees in environmental studies, environmental biology, environmental engineering, environmental law, geological sciences, geography, environmental policy, and other subjects. Several hundred graduate students are also pursuing advanced degrees involving research on environmental topics at CU.

ATOC is coordinated with the environmental program at the University of Colorado. Interdisciplinary education and research opportunities exist with the hydrology program and the environmental policy program. Interdisciplinary research opportunities also exist with the Cooperative Institute for Environmental Studies, the Institute for Arctic and

Alpine Research, the Center for Complexity, and the Laboratory for Atmospheric and Space Physics. Graduate students, research staff, and faculty work together on a wide range of research projects. ATOC has extensive computer facilities and laboratories in remote sensing, chemistry, and hydrodynamics. The presence of leading laboratories in the environmental sciences in Boulder, including the National Center for Atmospheric Research and the National Oceanic and Atmospheric Administration Environmental Research Laboratories, provides additional opportunities for a rich educational experience.

Climate research at the University of Colorado is driven by the goals and broad objectives that have been articulated by the World Climate Research Program and the U.S. Global Change Research Program, which are to develop the fundamental scientific understanding of the climate system and climate processes that is needed to determine to which extent climate can be predicted, as well as the extent of man's influence on climate. The program encompasses studies of the global atmosphere, oceans, sea and land ice, and the land surface, as well as their coupling. To achieve these goals, climate research at the University of Colorado plans to design and implement observational and diagnostic research activities that will lead to a quantitative understanding of significant climate processes, including the transport and storage of heat by the ocean; the exchange of heat, moisture, and momentum between atmosphere, ocean, and sea ice; and the interaction among cloudiness, radiation, the land surface, and the global hydrological cycle. Research in global and regional models capable of simulating the present climate and, to the extent possible, of predicting climate variations on a wide range of space and timescales are also being actively pursued.

CU is known internationally for its interdisciplinary research on a variety of global change issues. Working closely with Boulder-based federal research laboratories, CU research centers such as the Cooperative Institute for Research in the Environmental Sciences, the Institute for Arctic and Alpine Research, and the Laboratory for Atmospheric and Space Physics have successfully brought together a variety of academic

The University of Colorado at Boulder was founded in 1876 at the base of the Rocky Mountains. The natural beauty of the area draws many students interested in pursuing degrees in environmental studies and policies.

disciplines to work on global change issues, which cross traditional disciplinary and departmental lines. On the policy side, the Natural Resources Law Center and the Environmental Policy Program have brought together lawyers, economists, historians, and political scientists to study global change and other environmental issues. Unique interdisciplinary education programs in climate change are being developed at the University of Colorado through a partnership of the Department of Atmospheric and Oceanic Sciences and the Environmental Studies Program, overcoming the disciplinary and departmental barriers that exist in many university programs.

The program at the University of Colorado proves a unique combination of disciplinary depth and inter- and multidisciplinary breadth necessary for students who plan to work in this area. Current research topics include El Niño and tropical climate variability, polar climate; polar regional climate modeling, World Data Center for Glaciology, Institute for Arctic and Alpine Research, Program in Arctic Regional Climate Assessment, sea ice remote sensing, sea ice modeling, land/atmosphere interactions, land surface model, boreal forest dynamics model, Land-Atmosphere CO_2 exchange, paleoclimate, Past Global Change Group/Institute for Arctic and Alpine Research, impact of clouds and aerosols on climate, aerosol modeling research group home pages, and global climate modeling.

SEE ALSO: Colorado; El Niño and La Niña; National Center for Atmospheric Research (NCAR).

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Fernando Herrera
University of California, San Diego

University of Delaware

THE UNIVERSITY OF Delaware (UD) is the largest university in Delaware. The main campus is located in Newark, with satellite campuses in Dover, Wilmington, Lewes, and Georgetown. Approximately 16,000 undergraduate and 3,000 graduate students attend this university annually. Although UD receives public funding for being a land-grant, sea-grant, space-grant, and urban-grant state-supported research institution, it is also privately chartered. The university's endowment is currently valued at about $1.2 billion. In 2007, UD was ranked 15th nationally in *Kiplinger's Personal Finance* magazine list of the 100 best public institutions of higher education. The University of Delaware was also ranked 15th best value for in-state students and 10th best value for out-of-state students. Seven academic colleges confer degrees at UD.

The College of Marine and Earth Studies is one of the seven colleges at UD. The undergraduate component of the college is currently housed within the Department of Geological Sciences, where students can major in earth science education or geology. Geology majors can undertake concentrations in paleobiology or coastal and marine geoscience. Students may also major in environmental science, collaboration between the Departments of Geological Sciences, Geography, and Biological Sciences. Environmental science majors can select several concentrations including the geological environment or the marine environment. There are also marine studies courses that are open to undergraduate students. These range from introductory classes for nonscience majors to advanced programs for science and engineering majors. The college offers graduate programs (master's and doctoral degrees) in geology, oceanography, and marine studies. The College of Marine and Earth Studies brings the latest advances in technology to bear on ocean, Earth, and atmospheric research, as well as on teaching.

Graduate study in climatology involves exposure to a wide range of research methods that can be used to help solve climate-related environmental problems. Faculty and graduate student research interests span the range of climatology and include climatic modeling, synoptic climatology, atmospheric dynamics, climate dynamics, physical climatology, water-budget climatology, paleoclimatology, climatic geomorphology, glaciology, global climate change, human effects on climate, and climatic influences on society, particularly on human health and socioeconomic activity.

Climatology courses offered at UD include Geography 612: Physical Climatology, Geography 620:

Atmospheric Physics, Geography 623: Atmospheric Dynamics, Geography 651: Microclimatology, Geography 652: Seminar in Climatology, Geography 653: Synoptic Climatology, Geography 655: Water Budget in Environmental Analysis, Geography 657: Climate Dynamics, Geography 681: Remote Sensing of Environment, Marine Studies 809: The Ocean and Climate Variation, and Geography 855: Climatological Research.

SEE ALSO: Climate Change, Effects; Glaciology; Paleoclimates.

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Fernando Herrera
University of California, San Diego

University of East Anglia

THE UNIVERSITY OF East Anglia (UEA) is a leading campus university located in Norwich, England. It was founded as part of the British government's New Universities Program in the 1960s. The university is a member of the 1994 group of leading research-intensive universities. Academically, it is one of the most successful universities founded in the 1960s, consistently ranking among Britain's top higher-education institutions. It was 19th in the Sunday Times University League Table 2006, and joint first for student satisfaction among mainstream English universities in the 2006 National Student Survey. Furthermore, the university was ranked 57th in Europe and one of the top 200 universities in the world in the 2006 World University Rankings undertaken by the Shanghai Jiao Tong University.

The School of Environmental Sciences is one of the longest-established, largest, and most fully developed Schools of Environmental Sciences in Europe. The School of Environmental Sciences offers undergraduate and graduate degree programs with an emphasis in a number of studies. The school is also engaged in research in a number of areas from atmospheric sciences to marine sciences. The school has been ranked high in research and teaching.

The Climatic Research Unit (CRU) is widely recognized as one of the world's leading institutions concerned with the study of natural and anthropogenic climate change.The unit consists of a staff of around 30 research scientists and students and has developed a number of the data sets widely used in climate research, including the global temperature record used to monitor the state of the climate system, as well as statistical software packages and climate models. The aim of the Climatic Research Unit is to improve scientific understanding in three areas: past climate history and its effect on humanity, course and causes of climate change during the present century, and prospects for the future.

The Climatic Research Unit is part of the School of Environmental Sciences, with close links to other research groups within the department, such as the Centre for Social and Economic Research on the Global Environment. The unit undertakes collaborative research with institutes throughout the world on a diverse range of topics and is coordinating or contributing to a number of networking activities. The CRU participates in both pure and applied research, sponsored almost entirely by external contracts and grants from academic funding councils, government departments, intergovernmental agencies, charitable foundations, nongovernmental organizations, commerce, and industry. Alongside its research activities, the unit has an educational role through its contribution to formal teaching with the School of Environmental Sciences (most notably, the M.Sc. in climate change) and various forms of in-service training, including postgraduate education. It is regarded as an authoritative source of information on both the science and policy aspects of climate change by the media and maintains a high public profile. The unit staff have published many peer-reviewed articles as well as editing various scientific journals, newsletters, and bulletins.

SEE ALSO: Climate Change, Effects; United Kingdom.

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Fernando Herrera
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University of Florida

ORIGINALLY FOUNDED IN 1853 as the East Florida Seminary, the institution later renamed the University of Florida (UF) moved to its current location in Gainesville in 1906. The largest and oldest university in the state, UF resides on 2,000 acres and provides educational opportunities for over 46,000 students. As the flagship institution of higher learning in the state, UF has acted as a steward in addressing global warming and climate change issues through its sustainability initiatives.

In 1994, UF president Charles Young signed the Talloires Declaration in an effort to convey support for actions to reduce environmental degradation and the depletion of natural resources. Three years later, members of the UF community initiated a grassroots campaign called Greening UF to engender a sense of environmental stewardship on campus. During 2000, the need for an administrative presence to develop sustainability initiatives was realized in the creation of an Office of Sustainability, housed within the College of Design, Construction, and Planning. In 2001, UF took another step along the path to greater campus sustainability by mandating that Leadership in Energy and Environmental Design (LEED) criteria be followed on all new building and renovation endeavors. UF's own Rinker Hall became the first building in the state of Florida to earn LEED Gold certification in 2004 and the newly renovated Library West achieved Gold status in 2007.

The call for a campus-wide Office of Sustainability was made by the Student Senate in 2004, and in fall 2005, a national search was initiated for a director of a centralized Office of Sustainability. The search for a director of the Office of Sustainability concluded in 2006 with the hiring of Dedee DeLongpré, a former development director for schools in California and program administrator for Fauna and Flora International. UF galvanized support for statewide sustainable action by hosting the inaugural Florida Campus and Community Sustainability Conference in October 2006.

Though UF began supporting major environmental initiatives over a decade ago, much of the university's recent push to enhance its stewardship has taken place during the tenure of President Bernie Machen (2004–present). In 2005, UF became the first university to be recognized as a Certified Audubon Cooperative Society. Speaking of this accomplishment and of sustainability during National Campus Sustainability Day on October 25, 2005, President Machen described the challenges and opportunities that the university has faced. President Machen espoused a full-spectrum approach to increasing sustainability by addressing the university's effect on the environment through green building, decreasing energy dependence, and reducing waste disposal to zero by 2015.

A year later, at the Florida Campus and Community Sustainability Conference, President Machen took on a much more direct tone regarding the issue of climate change, which he declared to be an urgent problem. In his speech, he described how UF would tailor its sustainability goals for 2007 specifically to decrease the university's emissions to combat climate change. President Machen outlined the progress made toward this end and also described new programs that UF would implement. As an academic institution, UF has already made strides to integrate sustainability into the classroom, as evidenced by the over 100 courses, 10 programs, and over 20 research entities relating to sustainability that are offered by the university.

In terms of engaging climate change from a supply chain perspective, President Machen talked of UF's effort to reduce emissions by buying locally produced food for use in dorm cafeterias and by implementing a sustainable purchasing policy. President Machen also detailed the university's energy-reduction strategy, which involves using power produced by renewable sources, turning down heat and lights in many campus buildings during vacation breaks, and purchasing more fuel-efficient fleet vehicles. Following the announcement of these environmental actions, President Machen reinforced UF's dedication to addressing climate change by being the first to sign the American College and University Presidents Climate Commitment at the end of 2006.

Through its multifaceted sustainability initiatives and commitment to emissions and energy reductions at all levels, UF has emerged as an environmental steward in the state of Florida and among universities across the United States. With the aid of strong administrative backing and the support of an environmentally conscious student body and faculty, UF provides a prime example of how a large educational institution can foster widespread social responsibility while minimizing its own negative effect on the environment.

SEE ALSO: Florida; Green Buildings; Sustainability.

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Joshua Chad Gellers
Columbia University

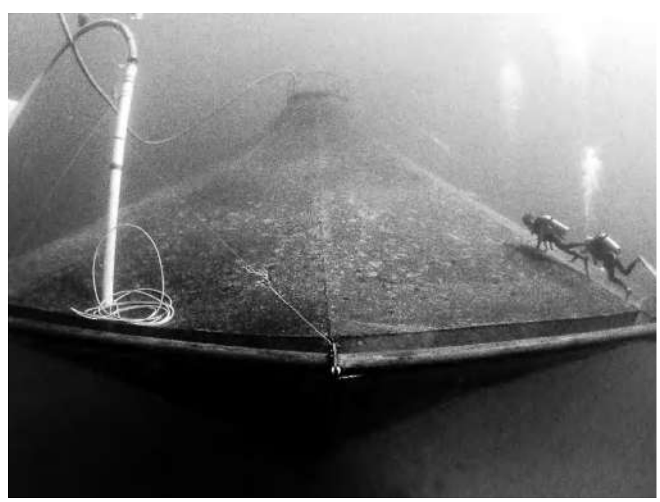
University of Hawaii

THE UNIVERSITY OF Hawaii, also known as UH, is a public, coeducational college and university system that confers associate, bachelor's, master's, doctoral, and postdoctoral degrees through three university campuses, seven community college campuses, an employment training center, three university centers, four education centers, and various other research facilities distributed across six islands throughout the state of Hawaii. All schools of the UH system are accredited by the Western Association of Schools and Colleges. UH at Manoa is the flagship institution of the system. It is well respected for its programs in Hawaiian/Pacific studies, astronomy, east asian languages and literature, asian studies, second language studies, linguistics, ethnomusicology, medicine, and law. UH education centers are located in more remote areas of the state, supporting rural communities via distance education.

A total of 616 programs are offered throughout the UH system, with 123 devoted to bachelor's degrees, 92 to master's degrees, 53 to doctoral degrees, three to first professional degrees, four to postbaccalaureate degrees, 115 to associate's degrees, and various other certifications. The Department of Oceanography offers a bachelor's degree program in global environmental science. This program emphasizes the study of Earth and Earth's physical, chemical, biological, and human systems. Students learn to investigate natural as well as economic, policy, and social systems and their response to and interaction with the Earth system.

The School of Ocean and Earth Science and Technology (SOEST) was established by the Board of Regents of UH in 1988 in recognition of the need to realign and further strengthen the excellent education and research resources available within the university. SOEST brings together four academic departments, three research institutes, several federal cooperative programs, and support facilities of the highest quality in the nation to meet challenges in the ocean, Earth, and planetary sciences and technologies.

The Hawaii Natural Energy Institute (HNEI), located on the campus of UH, is a one of the many research institutes housed by the SOEST. HNEI has become an acknowledged international leader in the energy field and has broadened its expertise to encompass the development of technologies that will enable us to tap our oceans for energy, food, minerals, and other resources. The institute's responsibilities include conducting and supporting basic research, managing research facilities and laboratories, demonstrating the applications of its work, and investigating the social, environmental, and financial effect of energy- and marine-related activities. Researchers at HNEI have a long history of investigating technology solutions, such as renewable energy systems and carbon sequestration, to reduce greenhouse gas emissions. Since 1989, HNEI has been a major participant in an international effort to study the feasibility of sequestering carbon dioxide in the deep ocean. Laboratory studies conducted in a novel large deep ocean



Divers clean the outside of SeaStation 3000, an open-ocean aquaculture project operated by the University of Hawaii.

simulator designed and built by HNEI have provided extensive data on the breakup of liquid carbon dioxide jets and fundamental information on carbon dioxide hydrate formation. HNEI cooperates in these endeavors with faculty from UH; federal, state, and local governments; private industry; public utilities; foreign governments; community groups; and universities and research institutes throughout the world.

The International Pacific Research Center is a climate research center housed by SOEST. This center was founded to gain greater understanding of nature and the causes of climate variation in the Asia-Pacific region, to determine whether such variations are predictable and to discover how global climate change affects the region.

SEE ALSO: Hawaii; National Science Foundation; Pacific Ocean.

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Fernando Herrera
University of California, San Diego

University of Illinois

THE UNIVERSITY OF Illinois is a system of public universities. It consists of three campuses: Urbana-Champaign, Chicago, and Springfield. The governing body of the three campuses is the board of trustees. The campus at Urbana-Champaign is known as the U of I and UIUC, whereas the Chicago campus is known as UIC, and the Springfield campus UIS. The largest university in the Chicago area, UIC has 25,000 students, 15 colleges, including the nation's largest medical school, and annual research expenditures exceeding $290 million. Playing a critical role in Illinois healthcare, UIC operates the state's major public medical center and serves as the principal educator of Illinois' physicians, dentists, pharmacists, nurses, and other healthcare professionals.

The modern UIC was formed in 1982 by the consolidation of two University of Illinois campuses: the Medical Center campus, which dates back to the 19th century, and the comprehensive Chicago Circle campus, which in 1965 replaced the two-year undergraduate Navy Pier campus designated to educate returning veterans. UIC's student body is recognized as one of the nation's most diverse, and the students reflect the global character of Chicago.

The School of Earth, Society, and Environment brings the resources of the Departments of Atmospheric Science, Geology, and Geography at the University of Illinois together to study Earth systems. The school awards bachelor of science degrees in atmospheric science, geography, and geology, as well as in the interdisciplinary major Earth Systems, Environment, and Society (ESES). The school also actively pursues advanced research and programs of graduate studies. At the Department of Atmospheric Sciences, students can pursue master of science (M.S.), and doctor of philosophy (Ph.D.) degrees. The University of Illinois is deeply involved in climate research at many levels, both within the department and in interdisciplinary research across the campus.

Faculty and students in the department carry out a number of research projects directed toward understanding climate variability and climate change. Students work with professors to conduct research to help explain the interactions between climate and the biosphere, ocean, and human activities, as humans alter the cycles of greenhouse gases such as carbon and methane. Students use global climate models to make projections of future changes under various plausible economic scenarios and simulate important geophysical processes, such as the past, present, and possible future behavior of the Atlantic thermohaline circulation.

Students also conduct research on how energy, water, and carbon are transported between the land surface and the atmosphere in systems ranging from agroecosystems to rainforests. Quantifying and understanding the causes of climate change is one of the greatest challenges of our time. The ESES major is an academic, liberal arts, and sciences degree. Students interested in a getting a more applied degree might be interested in the College of Agricultural, Consumer, and Environmental Sciences Natural Resources and Environmental Sciences (NRES) program, which offers a wide range of NRES and horticulture courses, from plant propagation to wildlife ecology.

Courses offered by UIC in the area of climate change include: ATMS 447: Climate Change Assessment, ATMS 448: Climate and Climate Change, ATMS 300: Weather Processes, ATMS 401: Atmospheric Physics, ATMS 402: Principles of Atmospheric Dynamics, ATMS 403: Weather Forecasting, ATMS 449: Biogeochemical Cycles and Global Change, ATMS 491: Topics in Atmospheric Sciences, GEOG 415: Physical Climatology, and IB 440: Plants and Global Change.

SEE ALSO: Climate Change, Effects; Illinois.

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Fernando Herrera
University of California, San Diego

University of Kentucky

THE UNIVERSITY OF Kentucky, also referred to as UK, is a public, coeducational university located in Lexington. Founded in 1865, the university is the largest in the commonwealth by enrollment, with 27,209 students. The university as a whole has been ranked the 19th-best public research university based on the scholarly activity of faculty. The university features 16 colleges, a graduate school, 93 undergraduate programs, 99 master's degrees, 66 programs in Ph.D.s and other doctoral degrees, and four professional programs.

The Department of Earth and Environmental Sciences at UK offers B.S., B.A., M.S., and Ph.D. degrees in geology, a minor in geology, and administers a topical major (B.S.) in environmental sciences. The department currently includes 10 regular faculty members, one lecturer, and 14 other faculty members who hold adjunct appointments. Approximately 40 graduate students and 35 undergraduates are enrolled annually. The study of environmental issues such as groundwater quality, waste disposal associated with the extraction of Earth resources, and climate change require understanding and application of several disciplines, including the fields of geology, chemistry, biology, agronomy, hydrology, and engineering. An environmental scientist must have a diverse background in all the natural sciences to develop creative solutions to environmental problems. The topical major in environmental sciences is intended to provide the breadth of scientific training needed to develop such solutions. At the same time, it provides flexibility for the student and adviser to build a curriculum tailored to the student's specific interests.

Courses with environmental applications offered at UK include: GEO 251: Weather and Climate, GLY 585: Hydrogeology, NRC 301: Resource Management and Conservation, NRC 359: Global Positioning Systems, NRC450G: Biogeochemistry, NRC 555 GIS: and Landscape Analysis, and PLS 366: Fundamentals of Soil Science.

Research within the Department of Earth and Environmental Sciences is funded by grants and contracts from the National Science Foundation, the Department of Energy, the PRF, and other federal, state, and industrial sources. Areas of graduate research include tectonics, hydrogeology, sedimentary geology, geochemistry, petrology, geophysics, and coal geology.

SEE ALSO: Climate Change, Effects; Global Warming.

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Fernando Herrera
University of California, San Diego

University of Leeds

THE UNIVERSITY OF Leeds is a major teaching and research university in Leeds, West Yorkshire. Leeds is a leading research institution and one of the largest in the United Kingdom with over 32,000 full-time students. Established in 1904, it is one of the six original civic universities, and in 2006 it was ranked second for the number of applications received. Leeds is now among the top 10 universities for research in the United Kingdom and is internationally acknowledged as a center of excellence in a wide range of academic and professional disciplines. Many of its research initiatives cross traditional subject boundaries, and Leeds currently promotes projects through 58 interdisciplinary centers and seven research schools. The university recognizes the importance of the environment and has established policies and programs to tackle environmental issues at a local and global level. Business in the Environment has ranked the University of Leeds as the top university in the region for environmental management and performance. The university also won the 2006 Green Gown Award for Waste Management and the 2007 Award for Continuous Improvement.

The School of Earth and Environment was formed in 2004 from the merger of the previous schools of Earth Sciences and of Environment. The school currently has over 60 academic staff, 35 support staff, and over 50 postdoctoral research fellows and associates. It is one of the largest schools in the United Kingdom that focuses on a multidisciplinary approach to understanding environment: the school studies the Earth from its core to its atmosphere and examines the social and economic dimensions of sustainability. The school offers both three-year BSc and four-year undergraduate degrees in geological, geophysical, and environmental sciences. The school also offers graduate degrees in Earth, atmospheric sciences, and sustainability research. The University of Leeds has recognized Earth and environmental systems science as one of its 12 gold research peaks of excellence. The school also has extensive ongoing research projects and collaborates with members of other departments and institutes such as mathematics and applied physical sciences and engineering, the Earth and Biosphere Institute, and the Earth, Energy, and the Environment Institute. This research grouping receives the second-highest research income nationally from the Natural Environment Research Council through competitive grant proposals.

The Earth and Biosphere Institute is a group of internationally recognized scientists with interests in the effects of biotic and environmental changes on a spectrum of time and space scales, from short term to geological, and from nanoscale to global. Research initiatives are ongoing within the University of Leeds and with groups from outside the university. The Earth, Energy, and Environment Institute is a multidisciplinary institute housed at the University of Leeds. The purpose of the institute is to provide integrated research solutions, knowledge transfer, and training in this energy-related area on all levels, from the regional to the global.

SEE ALSO: Education; European Union; United Kingdom.

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Fernando Herrera
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University of Maine

THE UNIVERSITY OF Maine, established in 1865, is the flagship university of the University of Maine system. It is located in Orono, just outside Bangor, one of Maine's largest cities. Also known as UMaine, the university has an enrollment of over 11,000 students, making it the largest university in the state. The college was the fourth to be established in Maine, after Bowdoin, Bates, and Colby. Originally intended as an agricultural college, it also places a large emphasis on engineering and the sciences. The University of Maine is a major research institute composed of six separate and distinct colleges offering 184 areas of study. The Department of Earth Sciences offers graduate degree programs focusing on climate change in conjunction with the Climate Change Institute.

The Climate Change Institute (formerly the Institute for Quaternary and Climate Studies) is an interdisciplinary research unit organized to conduct research and graduate education focused on the variability of the Earth's climate, ecosystems, and other environmental systems and on the interaction between humans and the natural world. Institute investigations cover the Quaternary period, a time of numerous glacial/interglacial cycles and abrupt changes in climate, ranging in time from the present to nearly 2 million years ago. Research activities include field, laboratory, and modeling studies that focus on the timing, causes, and mechanisms of natural and anthropogenically forced climate change and on the effects of past climate changes on the physical, biological, chemical, social, and economic conditions of the Earth. Institute research is supported by grants from a variety of sources including the National Science Foundation, the National Oceanic and Atmospheric Administration, NASA, and endowments from the Bingham Trust and the Dan and Betty Churchill Exploration Fund.

The Climate Change Institute offers an M.S. degree program with potential for a continuing Ph.D. program through Earth Sciences or an independent degree through the graduate school. Students in the program investigate human and global change, past, present, and future. This program involves in-depth documenting of past and present and predicting future environmental changes and human cultures through the primary disciplines of climatology, archaeology, glaciology, glacial geology, ecology, history, marine geology, and modeling. Over 40 faculty and staff of the institute provide multidisciplinary strength in the fields of climatology, archaeology, glaciology, glacial geology, geochemistry, ecology, history, remote sensing, and marine geology.

The institute's internationally recognized researchers have contributed to the scientific literature in multiple areas of study including understanding controls on the climate system, identifying and exploring abrupt behavior in the climate system, detecting and documenting human-source pollution in the atmosphere, exploring changes over time in the behavior of major atmospheric circulation systems such as El Niño/Southern Oscillation and the North Atlantic Oscillation, studying climate-induced changes in the distribution and abundance of plants and animals, detecting and documenting changes in civilization resulting from climate change, and identifying changes in the extent of ice sheets and mountain glaciers and their effect on the environment.

SEE ALSO: Greenhouse Effect; Maine.

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Fernando Herrera
University of California, San Diego

University of Maryland

THE UNIVERSITY OF Maryland in College Park was founded in 1856 as the Maryland Agricultural College and renamed in 1920 as the University of Maryland. The College Park main campus operates within a group of state-supported institutions of higher education in Maryland. The system's research and service components include the University of Maryland Biotechnology Institute in College Park and the Center for Environmental and Estuarine Studies, with laboratories at Horn Point, Solomons, and Frostburg.

The meteorology/oceanography program is a graduate department program with an expanded scope of activity to include the dynamic system of atmosphere in relation to oceans, land, and life. Though the department does not offer an undergraduate major, they do offer an undergraduate minor in meteorology and oceanography. Advantages to the university programs include proximity to nearby federal agencies such as NASA and the National Centers for Environmental Prediction, as well as the department's partnerships with NASA and the National Oceanic and Atmospheric Administration (NOAA), allowing for close collaboration. Graduate students in the department may have the opportunity to conduct research through these partnerships. An example of these partnerships is the Joint Global Change Research Institute—a university-based collaboration between the University of Maryland and the U.S. Department of Energy's Pacific Northwest National Laboratory or the Earth System Science Interdisciplinary Center, a joint center between the university's departments of meteorology, geology, and geography and the Earth Sciences Directorate at the NASA Goddard Space Flight Center.

The meteorology department conducts research in a broad range of areas, including atmospheric chemistry, climate studies, glaciology, numerical weather prediction, and remote sensing, with a range of activities including fieldwork, remote sensing, and numerical modeling from pole to pole and from the troposphere to the mesosphere. Current funded climate research in particular focuses on global change (including Earth system modeling and analysis and modeling of climate hesitative to greenhouse gas concentrations), atmospheric and oceanic reanalyses, hydroclimate studies, ocean-atmosphere interaction, monsoons, extratropical interannual variability, clouds and radiation, and NWP methods in climate modeling.

Founded as a joint collaboration between the Departments of Atmospheric and Oceanic Science and Geology and Geography at the University of Maryland and the Earth Sciences Directorate at the NASA/Goddard Space Flight Center, ESSIC (the Earth System Science Interdisciplinary Center) is based at the university. ESSIC's focus is to study and understand the dynamics of human activities on atmosphere, ocean, land, and biosphere components of the Earth. ESSIC also administers the Cooperative Institute for Climate Studies, sponsored by the NOAA National Satellite, Data, and Information Services and the NOAA National Centers for Environmental Prediction.

ESSIC's research centers on climate variability and change, atmospheric composition and processes, the global carbon cycle (including terrestrial and marine ecosystems/land use/cover change), and the global water cycle. ESSIC combines primary research of within-system observations with remote sensing and predictive models to forecast global changes and potential regional impact.

The University of Maryland Enterprise Campus, or M Square, is a 124-acre research park adjacent to the University of Maryland/College Park Metro Station. NOAA's National Center for Weather and Climate Prediction is one of the anchor tenants of M Square to take advantage of proximity to the University of Maryland—a leading center for climate research and numeric weather forecasting, which is developing major new partnerships with federal agencies in the areas of earth science, remote imaging, climate change, and energy research.

In addition to academics, the Center for Integrative Environmental Research (CIER) is based at the university. CIER is dedicated to creating a comprehensive understanding of the complex environmental challenges facing society and to developing valuable tools to inform policy and investment decision making. To support resilient flourishing natural and human systems, a truly integrative approach is needed. These multidisciplinary processes combine insights from the physical, engineering, natural, social, and health sciences and stimulate active dialogue across the science-society divide. CIER researchers and graduate students collaborate at global, national, regional, and local scales to explore issues with and across two major sustainability challenges: society's use of material and energy and urban environmental change.

The University of Maryland is setting an example for public and private sectors, as the president of the university joined other college presidents and chancellors around the country in taking a community leadership role and modeling ways to minimize global warming emissions and integrate sustainability into the curriculum and university environment, via membership in the Leadership Circle of the American College and University Presidents Climate Commitment.

SEE ALSO: Education; Maryland; National Oceanic and Atmospheric Administration (NOAA).

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Lyn Michaud
Independent Scholar

University of Miami

THE UNIVERSITY OF Miami, founded in 1925, is a private, coeducational teaching and research institution noted for its extensive study-abroad programs, marine science institute, and medical center. The university confers bachelor's, master's, doctoral, and professional degrees in a broad range of academic disciplines including the arts and sciences and marine science. The main campus is in Coral Gables, Florida, and the Rosenstiel School of Marine and Atmospheric Science (RSMAS) is located on Virginia Key on Biscayne Bay.

The university's undergraduate programs related to climate change include ecosystem science and policy and geological sciences. Ecosystem science and policy covers a range of environmental issues from various perspectives. The geological sciences program is taught in the College of Arts and Sciences; the major includes themes of Earth origins, environmental preservation, global dynamics, and internal and surface processes. A special aspect of the geological sciences program is an option for a five-year B.S./M.S.

program coordinated with RSMAS to complete the graduate portion of the education.

The Rosenstiel School was established in 1940 on the Coral Gables campus and moved to Virginia Key on Biscayne Bay in 1957 after outgrowing its initial location. RSMAS is now a 16-building complex and home to a museum with a collection of approximately 400,000 invertebrate specimens, the National Institute of Environmental Health Sciences Marine and Freshwater Biomedical Sciences Center, NSF/NIEHS Oceans and Human Health Center, and the Division of Marine and Atmospheric Chemistry. Research facilities include advanced technology computing and laboratories with precision instruments (mass spectrometer, X-ray spectrograph, gas chromatograph, and a scanning electron microscope).

RSMAS's Division of Marine and Atmospheric Chemistry is a graduate program offering master's and doctoral degrees in chemical processes of the atmosphere and chemical processes of the ocean and hydrology. Fieldwork plays a major role, and the department's small size ensures student access to faculty, staff, and research opportunities.

The teaching/research facilities include chemical laboratory instrumentation, a laboratory onboard a cruise ship for collecting marine and atmospheric data, a 90-ft. research catamaran, and a simulation wind and wave tank for observation of specific air/sea interactions. RSMAS's library holds an extensive marine science collection.

Research opportunities are diverse as a result of having a faculty with a wide range of expertise and research interests. Faculty members from the six divisions at RSMAS (Applied Marine Physics, Marine and Atmospheric Chemistry, Marine Affairs and Policy, Marine Biology and Fisheries, Marine Geology and Geophysics, and Meteorology and Physical Oceanography) are working on research related to changing climate impact. A sampling of climate-related studies include the Southeast Climate Consortium (using advanced forecasting tools for agriculture, forestry, and water resources management in the southeastern United States), water resource management in the drought-prone state of Ceara in northeast Brazil (human response to climate change), and climate and fisheries (how changes in sea-level pressure, sea surface temperature patterns, and global mean temperature affect fish stocks).

The Cooperative Institute for Marine and Atmospheric Studies (CIMAS) is a research institute of the University of Miami located in the RSMAS. CIMAS serves as a mechanism to bring together the research resources of the university with those of the National Oceanic and Atmospheric Administration (NOAA) to perform research for understanding the Earth's oceans and atmosphere within the context of NOAA's mission.

The scientific activities in CIMAS are organized under broad research themes. The themes are topics of climate variability, fisheries dynamics, regional coastal ecosystem processes, human interactions with the coastal environment, air-sea interactions and exchanges, and integrated ocean observations; their scientific objectives are guided by NOAA's Strategic Plan and its specific goals in the context of the research activities and expertise resident in the university and the local Miami laboratories of NOAA.

The University of Miami is setting an example for public and private sectors, as when the president of the university joined other college presidents and chancellors around the country in taking a community leadership role and modeling ways to minimize global warming emissions and integrate sustainability into the curriculum and university environment, via membership in the American College and University Presidents Climate Commitment.

SEE ALSO: Atlantic Ocean; National Oceanic and Atmospheric Administration (NOAA); Oceanography.

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Lyn Michaud
Independent Scholar

University of Michigan

THE UNIVERSITY OF Michigan (also known as Michigan, or UM) was established in 1817 and today is one of the premier research universities in the United States. The university has a strong reputation in all academic fields, with more than 70 percent of

Michigan's 200 major programs, departments, and schools ranking in the top 10 nationally. The university has one of the largest annual research expenditures of any university in the United States (nearly $800 million in 2006), and the university's endowment was valued at $5.65 billion also in 2006, making it the ninth-largest endowment in the United States and the third largest among public universities. The university has over 6,200 faculty members, 73 of whom are members of the National Academy and 400 of whom hold an endowed chair in their discipline. The university consistently leads the nation in the number of Fulbright Scholars and has matriculated 25 Rhodes Scholars, while having produced seven Nobel Prize winners.

The Michigan library system comprises 19 libraries with 24 collections, totaling 8.13 million volumes, with 177,000 volumes being added each year. The campus libraries include the Gerald R. Ford Presidential Library. Over 40,000 students attend UM, including 25,555 undergraduate and 14,470 graduate students in 600 academic programs. Students come from all 50 states and more than 100 countries. One quarter of all undergraduates are members of ethnic minority groups. The university also has a strong social conscience. It was on the steps of the Michigan Student Union on October 14, 1960, that President John F. Kennedy proposed the concept of the Peace Corps. Lyndon B. Johnson's speech outlining his Great Society program also occurred at Michigan.

Over 300 Michigan faculty members are engaged in research on environmental issues. Likewise, there are a number of institutes and centers at the university that are actively engaged in research concerning global warming and climatic change, as well as related issues such as sustainability and alternative energy. For example, the UM Climate Change Consortium is an initiative of the School of Engineering that runs an electronic forum about climate change. The School of Engineering is also renowned for its Solar Car Team, which placed first in the American Solar Challenge four times and third in the World Solar Challenge three times. The University of Michigan Transportation Research Institute provides leadership in interdisciplinary transportation-related research and also has experts conducting research on energy efficiency and emissions. The Frederick A. and Barbara M. Erb Institute for Global Sustainable Enterprises is affiliated with the School of Business and fosters global sustainable enterprise through interdisciplinary research and education initiatives. Even the operations of the university itself strive to be environmentally sensitive, with UM Waste Management Services encouraging recycling on campus. The university operates a 13,000-acre (53 sq. km.) biological station in the northern Lower Peninsula of Michigan—one of only 47 biosphere reserves in the United States.

The university also houses the Michigan Memorial Phoenix Energy Institute, which focuses on identifying and using secure, affordable, and sustainable energy sources. The institute uses public policy, economics, business, and social sciences to lay the foundation for successful implementation of scientific and technological achievements. Created in 1947 as a memorial to UM grads who gave their lives in World War II, the institute originally sought to explore peaceful ways to use atomic energy for the benefit of humankind. Then in 2004 the regents of the university broadened the charter of the Phoenix Project beyond atomic energy to encompass interdisciplinary research on and education about the development of energy policies that promote world peace, responsible use of the environment, and economic prosperity.

The UM Center for Sustainable Systems is located within the School of Natural Resources and Environment (SNRE) and focuses on the identification of systems-based approaches to sustainability through creative and effective teaching and research. SNRE also hosted in 2007 a national summit on climate change as part of the Clinton Global Initiative. The purpose of the summit was to bring together global leaders and key stakeholders to examine what is known about the composite regional effect of climate change and what management and policy options can help regions deal with changes in average conditions, as well as with extreme events.

SEE ALSO: Alternative Energy, Solar; Climate Change, Effects; Education.

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Michael J. Simsik
U.S. Peace Corps

University of Nebraska

THE UNIVERSITY OF Nebraska in Lincoln, Nebraska (UNL), founded in 1869, is part of the state-supported University of Nebraska system. The discipline of ecology began at the University of Nebraska, and the campuses are botanical gardens and arboreta. The university confers bachelor's, master's, doctoral, and professional degrees in a variety of academic and professional disciplines, including agricultural sciences, animal sciences, health sciences, atmospheric sciences, earth and space sciences (which includes the former departments of geology and geophysics), and environmental sciences. Research facilities include the Cedar Point Biological Station, the Center for Great Plains Studies, and the Engineering Research Centers.

Within the university, the College of Agricultural Sciences and Natural Resources encompasses 27 programs of study and two preprofessional programs ranging from animal science, fisheries and wildlife, and agribusiness to professional golf course management. The areas related to climate change and the environment include Environmental Restoration Science, environmental studies, natural resource and environmental economics, and applied climate sciences.

Environmental restoration science is the study of soil (for producing crops and supporting groundwater purification and the conversion of waste material). The program combines classroom work with out-of-class experiences (internships and fieldwork), with an emphasis on soil in an environmental context. In addition to frequent opportunities for faculty and staff contact, students may be involved in the Soil and Water Resources Club, Agronomy Club, Soil Judging Team, or the Lincoln Chapter of the Soil and Water Conservation Society.

Environmental studies provides interdisciplinary study encompassing a variety of academic departments in the College of Agricultural Sciences and Natural Resources and the College of Arts and Sciences to study environmental and social sciences, global issues, and environmental protection. In addition to academic work across academic disciplines, the Environmental Resource Center provides access to environmental information, internship opportunities, and a study area. Students may be involved in a variety of environmentally related student groups such as Ecology Now, the Soil and Water Resources Club, and the Wildlife Club.

Natural Resource and Environmental Economics brings together natural sciences with economics, law, and other social sciences with a focus on assessing public policies regulating the use of natural resources and environmental amenities.

The Applied Climate Sciences (ACS) program (formerly called the Department of Agricultural Meteorology) is a graduate program bringing together a variety of academic disciplines for academic study and applied research on climate effects and variability; drought monitoring, mitigation, and planning; environmental biophysics; global climate change; High Plains climate; micrometeorology; and severe weather, among others.

Within the program are the bio-atmospheric interactions specialization (to understand interactions between the atmosphere and the biosphere) and the agricultural meteorology specialization (to understand bioatmospheric interaction and agriculture).

The facilities include laboratory, office, and classroom facilities to support research, teaching, and outreach regarding natural resources; the Agro-Meteorology Laboratory at the University of Nebraska Agricultural Research and Development Center near Mead; measuring stations for the National Atmospheric Deposition Program and the U.S. Department of Agriculture Ultraviolet B Monitoring Network; the High Plains Climate Center and its Automated Weather Data Network; and the National Drought Mitigation Center.

A sampling of research opportunities related to climate in the ACS programs includes climate variations, climate modeling, micrometeorology, remote sensing, and climate effects.

UNL's School of Natural Resources hosts the Great Plains Regional Center of the National Institute for Global Environmental Change. The focus of the center's research is environmental change in the grasslands of Colorado, Iowa, Kansas, Minnesota, Missouri, Montana, Nebraska, North and South Dakota, and Wyoming. Because of the agricultural value of crops and livestock produced in this region, even minor climate changes could have a major effect on the nation and the world. The data collected are also valuable for reference with regard to global regions with semiarid grassland ecosystems similar to the Great Plains.

SEE ALSO: Climate Change, Effects; Education; Nebraska.

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Lyn Michaud
Independent Scholar

University of New Hampshire

THE UNIVERSITY OF New Hampshire in Durham, New Hampshire, was founded in 1866 as the College of Agriculture and Mechanic Arts. The school became the University of New Hampshire (UNH) in 1923 and is the main campus of the state's university system. Academic programs cover a variety of disciplines such as the arts and sciences, humanities, business, engineering, education, and the health professions. Research facilities included Anadromous Fish and Aquatic Invertebrate Research Laboratory, Jackson Estuarine Laboratory, Coastal Marine Laboratory, Jere A. Chase Ocean Engineering Laboratory, and Shoals Marine Laboratory.

Courses, programs, and departments interconnect on the subject of climate. The Climate Change Research Center (CCRC) is dedicated to the study of the Earth's atmosphere. Set up for graduate-level instruction, the CCRC also provides information materials (interactive displays) to various organizations and provides support to K–12 teachers through lesson guides and teacher training. Several center faculty also have appointments to the Departments of Earth Science, Natural Resources, Chemistry, and Engineering and work with undergraduates in the Research & Discover internship and Undergraduate Research Opportunity Program.

CCRC research focuses on understanding the fundamental properties of the atmosphere and how they have been affected by human activities and will continue to be so in the future, with areas of interest including air quality and climate, airborne sciences, biosphere-atmosphere exchange, halogen chemistry, ice course and air-snow exchange, new england climate assessment, and organic aerosols.

Courses taught by CCRC faculty are specific to the research being conducted in the department: Introduction to Atmospheric Science (fundamental principles and dynamics of the earth's atmosphere), Global Atmospheric Chemistry (relationship between atmospheric chemistry, climate, and global change), Atmospheric Aerosol and Precipitation Chemistry (processes determining the chemical and physical characteristics of atmospheric aerosol particles and precipitation), Measurement Techniques in Atmospheric Chemistry (instrumental methods used in atmospheric chemistry and biogeochemical research), Earth System Science (components, interactions, and concepts for characterizing the Earth's integrated system), and Regional Air Quality (measurement programs to examine air quality in New England and other global regions).

Earth Sciences is a multidisciplinary department including geology, oceanography, hydrology, ocean mapping, and geochemical systems specialization. Students have the option of choosing among the different disciplines in creating a program specific to interest and, in addition, have many different research opportunities from local research to field work at sites including Antarctica, Greenland, the Pacific and Indian oceans, Mexico, China, the Himalayas, Indonesia, Pakistan, and the western United States. Research in earth sciences covers all the Earth system components and relies on connections with researchers and faculty in natural resources.

Natural Resources and Earth Systems Science is an interdepartmental graduate program offering only a doctoral degree in natural resources and environmental studies or Earth and environmental science. The program relies on interdisciplinary work to understand and manage the environment with many possible options for study including atmospheric science and ethical and policy issues.

The UNH/National Oceanic and Atmospheric Administration Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET) researches coastal resource management. Working with a network of colleagues throughout the United States, CICEET's focus is ecosystem health and coastal resiliency to find technology to address coastal challenge as well as providing usable information for people to have continued access to clean water and healthy coasts.

UNH hosted the Global Analysis, Integration, and Modeling International Project Office of the International Geosphere-Biosphere Program until termination of the program in 2004. The decade-long project researched existing models. The more-than-decade-long project provided the foundation for the Global Carbon Project and created the platform for new integrative modeling activities.

The UNH is setting an example for public and private sectors; the president of the university joined other college presidents and chancellors around the country in taking a community leadership role and modeling ways to minimize global warming emissions and integrate sustainability into the curriculum and university environment with membership in the American College and University Presidents Climate Commitment. Since 1997, the University Office of Sustainability—the oldest endowed sustainability program in U.S. higher education—has brought together all members of the university community in integrating sustainability throughout UNH (in curriculum, operations, and research and engagement).

SEE ALSO: International Geosphere-Biosphere Program (IGBP); National Oceanic and Atmospheric Administration (NOAA); Sustainability.

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Lyn Michaud
Independent Scholar

University of Oklahoma

THE UNIVERSITY OF Oklahoma (OU), located in Norman, was founded in 1890. The university confers bachelor's, master's, doctoral, and professional degrees in a variety of academic and professional disciplines. The university is home to the College of Atmospheric and Geographic Sciences, containing the School of Meteorology and the Department of Geography.

The School of Meteorology will celebrate its fiftieth anniversary in 2010. The school is housed in the National Weather Center building, which also is home to 12 academic, research, and operational meteorology organizations. With over 320 undergraduate and 80 graduate students, OU has the largest meteorology program in the United States, and the department offers a Bachelor of Science in Meteorology degree or a Professional Meteorology master's degree. Undergraduate students also have the opportunity to participate in an international exchange program featuring the universities of Reading in England, Monash in Australia, and Hamburg in Germany.

The School of Meteorology performs shared research with the National Oceanic and Atmospheric Administration's National Severe Storms Laboratory and participates in a variety of national projects. In February 2008, the National Weather Center in Norman, Oklahoma, hosts the first U.S.–China Symposium on Meteorology: Mesoscale Meteorology and Data Assimilation.

The Department of Geography provides for the study of human interactions with climate, earth structures, and natural resources and the effect these interactions have on human culture. The department offers bachelor's, master's, and doctoral degrees. Faculty expertise includes cultural, historical, political, and economic geography; applied physical geography; and geographic information science. Research is conducted in climatology, natural resources, human effects on the planet, and cartography.

In addition to academics, the College of Atmospheric and Geographic Sciences hosts several research centers. The Center for the Analysis and Prediction of Storms includes the Center for Collaborative, Adaptive Sensing of the Atmosphere and the Linked Environments for Atmospheric Discovery. The mission of the center is the development of techniques to predict severe weather conditions using on-site and remote sensing systems.

The Cooperative Institute for Mesoscale Meteorological Studies was established in 1978 between OU and the National Oceanic and Atmospheric Administration. In addition to linking scientific expertise from academia, the center has collaborative relationships with all the National Oceanic and Atmospheric Administration units in Norman. Research programs include basic and convective mesoscale research, climate change monitoring and detection, and climatic effects. Additional research involves improving technology for the prediction of weather events.

Under legislative mandate, the Oklahoma Climatological Survey (OCS) was established in 1980 to collect, analyze, interpret, and provide information on climate and weather data to residents of Oklahoma. The OCS conducts research on climate change effects and provides data and support to the state climatologist.

Under joint administration by OU and Oklahoma State University, the Oklahoma Mesonet monitors weather and soil conditions at over 100 automated observing stations.

The Center for Spatial Analysis brings together various academic disciplines to study and apply geospatial science and technology.

Focused on strengthening the research of environmental scientists and facilitating relationships between the scientific community and the public, the Environmental Verification and Analysis Center participates in earth science work.

A network opportunity for teachers of geography, the Oklahoma Alliance for Geographical Education relies on affiliation with the National Geographic Society along with its associated state geographic alliances, as well as geography organizations from around the country.

The opportunity for Oklahomans to learn about and support NASA's mission research programs, including science and geography, along with other academic disciplines falls under the auspices of the Oklahoma NASA Space Grant Consortium. The consortium includes partnerships with Oklahoma universities, a science museum, a cooperative extension service, state and local governments, and other interested institutions.

Beyond academics and research, the president of the University of Oklahoma joined other college presidents and chancellors around the United States to take a community leadership role and to model ways to minimize global warming emissions and integrate sustainability within the curriculum and university operations and environment, with membership in the American College and University Presidents Climate Commitment.

SEE ALSO: National Aeronautics and Space Administration (NASA); National Oceanic and Atmospheric Administration (NOAA); University of Reading.

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Lyn Michaud
Independent Scholar

University of Reading

THE UNIVERSITY OF Reading is located in Reading, England. With a foundation made by joining the School of Art begun in 1860 and the School of Science begun in 1870, Christ Church of Oxford established an extension college in 1892. Funding and expansion ensured success and led to the University of Reading being given a royal charter in 1926. The University of Reading has several educational centers conducting research in a variety of disciplines in the arts, humanities, sciences, and social sciences, including environmental sciences and meteorology.

The environmental science degree investigates the components of the Earth system, along with providing a scientific understanding of current and future environmental issues and their management. Within the major, students may choose a pathway in consultation with a course adviser. The pathway options include earth and atmosphere (interactions between the solid Earth, the Earth's surface, the oceans, and the atmosphere through geology, soil science, and meteorology), earth systems and environmental change (changes in rates, causes, and extents of change; the contribution of human activity; and how that activity can be managed appropriately), and habitat management.

The Department of Meteorology was founded in 1965, and offers a range of courses for both undergraduates and postgraduates. The teaching facilities include a lecture hall, laboratories for practical experimentation, and a meteorological enclosure for observations and experimentation. For teaching purposes and general access, current weather data and satellite pictures stream into the department.

Active research in regional weather systems, data assimilation, global atmospheric modeling, and global circulation and climate are ongoing. Established research and teaching links with the European Centre for Medium Range Weather Forecasts and the U.K. Meteorological Office provide additional learning opportunities and access to state-of-the-art equipment.

In addition to academics, the University of Reading is the home of the National Centre for Atmospheric Science (NCAS) Climate @ Reading Programme, the Environmental Systems Science Centre (ESSC), and the Data Assimilation Research Centre (DARC).

Based within the Department of Meteorology is the NCAS Climate @ Reading Programme. NCAS was called the Centre for Global Atmospheric Modeling from May 1990 until April 2006. NCAS Climate @ Reading provides scientific expertise, technical support, and training to address the following key challenges: increasing knowledge of climate variability and change on various timescales, using advanced computer technology for simulations; establishing the usefulness and accuracy of climate prediction models; and integrating various specialties for creating adaptability or mitigation of climate change.

NCAS Climate @ Reading is part of the Climate Programme charged with carrying out climate change research into how the climate will change by the end of the century, while taking into account natural variation and finding ways to predict climate change for the benefit of society. NCAS carries out this mission by integrating dynamics of the global climate system with earth system modeling, improved prediction, and ever-improving computer technology.

ESSC is a research center that is not involved in undergraduate teaching. It is funded as such by the Natural Environment Research Council (NERC). ESSC is one of the focal centers in the country for the study of remotely sensed data; the work involves coupling data with computer models of environmental processes. The wide range of interests of researchers parallels the research interests of NERC: meteorology, oceanography, geology, and hydrology. ESSC forms part of the School of Mathematics, Meteorology, and Physics.

Research interests are largely driven by the strategy of NERC, and so address problems relevant to issues within topics of global environmental change, hazard assessment and mitigation, natural resources, waste, and pollution. Research includes land surface processes, marine science, meteorology, and others.

DARC is funded under the NERC Earth Observation Centre of Excellence Initiative. The meteorology department holds the directorship and partners with Rutherford Appleton Laboratory and the universities of Cambridge, Edinburgh, and Oxford. The focus of DARC is theory development research and studying applications of data assimilation methods. This work involves the highly integrated combination of various Earth observation data sources with information available from sophisticated Earth system models and the European Space Agency Enlist satellite.

In addition to many collaborative partnerships worldwide, the University of Reading is one site of an international exchange program with the University of Oklahoma.

SEE ALSO: Climate Change, Effects; Education; University of Oklahoma.

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Lyn Michaud
Independent Scholar

University of St. Gallen (Switzerland)

THE UNIVERSITY OF St. Gallen, Graduate School of Business Administration, Economics, Law, and Social Sciences (HSG) is located in St. Gallen in northeastern Switzerland. The town of St. Gallen is a commercial center with roots in the early 7th century and a hermitage established by the Irish missionary Saint Gall. The hermitage became a Benedictine abbey and noted educational center in the 8th century.

On May 28, 1898, the Cantonal Parliament of the Canton of St. Gallen issued a resolution to establish a school for transport, commerce, and administration; this academy opened in 1899. The school continued under various names until being established as the University of St. Gallen. For the 2000/2001 educational year, the curriculum was revised to offer bachelor's and master's degrees.

HSG remains true to its original mission to provide an education easily translated into real life. Topics of study include business administration, economics, law, and social sciences leading to bachelor's, master's, and doctoral academic degrees. More programs are being offered in English, drawing many international students. In addition, executive education is offered by HSG to provide educational opportunities to people in business.

The Institute for Economy and the Environment (IWOe-HSG) was founded on October 1, 1992, at the University of St. Gallen to explore the global intersections of the natural world with the forces of economy and society. IWOe-HSG identifies potential problems and researches options to determine practical solutions. These issues cover a wide range of topics regarding renewable energy, financing renewable and sustainable options as well as addressing issues of concern like landscapes for the use and production of electricity from wind farms. To perform this work, the institute maintains a network with international businesses, other educational institutions, and research organizations.

In general, the institute analyzes conditions necessary for an environmentally sound market economy and corporate sustainability management. Furthermore, it imparts the findings to practical business situations to ensure that the work it does is relevant and has an effect on real-life situations. The foundation of the IWOe-HSG was supported by Oikos (the environmental student organization at the HSG) and the Oikos Foundation for Economy and Environment. IWOe-HSG is a nonprofit organization that receives support from the university and from private and nonprofit companies. At present, the institute's primary research projects include culture and sustainability, management systems for corporate sustainability, sustainability marketing and sustainable consumption, life cycle assessment, environmental finance and entrepreneurship, and renewable energy technologies.

In 1968, five students from the University of St. Gallen chose to make a difference by fostering dialogue between groups instead of joining the protests of many of their peers. They set up the International Students' Committee and formed a symposium designed to foster cross-generational dialogue in a neutral environment. Each year in May since 1970, the St. Gallen Symposium has been held at the university as a forum for international dialogue on the connections among business, politics, and society. Attendees include business professionals (corporate and entrepreneurial), policymakers, academic professionals, and students from the University of St. Gallen in Switzerland for integrative discussions on sustaining business and society in general. The topic for the symposium held in 2007 was "The Power of Natural Resources."

The International Students' Committee organizes the St. Gallen Symposium under the auspices of the St. Gallen Foundation for International Studies (which serves in an advisory and supervisory capacity). In addition to the students from St. Gallen an office (International Students' Committee Harvard) at Harvard University in the United States fosters international cooperation, with Harvard students supporting the St. Gallen member students. The team of students designs and plans the symposium from concept and content through to marketing and implementation. The team also determines key themes and interacts with a network of selected speakers from business, politics, and society, along with maintaining contacts with other leading international universities.

SEE ALSO: Climate Change, Effects; Harvard University.

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Lyn Michaud
Independent Scholar

University of Utah

THE UNIVERSITY OF Utah, founded in 1850, is a public, coeducational institution located in Salt Lake City. The university confers bachelor's, master's, doctoral, and professional degrees in a variety of academic and professional disciplines. The university offers a focus on environmental science, and the university's College of Mines and Earth Sciences is home to the Departments of Meteorology and Geology and Geophysics.

The Department of Meteorology focuses on offering a background for meteorology and related environmental science careers with an understanding of system processes involving weather and climate. The program's emphasis on mountain weather and climate (as well as the complexities involved in forecasting weather on complex terrain) stems from Salt Lake's location on the western slope of the Wasatch Mountains (a range in the Rocky Mountains). Integrating math, physics, and chemistry and a broad range of academic opportunities with dynamic, physical, and synoptic meteorology prepares students for employment as meteorologists with the National Weather Service or for a broad range of careers with government and private employers in meteorology or environmental sciences.

The department's small size ensures student access to faculty, staff, and research opportunities. The faculty has diverse expertise and research interests in a broad range of observational, modeling, and theoretical studies. Current interests include tropical convection and hurricanes; boundary layer modeling; fire weather prediction and fire modeling; mountain meteorology; weather analysis and prediction; parameterization, remote sensing, and modeling of clouds; aerosol physics and

Water levels have been steadily decreasing in Lake Powell, which borders Utah and Arizona. The university's environmental program focuses on environmental policy and how human actions affect the natural dynamics.

air pollution; numerical modeling, data assimilation, and predictability; and climate change.

The department's teaching facilities on the main campus of the University of Utah include an audiovisual teaching laboratory also serving as a classroom, research equipment, and computing resource. A mountain meteorology laboratory is located about a mile away from the primary meteorology department.

Active research currently being done within the department by faculty members and funded by governmental and private organizations includes active research in clouds, aerosols, and climate; numerical weather prediction; mountain weather and climate; tropical convection and storms; and climate variability and change.

The Department of Geology and Geophysics offers both undergraduate and graduate degree programs. Undergraduates may declare majors in geoscience (with emphases in geology, geophysics, or environmental geoscience), geological engineering, or Earth science teaching. The four graduate programs are in geology, geophysics, geological engineering, and environmental engineering.

The Earth sciences overlap and integrate with a broadening range of disciplines. With a specific understanding of specialized processes and of fitting them into the broader system framework, students and researchers both gain a better understanding of earth science systems and the internal functional processes of geophysics, geobiology, and geochemistry. A sampling of projects and themes of special interest to those studying climate change includes environmental geology, paleoclimatology, geothermics, marine geology, and groundwater and surfacewater hydrology. Recent investigations of special note undertaken by University of Utah faculty, students, and collaborators were borehole thermal gradients as long-term records of earth surface paleotemperatures and global warming and Antarctic drill holes as recorders of Tertiary paleoclimate change.

The Environmental Studies Program at the University of Utah focuses on environmental policy and exists not as a single field of study but as a curriculum to provide an understanding of environmental systems and how human actions affect the natural dynamics. Students have the option of choosing from three different perspectives: biology and natural sciences, humanities and aesthetics, or human behavior/policy/decision making. In addition to academics, the University of Utah is home to the National Oceanic and Atmospheric Administration Cooperative Institute for Regional Prediction (CIRP). Established in 1996, and building on an applied research program started in 1991 for faculty and students to work in cooperation with local and regional forecasters, CIRP conducts research to improve regional forecasting and knowledge of western U.S. meteorology.

Benefits of this research to weather professionals, researchers, and the general public relate to improved access and quality of data related to weather prediction. Various programs within CIRP provide access to surface observations incorporated from numerous sources (surface stations around the United States), analyses of compiled data, specific information for the fire weather community, and extended forecasts. CIRP also provides workshops.

SEE ALSO: National Oceanic and Atmospheric Administration (NOAA); Paleoclimates; Utah.

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University of Washington

THE UNIVERSITY OF Washington, located in Seattle, was founded in 1851. The university confers bachelor's, master's, doctoral, and professional degrees in a variety of academic and professional disciplines including atmospheric sciences and Earth and space sciences (includes the former Departments of Geology and Geophysics) and environmental sciences.

Founded in 1947, the Department of Atmospheric Sciences focuses on teaching excellence incorporating a wide range of topics including weather forecasting, global warming, air quality, mountain weather, marine weather, El Niño, the ozone hole, ice ages, and the weather of Mars. Students who choose atmospheric science majors are prepared for a range of career options (weather forecasting, environmental meteorology, broadcast weather, and a broad range of careers with government and private employers in meteorology or environmental sciences).

The teaching facilities include a map room (for viewing weather data including radar and satellite imagery and forecast models) and an instruments laboratory (for learning about various types of observational instruments and computer interfacing by taking local observations).

The department's internship program encourages students to explore a variety of career paths while gaining valuable experience in addition to academic credit and possible stipends. The internships range from National Weather Service Forecast Offices to television stations, U.S. Forest Service, the Northwest Avalanche Center, the Pacific Marine Environmental Lab, and other laboratories and businesses. The faculty has diverse expertise and research interests, with research opportunities available to students.

The Department of Earth and Space Sciences integrates geology, math, physics, biology, and chemistry into a program to further the understanding of Earth structure, processes, and history and solar system structure, processes, and histories. The faculty areas of research are aimed toward predicting the future conditions of Earth, studying the geologic record, observing conditions, and modeling the present state. A sampling of projects of special interest to those studying climate changes includes glaciology, Quaternary research, climate, and paleoclimate.

The Program on the Environment offers interdisciplinary environmental education and is a focal point for information exchange on environmental education and research opportunities. The Earth Initiative encourages innovative partnerships to address environmental and natural resource challenges. By focusing on problem-specific environmental issues in the Pacific Northwest and beyond, the initiative brings together faculty, students, and community partners to create collaborative research, teaching, and scholarship.

The Program on the Environment, established in 1997, exists not as a separate department but as a collaborative network linking all university departments in providing environmental education. The programs provide education in natural sciences; social sciences; law, policy, and management; and ethics, values, and culture.

In addition to academics, the University of Washington is home to the Climate Impacts Group (CIG), which integrates climate science with public policy. With a focus on the U.S. Pacific Northwest, the group performs research on the consequences of climate change and provides information to policy makers on preserving regional resources vulnerable to climate changes.

By bringing together various disciplines to examine past climate and stressors, to analyze patterns of and predictable climate variations, as well as to determine past climate change effects, CIG extrapolates possible future responses to climate change in the Pacific Northwest's vulnerable areas.

CIG makes recommendations for approaches of human-induced changes on natural resources and overall climate effect. By developing close connections and maintaining networks with government, private, and North American tribal groups, as well as the agencies in charge of water, forests, fisheries, and coastal resources, the group ensures that their information is useful, informative, and transformational to the daily activities of appropriate resource management.

The University of Washington is setting an example for public and private sectors. The president of the university joined other college presidents and chancellors around the country in taking a community leadership role and modeling ways to minimize global warming emissions and integrate sustainability into the curriculum and university environment, with membership in the Leadership Circle of the American College and University Presidents Climate Commitment. By doing so, the university is building on past successes in developing plans for reducing energy consumption with the Environmental Stewardship Advisory Committee and Policy on Environmental Stewardship adopted in 2004, joining the UPASS program (bus pass) to reduce single-occupancy vehicle trips to campus, and acting as a founding partner of the Seattle Climate Partnership. In addition, the university has pledged to reduce greenhouse gas emissions by 2012 to 7 percent below the levels in 1990.

SEE ALSO: National Oceanic and Atmospheric Administration (NOAA); Washington.

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Upwelling, Coastal

COASTAL UPWELLING OCCURS when water along a coastline flows offshore and deeper water—usually relatively cool, rich in nutrients, and high in partial pressure of carbon dioxide—flows upward to fill its place. Upwelling areas are notable for their effect on carbon cycling, as upwelling not only brings dissolved inorganic carbon to the surface, where it is released into the atmosphere, but also stimulates phytoplankton blooms that further remove some of that carbon through photosynthesis; a small percentage of this bloom also sinks in the form of organic matter (organic carbon) to deep water and becomes buried in sediment, creating a long-term carbon sink. There is considerable interest among carbon-cycle scientists regarding the reciprocal interactions between upwelling systems and climate change. Although such upwelling can in principle occur along any coastline, marine or freshwater, some marine coastlines (e.g., Peru, the western United States, northwest Africa, and southwest Africa) are renowned for their annual upwelling events that are the source of major blooms of diatoms and dinoflagellates, which become the base for extensive marine food webs and coastal fishing industries.

In the past several decades, major research programs have developed around the influence of coastal upwelling ecosystems on ocean carbon cycling and atmospheric carbon dioxide, how natural climate change (such as glacial-interglacial cycles) has affected coastal upwelling and associated biological productivity over a range of timescales, and how human-induced climate change is affecting coastal upwelling rates and timing and the associated fisheries.

Carbon dioxide exchange between coastal surface water and the atmosphere varies considerably in time and space. Because the pattern is complicated and dynamic relative to the number of direct measurements, considerable uncertainty lingers regarding the net carbon flux through the system over the course of a year. In general, outgassing occurs near the coastline, where upwelled water outcrops at the surface. This water is often rich in carbon dioxide arising from the respiration of organisms ingesting organic matter that sank from the surface to deeper water (which may be the sea bottom along the continental shelf). As upwelled water moves from shore, phytoplankton bloom in response to dissolved nitrogen, phosphorus, and other nutrients and begin to use up some of the dissolved inorganic carbon, reducing the partial pressure of carbon dioxide.

Because this process occurs over a period of several weeks, the rate of uptake of dissolved inorganic carbon also changes through time, so that net outgassing will occur early in an upwelling event, gradually changing to net ingassing. Much of the phytoplankton is recycled in the surface layer, prolonging the bloom, but some of the nutrients and carbon escape the system through the fecal material of heterotrophs feeding on the phytoplankton. The nutrients of remineralized organic matter that sink may come to the surface in future years through upwelling, or the organic matter may sink below the depth of upwelled water into the deep sea or get buried in sediment. The latter two processes can take carbon out of the atmosphere for thousands or millions of years, respectively. Although these processes occur in other aquatic areas, enough of the global ocean carbon flux in a given year occurs through coastal upwelling zones to affect atmospheric carbon dioxide.

The strength and direction of surface winds that drive coastal upwelling vary over a broad spectrum of timescales. Changes in global heat retention through time affect the potential for temperature gradients that influence wind speed, and the distribution of land masses and topographic features such as mountains affect coastal shape, coastal currents, sea level and coastal profile, and atmospheric circulation patterns. Temperature and precipitation patterns and sealevel, among other variables, affect nutrient distribution in the oceans. All of these affect upwelling strength, biological productivity, carbon burial, and net effect on the global carbon cycle. Much research has been dedicated to understanding upwelling changes during glacial-interglacial cycles, tracking responses to changed wind speeds and to lowered sea level, and therefore steeper coastal profiles. Other research has examined how to predict occurrences of upwelling in, for example, the Mesozoic, under the assumption that upwelling is responsible for the accumulation of some petroleum deposits.

Both models and empirical observations of several coastal upwelling areas, such as off the coast of California and northwest Africa, suggest that atmospheric warming is leading to greater rates of upwelling. This increase is driven by a greater land-ocean temperature gradient and therefore greater wind speeds. This can lead both to greater outgassing of carbon dioxide (if not balanced by increased productivity) and loss of certain fish that cannot maintain their population position as a result of higher offshore current velocities.

SEE ALSO: Benguala Current; Oceanic Changes; Peruvian Current; Upwelling, Equatorial.

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Upwelling Equatorial

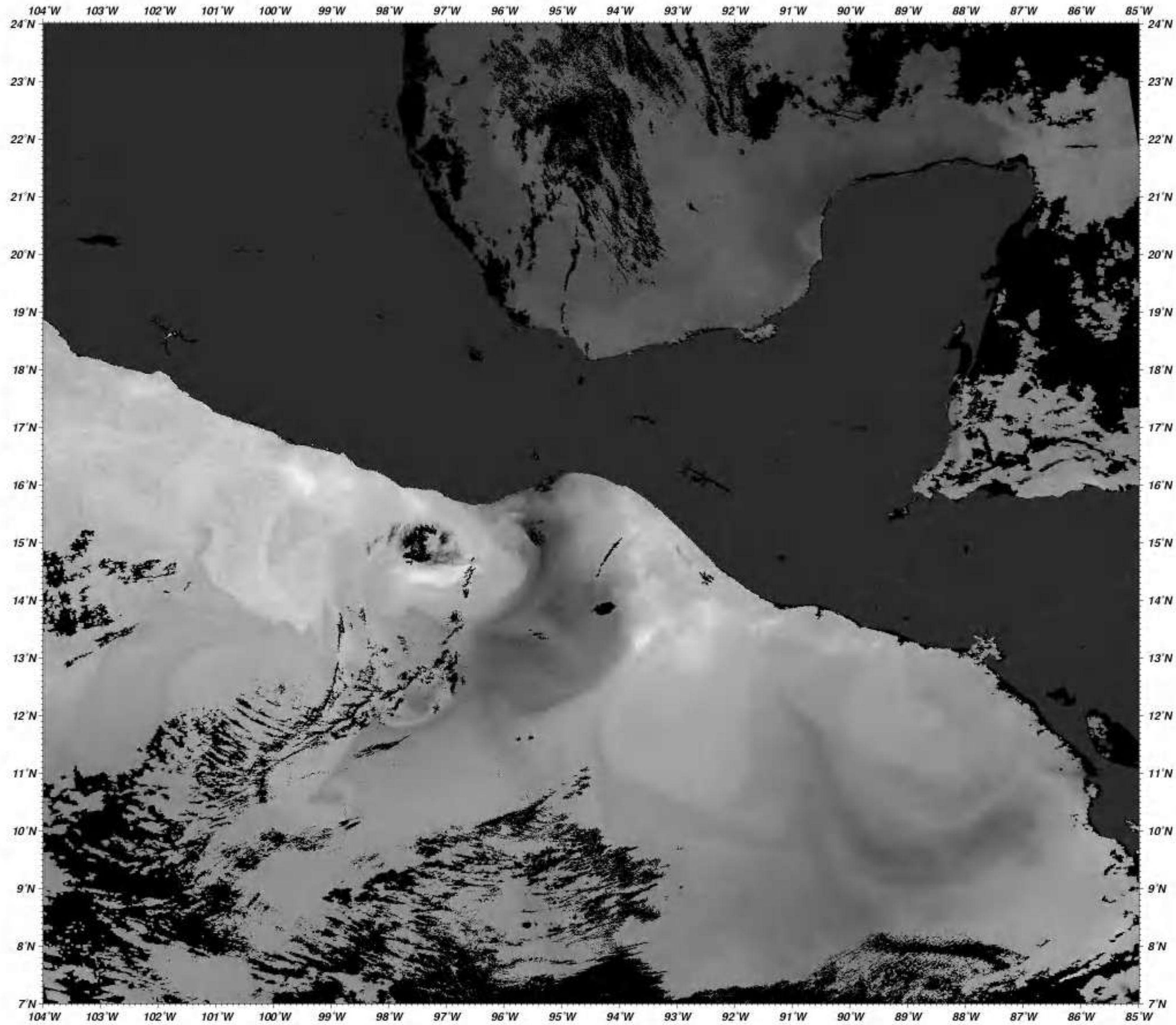
UPWELLING EQUATORIAL (UE) is upward water's motion in the upper layer of the Equatorial Ocean and occurs when a persistent easterly wind is blowing over the equatorial zone. Maximum upward velocity in the UE occurs just at the equator.

UE is a result of the permanent divergence of a westward surface south equatorial current in the narrow equator vicinity, forced by the southeast trade wind. Divergence of westward current at the equator is caused by the change of sign of the Coriolis force between the Northern and Southern hemispheres. As a consequence of divergence, the upper thermocline becomes shallower at the equator. Strong permanent equatorial divergence also causes an intense entrainment of more cold water from the thermocline into the upper mixed layer. This leads to cooling of the upper mixed layer. As a result, the sea surface temperature is about 1.8 degrees F (1 degree C) lower in the equator vicinity than in the interior Equatorial Ocean outside of it.

Pure UE occurs in the narrow vicinity of the equator, just within the divergent zone. Because of the slope of equatorial thermocline in a zonal direction (the thermocline is deeper in the western equatorial Atlantic and Pacific oceans than in the eastern) and the generation of coastal upwelling in the eastern Equatorial Oceans, UE manifestation, as relatively cold surface water, is more pronounced in the upper layer of the eastern Equatorial Oceans. Therefore, the cooler sea surface water looks like a long and thin equatorial tongue spreading from the eastern Equatorial Oceans. There is also quite high biological activity in this relatively cold tongue.

The thickness of the UE is restricted by the upper boundary of the equatorial undercurrent because the eastward current is accompanied by equatorial convergence and, hence, downward water's motion. That is why this thickness varies from about 328 to 656 ft. or 100 or 200 m. (in the western Equatorial Atlantic or Pacific Ocean, respectively) to 33 to 66 ft. or 10 to 20 m. (in the eastern Equatorial Atlantic and the Pacific Ocean).

UE is a quite persistent phenomenon in the Atlantic and Pacific oceans because the westward surface south equatorial current occurs there in the equator's vicinity almost throughout the entire year. However, UE intensity varies from season to season and from year to year. Seasonally, it is at a maximum in the Equatorial Atlantic and Pacific, when the south equatorial current intensifies, following the seasonal cycle of the southeast trade wind (with some delay that does not typically exceed a month); that is, in boreal late summer to early fall. Interannular variations of UE are mostly to the result of the El Niño/La Niña phenomena, especially in the Pacific Ocean. Just before El Niño developing (i.e., an anomalous warming of the upper layer in the Equatorial Pacific), the southeast trade wind dramatically weakens, and UE is over. In contrast, during La Niña (a cold episode in



Cold-water upwelling in the Gulf of Tehuantepec: This image of the Isthmus of Tehuantepec in Mexico shows sea surface temperatures observed by the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Aqua satellite.

the Equatorial Pacific Ocean), UE is strongly developed as a result of an anomalous intensification of the southeast trade wind and, hence, the south equatorial current. Interannular variability of the UE in the Equatorial Atlantic follows Pacific variability with some delay, which is typically not more than a few months. However, the magnitude of interannular UE variations in the Atlantic Ocean is not as large as in the Pacific Ocean. A seasonal cycle prevails in the Equatorial Atlantic, where the magnitude of the seasonal UE variations is two to three times bigger than the interannular ones.

In the Indian Ocean, UE (as a persistent phenomenon) occurs only in boreal winter, when the northeast monsoon has been developing. The UE is most pronounced in the western part of this basin. Seasonal UE variability is at maximum in the Indian Ocean. Interannular UE variability in the Indian Ocean is controlled by the Indo-Ocean Dipole, which is an inherent Indo-Ocean mode interrelated with the Pacific interannular variability (i.e., El Niño/La Niña phenomena), as can be seen in the recent results of Alexander Polonsky and coauthors and of Swadhin Behera and Toshio Yamagata.

Low-frequency (decade-to-decade) variability of the southeast trade wind or the northeast monsoon generates quasi-equilibrium UE variations. A more (or less) intense southeast trade wind and northeast monsoon leads to more (or less) intense UE.

SEE ALSO: Atlantic Ocean; Equatorial Undercurrent; Indian Ocean; Mixed Layer; Pacific Ocean; Thermocline; Trade Winds; Upwelling, Coastal.

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Uruguay

URUGUAY IS LOCATED in southern South America, making a small wedge between Argentina and Brazil. Most of the country is covered by rolling grasslands, though it is crossed by several river systems and has a coastline on the Atlantic Ocean. Uruguay has no mountain ranges to buffer it from weather systems, making it susceptible to rapid weather changes. Droughts and periodic flooding are common. Climate change is expected to have some initial benefits for the livestock industry, but its long-term effects are unclear. Current climate models predict that Uruguay will see temperature increases of 2 degrees F (1.1 degrees C) by 2050 and 3.4 degrees F (1.9 degrees C) by 2100. Some models also indicate that there will be increased precipitation in both the summer and winter seasons, although there is some disagreement in these models.

Most of Uruguay is covered with evergreen grasslands perfect for the raising of cattle and sheep, which is a major part of the national economy. The grasslands may at first benefit from increased temperatures and higher atmospheric concentrations of CO_2, but it is not clear at which point the positive becomes a negative.

Sea-level rise is a concern along the Atlantic coastline. The capital city of Montevideo, home to about 45 percent of the population, sits on the coast, and much of the country's industrial infrastructure is concentrated around Montevideo Bay. A 1997 study predicted a rise in sea level of between 1.6–3.2 ft. (0.5–1.0 m.) by 2100. This would destroy much of the high-value real estate along the coast and severely damage the sewage and water purification systems of the city.

Uruguay has a population of just 3.5 million people. It has low population density, relatively high per capita income, and a well-developed economy. It is not a significant contributor to global carbon emissions; in fact, it is one of only a handful of countries that is carbon neutral, removing as much carbon from the atmosphere as it releases. In 1998, CO_2 emissions were about 1,800 metric tons per capita. Ninety-two percent of emissions come from liquid fuel use, and 8 percent from cement manufacture. Uruguay was one of the first countries to submit a greenhouse gas inventory to the United Nations Framework Convention on Climate Change, of which it is a signatory, and it has made regular reports on its progress.

Uruguay's government has moved aggressively to institute sustainable practices since the 1980s. In 1982, it instituted a law on soil management that has led to the sequestration of 1.8 million metric tons of carbon annually for the past 20 years; the Forest Protection Act of 1987 has increased the size of forest plantations from 200 to 6,500 sq. km. (77 to 2,510 sq. mi.), and the country has had a cumulative net carbon sequestration of 27.4 million metric tons.

SEE ALSO: Atlantic Ocean; Carbon Dioxide; Climate Change, Effects; Drought; Floods; Global Warming.

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U.S. Global Change Research Program

THE U.S. Global Change Research Program (USGCRP) supports research on the interactions of natural and human-induced changes in the global environment and their effects on society. The USGCRP began as a presidential initiative in 1989 and was codified by Congress in the Global Change Research Act of 1990, which mandates development of a coordinated interagency research program. Participants in the USGCRP include the Agency for International Development, Department of Agriculture, Department of Commerce, National Oceanic and Atmospheric Administration, Department of Defense, Department of Energy, Department of Health and Human Services, National Institutes of Health, Department of State, Department of Transportation, Department of the Interior, U.S. Geological Survey, Environmental Protection Agency, National Aeronautics and Space Administration, National Science Foundation, and the Smithsonian Institution.

The Office of Science and Technology Policy, the Office of Management and Budget, and the Council on Environmental Quality supervise the activities on behalf of the Executive Office of the President. Since its establishment, the USGCRP has funded research and activities, together with several other national and international science programs, to document important aspects of the sources and lifetimes of greenhouse gases. The program has also established extensive space-based systems for global monitoring of climate and ecosystem. Its researchers have started to analyze the complex issues of various aerosol species that have a significant effect on the climate. They have also furthered understanding of the global water and carbon cycles and made major progress in computer modeling of the global climate.

The USGCRP carries out research in several focus areas. The research in atmospheric composition focuses on how human activities and natural phenomena affect the atmosphere and on how those changes relate to important issues such as climate change and ozone layer depletion. The research in this area aims to develop a framework for observation that will provide decisionmakers with sound scientific information both in the United States and abroad. The research carried out in this area has contributed to the approval of laws and international treaties that protect the national and global environment. In addition, it has shown connections between global change and ozone depletion, as well as air-quality degradation at local, regional, and global levels. Scientists have been able to improve predictive models on climate change by taking into account the interconnectedness of these factors. This area of study has also tackled the important problem of atmospheric aerosols (particulate matter). Similar to greenhouse gases, aerosols have increased greatly in their atmospheric concentration since the Industrial Revolution and cause changes to the energy balance of the planet. Unlike greenhouse gases, however, aerosols can have either a warming or a cooling influence on the climate.

Since 2002, the Global Change Research Program and the administration's U.S. Climate Change Research Initiative (CCRI) established the Climate Change Science Program (CCSP) to allow the United States and the global community with scientific knowledge to manage risks and opportunities of change in the climate and the related environmental systems. Every year the CCSP produces the report "Our Changing Planet," which supplements the president's budget for that fiscal year. The preview of the report for year 2008 unmistakably states that "climate research conducted over the past several years indicates that most of the global warming experienced in the past few decades is very likely due to the observed increase in greenhouse gas concentrations from human activities. Research also indicates that the human influence on the climate system is expected to increase." Because of these findings, the report recommends that society should be "equipped with the best possible knowledge of climate variability and change so that we may exercise responsible stewardship for the environment, lessen the potential for negative climate impacts, and take advantage of positive opportunities where they exist."

The scientists working in climate variability and change have made significant progress in identifying the causes of climate change. USGCRP projects in this area have also attempted to incorporate this new knowledge into models for the prediction of future climate variability and for the exploration of the effects of human activities on climate. A new generation of climate models improved representations of physical processes, as well as increased resolution. Despite these improvements, there are still significant uncertainties associated with certain aspects of climate models.

Research on the global carbon cycle has attempted to quantify the extent of the dynamic reservoirs and fluxes of carbon within the Earth system. Researchers have also tried to predict how carbon cycling might change and be managed in future years. This research should supply guidelines on how to achieve an appropriate balance of risk, cost, and benefit.

The Global Water Cycle was selected as a focus area in USGCRP research, as the cycle plays a critical role in the functioning of the Earth system, and an incorrect understanding of such a cycle is one of the main sources of uncertainty in climate prediction. The water cycle includes all the complex physical, chemical, and biological processes that are necessary for ecosystems and that influence climate. The research in this area aims at developing responses to the consequences of water cycle variability. The changing ecosystems area is motivated by the awareness that global change can affect the structure and functioning of ecosystems in complex ways. The role of ecosystems research is to assess the potential effects of global change on ecosystems to help society respond effectively to such change. Research focuses on modifications in ecosystem structure and functioning and on potential alterations in the frequency and intensity of climate-related disturbances that may have significant effects on society.

The area of land use and land cover change acknowledges that land use and land cover are connected to climate. They can be the determining factors in the exchange of greenhouse gases between the land surface and the atmosphere, the radiation balance of the land surface, and the exchange of sensible heat between the land surface and the atmosphere. Researchers in this area analyze how changes in land use and land cover contribute to climate change and variability.

The research in human contributions and responses is based on the assumption that decision makers and other interested citizens need reliable scientific data to make decisions and actions that address the risks of and opportunities for changes in climate and related systems. The results of these USGCRP researchers are intended to shape public debates about climate-related issues. They should point at ways to reduce climate change and to adapt to climate variability.

In addition to these focus areas, the USGCRP also has a series of cross-cutting activities. The Observing and Monitoring the Climate System interagency working group develops research in the planning and operation of observing systems, including several new Earth-observing satellites, suborbital systems, surface networks, reference sites, and process studies. These can supply reliable data on the Earth's climate system and can be helpful in the prevention of natural disasters. USGCRP sections and researchers are all involved in communications initiatives to improve public understanding of climate change research and to make scientific findings more accessible to different audiences. Finally, the interagency working group of International Research Cooperation works with major international scientific organizations on behalf of the U.S. government and the scientific community.

SEE ALSO: Carbon Dioxide; Climate Change, Effects; Department of Defense, U.S.; Department of Energy, U.S.; National Aeronautics And Space Administration (NASA); National Oceanic and Atmospheric Administration (NOAA).

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Utah

THE EARTH'S CLIMATE has changed since the Industrial Revolution, and there is substantial evidence that man is influencing the change through greenhouse gas production. Utah's contribution to global climate change is significant and comes mostly from carbon dioxide (CO_2) emissions from electricity production, mainly from coal consumption in power plants. Other leading contributors to Utah's greenhouse gas emissions are transportation, oil and gas production, and emissions from livestock and microbial processes. By 1993, Utah's per capita greenhouse gas emissions were twice the global average, and Utah's total emissions were 1.2 percent of the global total. Baseline CO_2 emissions for Utah are projected to be 54 percent above 1990 levels by 2010 and 95 percent above 1990 levels by 2020, mainly as a result of its growing population.

The effect of climate change on Utah is likely to be significant as well. The western United States is warming faster than the global average, and Utah's average temperature for the last decade (1996–2006) was 2 degrees F (1 degrees C) warmer than the state's average over the past 100 years. This trend is causing earlier springs, less snowfall and more rain, earlier plant blooms, and a shorter frost season, although Utah's mountain snowpack has shown no long-term changing trends. Furthermore, climate models project that, even if greenhouse gas emissions stabilize, global average temperatures will continue to increase for centuries, and current and future emissions will affect Earth's temperature more over the next 100 years than in the past 100 years. The effect is projected to be even greater on Utah. For example, a climate model based on a 2.5-times atmospheric CO_2 increase by 2100 projects that Utah's mean annual temperature will increase by approximately 8 degrees F (4.4 degrees C), whereas the global average will increase by 5 degrees F (2.7 degrees C).

Higher temperatures will likely mean earlier springs and less water storage in Utah. Earlier Utah springs will cause rainfall instead of snowfall. This will replenish the reservoirs, but the mountain snowpacks will receive less snowfall and melt earlier in the season, and the increased temperatures will increase evaporation in the reservoirs. The combination of these factors could jeopardize the state's already-taxed water supply. Climate model projections show that there may be heavier episodes of precipitation, but there also will be longer time spans between them.

This weather pattern may induce a higher chance of flash flooding and a larger amount of runoff to the rivers and reservoirs, instead of steady groundwater replenishment through more frequent, but less intense, rainfall. In addition, there will likely be ecological impacts from warming rivers and lakes—animal and insect populations may migrate, and insect migration times may no longer be synchronized with the plants they pollinate. Utah's agricultural economy may also be affected. With a 2 to 5 degree F increase, Utah's crops may thrive, but with the decreased water supply and infrequent rainfall, more frequent and severe droughts may counter the positive effects of a slight warming. Beyond an increase of a few degrees, crops may no longer endure the heat, and Utah's agriculture would need to change to accommodate the increased temperature.

GRASSROOT EFFORTS

Statewide, grassroots campaigns designed to educate the general public on the state of the science on climate change and its potential effect are neither common nor well received in Utah. However, over the past several years, state officials of this politically conservative state have become increasingly aware and proactive in climate discussions and policymaking. Recent policies have focused on energy efficiency in the form of corporate and personal tax credits for renewable energy, sales tax exemptions for renewable energy, and grants and loan programs for clean fuels and vehicle technology.

In May 2007, Utah was the sixth state to sign the Western Region Climate Action Pact, an agreement between states designed to set standards for reducing greenhouse gas emissions under a market-based program. In line with this new pact and Utah's focus on energy efficiency, Governor Jon Huntsman established a goal for increased energy efficiency in all state facilities of 20 percent by 2015. To aid in reaching this goal and in developing future policies, the governor formed the Blue Ribbon Advisory Council (BRAC). BRAC is a council of atmospheric, climate, and environmental scientists within Utah who advise the governor on the state of science on climate change. These scientists work alongside politicians and economists to evaluate the potential effect of policies designed to control and mitigate future climate change in Utah.

The scientific and political communities recognize that there is sound scientific evidence of human-induced climate change in Utah. This, in combination with the projections of future climate change and the concern over future water availability in the region, has spurred local and state leaders to take a close look at current climate initiatives and future policies. Although some of the general populace and politicians of Utah remain skeptical, many state officials are embracing advice from atmospheric scientists and climatologists and are making efforts to decrease Utah's footprint on global and regional climate change.

SEE ALSO: Carbon Dioxide; Climate Models; Greenhouse Gases.

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Utah Climate Center

THE UTAH CLIMATE Center aims to disseminate climate data and information and to use expertise in atmospheric science to interpret climate information in an accurate and original way for the public. The mission includes the design of new products to meet the present and future needs of agriculture, natural resources, government, industry, tourism, and educational organizations in Utah and the intermountain region. It is part of Utah State University and has been recognized as a state center by the American Association of State Climatologists.

Much of climate information requested from the center comes from published records and computerized databases. Published records in print form extend through 2006 and are available at the National Climatic Data Center (NCDC). Many original historical data records for Utah for the 19th and early 20th centuries have been transferred to and archived in the Utah State University Merrill-Cazier Library. The Utah Climate Center serves as an official repository for both published climate data records and official publications from the NCDC, encompassing several decades, as part of an official agreement with the NCDC.

The weather and climate data provided by the Utah Climate Center are elaborated with the cooperation of the National Oceanic and Atmospheric Administration, the Federal Aviation Administration, and other federal, state, and local authorities. The Utah Climate Center strives to provide quality climate data.

In the past, the Utah Climate Center has provided information through paper via the postal service, via fax, or via electronic mail, but it now uses a GIS search facility. The Utah Climate Center gathers and archives climatic data from 22 networks throughout the state. It also monitors and compiles information from networks used by the Forest Service, the University of Utah, the Department of Agriculture, the Bureau of Land Management, the Natural Resource Conservation Service, and others. Data such as maximum and minimum temperature, precipitation, evaporation and evapotranspiration (a measure of water lost from the soil as a result of transfer to plants, rather than straight evaporation), and solar radiation are collected from various sites. The center collects 57,000 pieces of information from hundreds of locations each day. The earliest data at the UCC date back to the 1870s and 1880s, although most of the stations were put in place in the 1900s.

The center was initially timid in assessing global warming. In 1998, then-director Donald T. Jensen stated that any signals of global warming in Utah "have been lost in the noise of other temperature fluctuations. … It's hard to find any real evidence here because temperatures here have always bounced up and down." However, with the passing years, the center has expressed views that are more attuned to the general opinion on global warming. Robert Gillies, the present director of the center, has pointed out that "the massive and growing scientific evidence has convinced the atmospheric science community that climate change is occurring, and is the result of human activities, specifically the release of greenhouse gases."

SEE ALSO: Carbon Dioxide; Climate Change, Effects; Greenhouse Gases; Utah.

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Uzbekistan

UZBEKISTAN IS LOCATED in central Asia, south of Kazakhstan. It is one of the world's two doubly-landlocked countries, being totally surrounded by other landlocked countries. The terrain is mostly rolling desert, with about 10 percent of the land lying within fertile river valleys. Poor conservation practices during the Soviet era had already caused enormous environmental damage, and many believe that this damage will exacerbate the effects of climate change in coming years.

The Aral Sea, which Uzbekistan shares with neighboring Kazakhstan, is one of modern history's great environmental disasters. The inland sea is over 5 million years old and used to be the world's fourth largest lake; today it is the world's eighth largest and is shrinking fast. During the Soviet era, massive amounts of water were diverted to irrigate crops, both from the Aral itself and from its feeder rivers. At the same time, it was used as a dumping ground for pesticides, raw sewage, and even nuclear waste.

Over the last two decades, 90 percent of the lake's source flow has dried up. Its surface area has decreased by 50–60 percent, and it has lost 80 percent of its volume. Salinity has increased from 10 grams per liter in 1960 to over 45 grams per liter in 2000. Many fish populations within the lake have long since died out. The lake has shrunk so much that it has actually split into separate parts, which had to be reconnected with a man-made channel.

Climate change will have an equally negative effect on the Aral. The glaciers that form an important part of the Aral Sea Basin shrank by 34 percent between 1960 and 2000. Runoff from mountain snow packs and annual rainfall has also decreased. The Amudarya River, a critical irrigation source, has decreased in flow to the point that it no longer reaches its outlet on the Aral.

Climate models expect the country's two main climate zones, the dry/tropical and moderate zones, to shift 93 to 124 mi. (150 to 200 km.) to the north by 2100. Air temperature is expected to increase by between 2.7–3.6 degrees F (1.5–2 degrees C). In the initial phases, the shift in climate zones and increased temperature, along with higher atmospheric concentrations of CO_2, might help the country's agricultural output, but with water sources already strained, that increase will be shortlived. Warmer temperatures and less water will damage the fertility of the grasslands, increase desertification, and reduce the country's livestock population.

Uzbekistan has a population of about 28 million people and is not a significant contributor to global carbon emissions. In 1998, per capita emissions were about 4,600 metric tons. About 80 percent of these emissions came from the release of gaseous fuels, 16 percent from liquid fuel sources, and 5 percent from cement manufacturing and solid fuel use.

The Uzbeki government has worked to study the potential effects of climate change and to raise public awareness of the problem. It is currently formulating plans to change damaging agricultural and industrial practices and move toward more sustainable growth.

SEE ALSO: Carbon Dioxide; Climate Models; Greenhouse Gases.

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Validation of Climate Models

THE CLIMATIC SYSTEM is constituted by four intimately interconnected subsystems—atmosphere, hydrosphere, cryosphere, and biosphere—which evolve under the action of macroscopic driving and modulating agents, such as solar heating, Earth's rotation, and gravitation. The climate system features many degrees of freedom, which make it complicated, and nonlinear interactions taking place on a vast range of time-space scales accompanying sensitive dependence on initial conditions, which makes it *complex*. The climate is defined as the set of statistical properties of the observable physical quantities of the climatic system.

The evaluation of the accuracy of numerical climate models and the definition of strategies for their improvement are crucial issues in the Earth system scientific community. On one hand, climate models of various degrees of complexity constitute tools of fundamental importance to reconstruct and project in the future the state of the planet and to test theories related to basic geophysical fluid dynamical properties of the atmosphere and of the ocean, as well as of the physical and chemical feedbacks within the various subdomains and between them. On the other hand, the outputs of climate models, and especially future climate projections, are gaining an ever-increasing relevance in several fields, such as ecology, economics, engineering, energy, and architecture, as well as for the process of policymaking at a national and international level. Regarding influences at the societal level of climate-related finding, the effects of the fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC4AR) are unprecedented.

The validation or auditing—overall evaluation of accuracy—of a set of climate models is a delicate operation that can be decomposed in two related, albeit distinct, procedures. The first procedure is the intercomparison, which aims at assessing the consistency of the models in the simulation of certain physical phenomena over a certain time frame. The second procedure is the verification, the goal of which is to compare the models' outputs with corresponding observed or reconstructed quantities. Difficulties emerge because we always have to deal with three different kinds of attractor: the attractor of the real climate system, its reconstruction from observations, and the attractors of the climate models. Depending on the timescale of interest and on the problem under investigation, the relevant active degrees of freedom (mathematically corresponding to the separation between the slow and fast manifolds) needing the most careful representation change dramatically. For relatively short timescales (below 10 years), the atmospheric degrees of freedom are active, whereas the other subsystems can be considered to be essentially frozen. For longer timescales (100–1,000 years), the ocean dominates the dynamics of climate, whereas for even longer timescales (over 5,000 years), the continental ice sheet changes are the most relevant factors of variability. Therefore, the scientific community has produced different families of climate models, spanning a hierarchical ladder of complexity, each formulated and structured for specifically tackling a class of problems.

COUPLED GLOBAL CLIMATE AND REGIONAL CLIMATE MODELS

Here, whereas most considerations are quite general, we mainly refer to the coupled global climate models (GCMs) and regional climate models (RCMs) currently used for the simulation of the present climate and for the analysis of the climate variability up to centennial scales. In these models, whereas the dynamical processes of the atmosphere and of the hydrosphere are represented within a wide framework of numerical discretization techniques applied to simplified versions of thermodynamics and Navier-Stokes equations in a rotating environment, the continental ice sheets are typically taken as fixed parameters of the system. In contrast, the so-called subscale processes, which cannot be explicitly represented within the resolution of the model, are taken care of through simplified parameterizations.

Several crucial processes, such as radiative transfer, atmospheric convection, microphysics of clouds, land-atmosphere fluxes, ice dynamics, and eddies and mixing in the ocean, as well as most of those controlling the biosphere evolution, undergo severe simplifications. With time, the formulation of the GCMs has developed through refinements to the spatial resolution, ameliorations of numerical schemes, and improved parameterizations, as well as through the inclusion of a larger and larger set of processes, such as aerosol chemistry and interactive vegetation, which are relevant for the representation of the system feedbacks and forcings.

In addition, limited-area climate modeling faces the mathematical complication of being a time-varying boundary conditions problem, as RCMs are nested into driving GCMs. Therefore, RCMs tend to be enslaved on timescales, depending on the size (and position) of their domain, and in principle, the balances evaluated over the limited domain are constrained at all times. Therefore, climate reconstructions and projections performed with an RCM can critically depend on the driving GCM. Other more technical issues arise from the delicate process of matching the boundary conditions at the models' interface, where rather different spatial and time grids have to be joined.

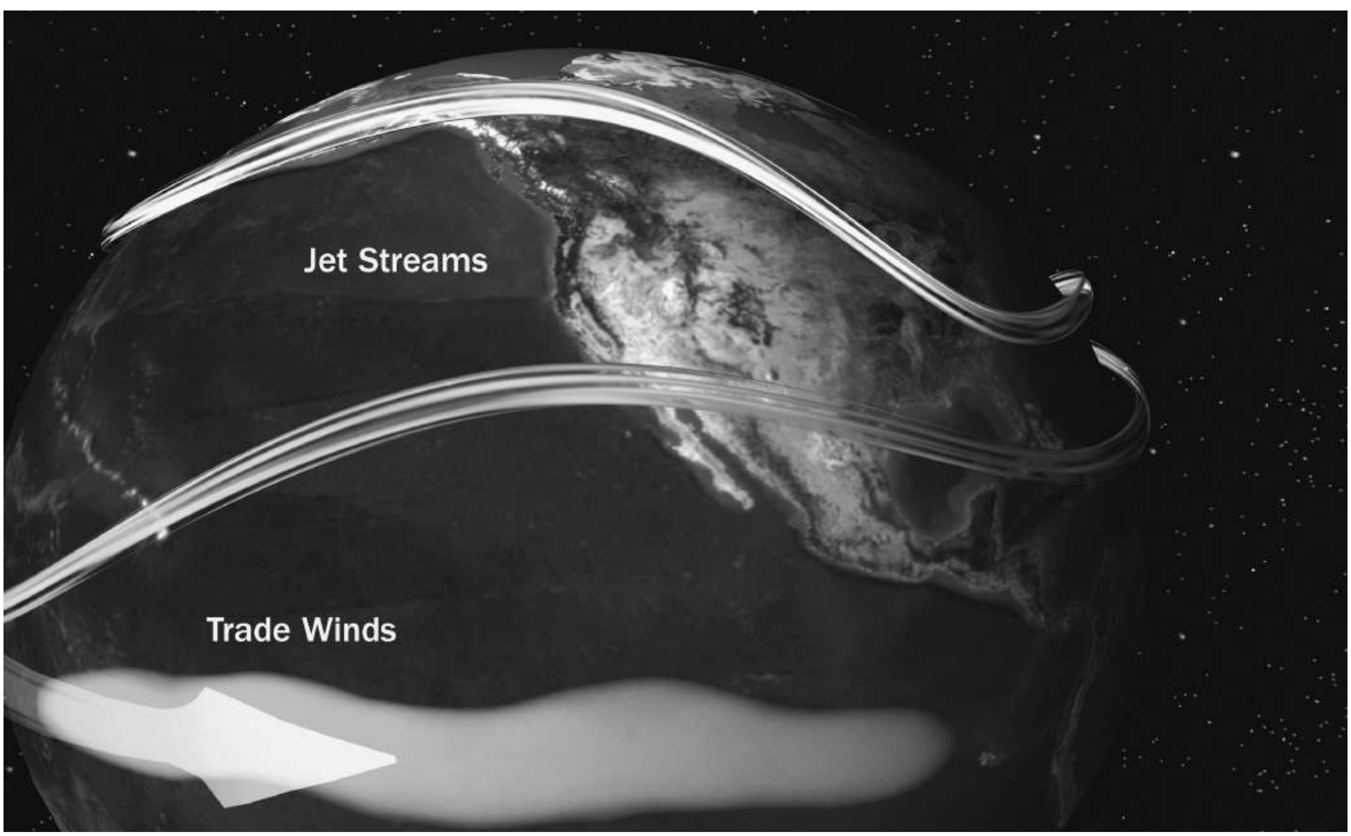
Model results and approximate theories can be tested only against past observational data of nonuniform quality and quantity, essentially because of the space and the timescales involved. The available historical observations sometimes feature a relatively low degree of reciprocal synchronic coherence and individually present problems of diachronic coherence, as a result of changes in the strategies of data gathering with time, whereas proxy data, by definition, provide only semiquantitative information on the past state of the climate system. Extensive scientific effort is aimed at improving the quality and quantity of the climatic databases. In particular, the best guess of the atmospheric state of roughly the last 50 years has been reconstructed by two independent research initiatives, through the variational adaptation of model trajectories to all available meteorological observations, including the satellite-retrieved data, producing the so-called reanalyses.

Given all the above mentioned difficulties, as well as the impossibility, because of the entropic time arrow, of repeating world experiments, the validation of GCMs is not epistemologically trivial, as the Galilean paradigmatic approach cannot be followed. Validation has to be framed in probabilistic terms, and the choice of the observables of interest is crucial for determining robust metrics able to audit effectively the models. Recently, the detailed investigation of the behavior of GCMs has been greatly fostered and facilitated, as some research initiatives have been providing open access to standardized outputs of simulations performed within a well-defined set of scenarios. Relevant examples to be mentioned are the project PRUDENCE (RCMs) and the PCMDI/CMIP3 initiative (GCMs included in the IPCC4AR).

One aim—from the end-user's viewpoint—is checking how realistic the modeled fields of practical interest are, such as surface temperature, pressure, and precipitation. In these terms, current GCMs feature a good degree of consistency and realism when considering present climate simulation, and they basically agree on short-term climate projections down to seasonal averages on continental scales. When decreasing the spatial or the temporal scale of interest, the signal-to-noise ratio of climatic signals—both observative and model generated—typically decreases, so that the validation of GCMs in control runs and climate change simulations becomes more difficult, even if improvements are observed over time by state-of-the-art models. Statistical and dynamical—provided by nested RCMs—downscaling of climatological variables enlarges the scopes of model validation. In particular, RCMs provide a better outlook on small-scale and nonlinear processes, such as surface-atmosphere coupling, precipitation, and effects of climate change on the biosphere.

However, the above-mentioned quantities can hardly be considered climate state variables, whereas strategies for model improvement can benefit from understanding the differences in the representation of the climatic machine among GCMs. The comparison of the statistical properties of bulk quantities defining the climatic state, such as top-of-the-atmosphere energy fluxes, tropospheric average temperature, tropopause height, geopotential height at various pressure levels, tropospheric average specific humidity, and ocean water structure, allows the definition of global metrics that constitute robust diagnostic tools. Moreover, to capture the differences in the representation of specific physical processes, it is necessary to use specialized diagnostic tools—process-oriented metrics—as indexes for model reliability.

Examples of these metrics are major features of atmospheric variability, such as tropical and extratropical cyclones; detailed balances, such as water vapor convergence over continents or river basins; teleconnection patterns, such as El Niño–Southern Oscillation or Madden–Julian Oscillation; or oceanic features, such as the overturning circulation and the Antarctic current intensity. The latter approach may be especially helpful in clarifying the distinction between the performance of the models in reproducing diagnostic and prognostic variables. Even if improvement



A NASA diagram of a strong El Niño striking surface waters in the Pacific Ocean. Warm water anomalies develop (indicated by shape at bottom) and westerly winds weaken, allowing the easterly winds to push the warm water against the South American coast.

is ongoing and promising, in these more fundamental metrics describing the climatic machine, current GCMs do not generally feature a comparable degree of consistency and realism at a quantitative level, and further investigations on basic physical and dynamical processes are needed.

Because the goal of a climate model is to reproduce the most relevant statistical properties of the climate system, the structural deficiencies, together with an unavoidably limited knowledge of the external forcings (uncertainties of the second kind) limit intrinsically the possibility of performing realistic simulations, especially affecting the possibility of representing abrupt climate change processes. The uncertainties of the initial conditions (uncertainties of the first kind), constituting, because of the chaotic nature of the system, probably the most critical issue in weather forecasting, are not in principle so troublesome—assuming that the system is ergodic—when considering the long-term behavior, where "long" is evaluated with respect to the longest timescale of the system. Nevertheless, to avoid transient behaviors, which may induce spurious trends in the large-scale climate variables on the multidecadal and centennial scales, it is crucial to initialize efficiently the slowest dynamical component of the GCMs, namely, the ocean. The validation of GCMs requires considering such uncertainties and devising strategies for limiting their influence when control run and, especially, climate change experiments are performed.

As for taking care of possible issues related to initial conditions, often an ensemble of simulations, where the same climate model is run under identical conditions from a slightly different initial state, allows a more detailed exploration of the phase space of the system, with a better sampling—on a finite time—of the attractor of the model. Some climate models have recently shown a rather encouraging ability to act as weather forecasting models, thus featuring encouraging local, in-phase space properties. Although such an ability gives evidence that short timescales' physical processes are well-represented, it says little on the overall performances when statistical properties are considered.

The structural deficiencies of a single GCM and the stability of its statistical properties can be addressed, at least empirically, by applying Monte Carlo techniques to generate an ensemble of simulations, each characterized by different values of some key uncertain parameters characterizing the global climatic properties, such as the climate sensitivity. Therefore, in this case, sampling is performed by considering attractors that are parametrically deformed.

To describe synthetically and comprehensively the outputs of a growing number of GCMs, recently it has become common to consider multimodel ensembles and to focus the attention of the ensemble mean and the ensemble spread of the models, taken respectively as the (possibly weighted) first two moments of the models outputs for the considered metric. Then information from rather different attractors is merged. Although this procedure surely has advantages, especially for GCMs intercomparison, such statistical estimators should not be interpreted in the standard way—with the mean approximating the truth and the standard deviation describing the uncertainty—because such a straightforward perspective relies on the (false) assumptions that the set is a probabilistic ensemble, formed by equivalent realizations of given process, and that the underlying probability distribution is unimodal.

SEE ALSO: Abrupt Climate Changes; Atmospheric Component of Models; Atmospheric General Circulation Models; Biogeochemical Feedbacks; Chaos Theory; Climate; Climate Models; Climate Sensitivity and Feedbacks; Climatic Data, Historical Records; Climatic Data, Proxy Records; Climatic Data, Reanalysis; Intergovernmental Panel on Climate Change (IPCC); Modeling of Paleoclimates; Ocean Component of Models.

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Vanuatu

VANUATU IS A country located in the South Pacific Ocean, composed of an archipelago of 83 volcanic islands with a population around 220,000. It has been a global leader in the development of renewable resources for sustained energy.

Vanuatu is governed by a parliamentary democracy, with the prime minister, elected by Parliament, being the leader of the government.

Its economy is primarily agricultural, with 80 percent of the population engaged in agricultural activities. Coconut is by far the most important cash crop, making up more than 35 percent of the country's exports, with petroleum fuels making up the majority of its imports. Interestingly, Vanuatu is a tax haven and international financial center. Despite this, Vanuatu is still a country in need of substantial foreign aid.

Vanuatu is also member of Alliance of Small Island Developing States, which is a progressive force in the United Nations for initiating climate change protocols.

In 1999, coral reef scientists reported massive coral reef death directly attributed to global warming. This, along with the high price of importing oil, led Vanuatu to commence switching from reliance on fossil fuels to becoming dependent on renewable energy economies based on hydrogen fuel technologies.

Thus, in September 2000 at the Eco-Asia conference, the chairman of the conference, Vanuatu Parliament member and former prime minister Maxime Carlot Korman challenged top scientists in the field to find realistic solutions for sustainable resources.

Korman proposed that his country would be the testing site for these solutions because of a variety of social and economic issues. First of all, the country had an electricity consumption of around 35 GWh (by comparison, in 1998, California used 570,000 GWh), all of which produced by fossil fuels, which is an amount that could feasibly be replaced by renewable resources. Second, this project would need to be funded by private investors, and Vanuatu's status as a tax haven provided incentive. Finally, the combination of reducing the country's dependence on foreign oil at the same time it was bringing in foreign investors would help the country reduce its need for outside aid.

The plan was to primarily use geothermal and solar energy to produce hydrogen to be used in hydrogen-cell-powered generators. In addition, this would be supplemented by directly converting wind and water currents into energy and storing them in batteries. The endpoint was to stop importing fossil fuels by 2010 and by 2020, to eliminate remaining internal combustion engines. Some privately funded projects currently being undertaken include Pacific Energy installing solar panels to supply energy to schools, Unelco using Vanuatu's natural resources and producing a coconut oil-diesel fuel blend, and the VANREPA research company installing wind turbines and solar panels to generate electricity for local schools and a solar still to desalinize ocean water.

Although it appears imminent that, as of 2007, Vanuatu appears to be heading toward failing to meet its objective of independence of foreign oil by 2010, the country has made tremendous strides in becoming a green nation. Despite this, Vanuatu was listed as the world's happiest nation in 2006 by the Happiest Planet Index, a New Economics Foundation index based on human well-being and environmental impact.

SEE ALSO: Climate Change, Effects; Global Warming.

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Venezuela

VENEZUELA IS A major oil-producing state and a founding member of the Organization of Petroleum Exporting Countries (OPEC). Its leaders resist global efforts to accelerate cuts in carbon dioxide emissions, and the country's low-cost oil supply to Latin America and the Caribbean countries may stall regional transition to alternative energy sources. Venezuela has been criticized for encouraging energy inefficiency with oil subsidies, but new state environmental programs promote conservation.

Venezuela has proven crude oil reserves of 80,012 million barrels, and the state-owned Petróleos de Venezuela (PDV) is one of the world's largest oil companies. Most of the nation's oil exports enter the United States. PDV's subsidiary Citgo refines the crude oil in Texas. In addition to Venezuela's petroleum trade with the United States, its Chinese oil investments are growing. Venezuela recently signed energy agreements guaranteeing petroleum to many Latin America and Caribbean countries. These pacts include subsidized oil, an exchange of goods and services for oil, and interest-deferred financing for oil purchases.

Angel Falls in Venezuela is the world's highest free-falling, freshwater waterfall, with a drop of 2,648 feet.

There are many uncertainties about the potential effect of climate change on Venezuela. As a precautionary method, the development of agricultural varieties resistant to drought and adverse climate conditions has been recommended. Flooding is likely in other areas. In December 1999, Venezuela experienced its highest monthly rainfall in a century. Massive landslides and flooding led to the deaths of more than 30,000 people. The risk of increased mortality from diseases with mosquito vectors such as yellow fever increases after floods, and malaria has been documented to increase in the country's coastal regions after the onset of El Niño.

Although the country has been criticized for contributing to global warming, some conservation measures are in place. Venezuela ratified the UN Framework Convention on Climate Change in 1994 and the Kyoto Protocol in 2005. In 2006, President Hugo Chavez launched a reforestation program to plant 100 million trees. These trees will be intercropped with cacao and coffee to give farmers an incentive to abandon environmentally destructive farming methods. Chavez also launched an energy efficiency program that promotes improved light bulbs and natural gas, wind, and solar power. Venezuela's large reserves of natural gas remain largely untapped.

Venezuela is among the top 20 countries in terms of endemism, and more than 200 protected areas cover in excess of 70 percent of the nation. Its diverse climatic and biogeographical regions cover a range of elevations, and there are 1,740 mi. (2,800 km.) of coastline, including vast mangrove swamps and numerous islands. There has been a documented retreat of glaciers in the Sierra Nevada range, however, and the glacier on Pico Bolivar may completely disappear during the next decade.

A climate change mystery occurs in Venezuela: methane builds up over the country at night. Scientists that researched this peculiar phenomenon have recently suggested, amid some skepticism, that the methane is being released from certain plants growing in the savanna.

SEE ALSO: El Niño and La Niña; Floods; Oil, Consumption of; Oil, Production of.

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Vermont

KNOWN AS THE Green Mountain State, Vermont underwent widespread reforestation following farm abandonment in the mid-1800s. In addition to the existence of several land trusts, the Green Mountain Club has protected more than 55 mi. (88 km.) along a hikers' Long Trail. There is a strong state environmental movement, with local groups and chapters of national organizations. Vermont hosts one of the nation's leading environmental law and policy programs at the Vermont Law School. The state government has invested in energy efficiency and joined regional efforts to reduce greenhouse gas (GHG) emissions. Climate change and global warming concern Vermonters because of the economic revenue the state gains from nature tourism, particularly during the autumn foliage and winter skiing seasons.

In spite of some local variation, the northeastern United States has experienced a temperature increase of 1.8 degrees between 1899 and 2000. The average length of the annual growing season has been extended by eight days, and bloom dates have changed. Scientists have documented quicker thawing of lakes, known as ice-in and ice-out dates, as well as earlier runoff from mountains.

Data have suggested that maple production from the sugar maple (*Acer saccarum*), the Vermont state tree, may be vulnerable to climate shifts. Under several climate change models, this species may entirely shift out of the United States. Studies suggest that seven of 80 eastern tree species may decline by as much as 90 percent in the next century if temperature changes continue at current rates.

In terms of GHG emissions, Vermont's energy portfolio is one of the greenest in the nation. Vermont Yankee Nuclear Power Plant, online since 1973, provides approximately 35 percent of the state's energy requirements. Its license is scheduled to expire in 2012, but petitions are in place for renewal and expansion of production. There is some local opposition to both proposals.

Energy from Hydro-Quebec, an extensive series of dams across Quebec Province in Canada, provides a third of Vermont's energy needs. Although hydropower is a renewable energy source, the creation of the project's dams has been controversial, in that it caused flooding of indigenous lands. Research on dam building also suggests that methane may be released from the decomposition of flooded forests. Releases are expected to be considerably higher in tropical ecosystems, but more research is needed to determine the exact levels. Fossil fuels are also used in the creation and maintenance of dam structures.

Nearly one-third of Vermont's energy is created from a mixture of in-state renewable energy resources. The Cow Power program uses manure to create energy and provide income to dairy farmers. Efficiency Vermont is the nation's first statewide provider of energy efficiency services. The program is operated by an independent, nonprofit organization under contract to the Vermont Public Service Board. It provides technical advice, financial assistance, and design guidance to make homes, schools, and businesses more energy efficient. The program is funded by a charge on users' electric bills.

In 2006, Governor Jim Douglas announced a public-private partnership that will invest $20 million in energy efficiency. He also extended state energy efficiency programs. In addition to $8 million in weatherization grants available to low-income Vermonters each year, Douglas' program also created private capital to provide $20 million no- or low-interest loans to assist homeowners and small businesses to make buildings more fuel efficient.

Vermont has joined regional climate change mitigation initiatives. The state joined seven others in 2004 in a legal suit against several energy companies to require them to reduce carbon dioxide emissions and control GHG outputs. Vermont is part of the Regional Greenhouse Gas Initiative's cap-and-trade program for power plants, aimed at reducing carbon emissions. Six New England states and five eastern Canadian provinces adopted a joint Climate Change Action Plan to reduce GHG emissions.

SEE ALSO: Energy Efficiency; Energy, Renewable; Greenhouse Gases; Vermont Law School.

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Vermont Law School

VERMONT LAW SCHOOL'S (VLS's) environmental law program is ranked number one in the nation by *U.S. News & World Report*. Students at VLS participate in a variety of legal and environmental study programs, many of which focus on climate change and related policies. The Environmental Law Center at VLS includes several specialized institutes and clinics that are involved in various aspects of climate change research and litigation. At present, VLS is home to 612 students, participating in four different degree programs: Juris Doctor (JD), Master of Studies in Environmental Law (MSEL), Master of Laws in Environmental Law (LLM), and Master of Laws in American Legal Studies (LLM) for international students.

VLS is known not only for its academic commitment to reducing the effects of global climate change but also for putting this commitment into action in its day-to-day operations. The U.S. Green Building Council awarded Debevoise Hall, VLS's main administration and academic building, with a Leader in Energy Efficiency and Design Silver Certification. The renovated 1893 school building features an energy-efficient, compact fluorescent lighting system that is linked to sensors that turn off the lights when no one is present. A cross-flow heat exchanger and desiccant wheel provide temperature- and humidity-adjusted airflow year-round. Debevoise Hall and the adjacent classroom building Oakes Hall (constructed in 1998) both feature composting toilets and other water conservation measures. In Oakes Hall, these measures have decreased the projected water consumption rate from 15 gallons used per person, per day, to 15.5 gallons used per day, total, for the entire facility.

VLS contains several academic centers that support climate change research, litigation, and problem solving. The Institute for Energy and the Environment is VLS's premier research institution on energy policy and law. Professor Michael H. Dworkin, former chair of the Vermont Public Service Board (1999–2005), directs the institute. The institute provides conferences and produces scholarly publications on topics such as biofuels and related policy recommendations; net-metering legislation; energy efficiency and the need for demand-side regulation; and health and environmental costs of burning fossil fuels.

The Land Use Institute, directed by Professor L. Kinvin Wroth, seeks to address the legal and planning issues surrounding current forms of land use. This includes sustainable design and ecology planning, siting of new energy facilities, revisions to permit composition and process, and the scope of eminent domain.

The Climate Legacy Initiative, under the directorship of Professor Burns Weston, has been established to clarify and advocate the legal rights, including human rights, of present and future generations relative to the harms likely to result from global warming both in the United States and internationally.

VLS also offers an Environmental and Natural Resources Law Clinic, the *Vermont Journal of Environmental Law*, the Environmental Tax Policy Institute, and an environmental summer session. Because global climate change is one of the world's most expansive environmental challenges, each of these programs are working to address global warming–related issues and inspire future problem solvers. In all, VLS promotes a commitment to bettering the environment through education.

SEE ALSO: Education; Energy; Green Design; Policy, US; Regulation; Vermont.

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Vienna Convention

THE VIENNA CONVENTION for the Protection of the Ozone Layer came into being in March 1985. The convention was developed initially out of recognition of the international concern over the loss of the ozone in the stratosphere. Subsequently, the Montreal Protocol in 1987 strengthened the convention, which was further adjusted and amended on June 29, 1990.

The concern over ozone was linked to attention to the observed phenomena of climate change. Eventually, the issue of the ozone appears to have been stabilized, and the issue of climate change evolved into a larger international concern.

The attention to the ozone issue relied on the scientific understanding of the effects of chlorofluorocarbons in the context of the atmosphere. As a result of the interest in the subject, scientific research invested in developing increasingly complex models of the atmosphere to more accurately address climate issues.

Over time, concern over the issue of the loss of ozone in the stratosphere declined, as international efforts appeared to have improved the condition of the stratospheric ozone layer. Ozone levels in the troposphere continue to be a contributor to local pollution.

As the concern over stratospheric ozone declined, the broader concern over climate change that was noted in the convention continued and assumed a proportionately larger role. The improved science used to address the ozone issues then also became valuable in addressing the more complex climate change matter.

The development of the convention and climate change regulations through the United Nations Environment Programme has been closely associated with the science and models of the atmosphere. The science was addressed in related conferences and workshops including the Villach Conference in 1985. Eventually, the convention led to the formulation of the UN Framework Convention on Climate Change.

The preamble to the convention indicates the generally accepted views of the international community. This preamble mentions the relationship between the environment, its modification, and the potentially harmful effects on human health.

The awareness noted in the preamble is an acknowledgement that human activity can and does modify the environment. It also permits the recognition of the association between modifying the environment and its effect on human health itself. This awareness then establishes the possibility of regulating human activity.

Human activity is also associated with relevant scientific and technical considerations. There is then a recognized need for research and systematic observations into the phenomena. The use of science and technology is an important part of the convention and its implementation.

The intended result of the convention is twofold. First, the twin concerns are to protect human health and the environment. The particular focus then is the concern about adverse effects to both humans and the environment, which result specifically from modifications of the stratospheric ozone layer.

The convention is not concerned with all modifications of the ozone layer but only those that have adverse effects on human health and the environment. In fact, any modification of the ozone layer that has a positive effect on human health and the environment would be favorable. Under the definitions in Article 1, "adverse effects" refer to changes in the physical environment or biota, including changes in climate. The relevant changes are those that have significant deleterious effects on human health, on ecosystems whether natural or managed, and on "materials useful to mankind."

To achieve the intended result, the preamble raises some significant considerations. The reference to principle 21 of the Declaration of the UN Conference on the Human Environment highlights the context for the convention, which includes the sovereignty of each country, also known as a state, over its own domain and resources. It also underlines the responsibility of each such state not to cause damage beyond its national jurisdiction or to other states.

In such circumstances, a state's performance can then be evaluated in the international context against its own sovereign jurisdiction and its effect beyond its boundaries.

The sovereignty of each state also necessarily involves the recognition of cooperation between states. It is through cooperation and action that states can then be brought within the scope of international law and the Charter of the United Nations.

The preamble discloses its relatively recent formulation when it includes nonsovereign entities in its discussions. It generally acknowledges international and national organizations, whose work and studies are pertinent to the scope of the convention. An example of such an organization noted in the convention is the World Plan of Action on the Ozone Layer of the UN Environment Programme.

Another significant feature of the convention is the attention to developing countries in the global effort. The preamble generally recognizes the circumstances and particular requirements of developing countries. This recognition eventually leads to the more complex form of differentiated contributions to the total human activities and their consequences.

The agency responsible for the Convention is the Ozone Secretariat of the UN Environment Programme. In 1988, the assessment panel process was initiated under the Montreal Protocol, Article 6, and four panels were established. These are the panels for scientific, environmental, technology, and economic assessments. In 1990, the Panels for Technical Assessment and for Economic Assessment were merged into the Technology and Economic Assessment Panel.

Under Article 6 of the convention, a Conference of the Parties was established. The Conference of the Parties to the Convention, in its decision VCV/2 of its fifth meeting, acknowledges and encourages the collaboration of the three assessment panels with other entities. These entities link the convention with other international entities involved in addressing climate change issues. These other entities named in this decision are the Intergovernmental Panel on Climate Change, the Subsidiary Body on Scientific, Technical and Technological Advice under the UN Framework Convention on Climate Change, the International Civil Aviation Organization, and the World Meteorological Organization.

These entities were in addition to those recognized in Article 6, which included the World Health Organization and the International Atomic Energy Agency. Within limits, it also allowed for any state not a party to this convention and for any body or agency, whether national or international, governmental or nongovernmental, to be represented at the Conference of the Parties by observers.

The convention is specifically referred to in the preamble of the UN Framework Convention on Climate Change, signed in 1992, which came into force in 1994.

SEE ALSO: Atmospheric Composition; Climate Change, Effects.

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Vietnam

THIS SOUTHEAST ASIAN country, with a long coastline on the South China Sea, has a land area of 128,065 sq. mi. (331,689 sq. km.), with a population of 87,375,000 (2006 est.) and a population density of 655 people per sq. mi. (253 people per sq. km.). The largest city and the former capital of South Vietnam, Ho Chi Minh City (formerly Saigon) has a population of 3,525,300, making it the 49th largest in the world. Some 17 percent of the land in Vietnam is arable, with 4 percent being under permanent cultivation and 1 percent used as meadow or pasture. In addition, 30 percent of the country is forested, with an increasing logging industry operating in the country.

As there are three major rivers in Vietnam—the Red River, the Pearl River, and the Mekong—there has been a heavy investment in hydropower. In 1964, at a speech at Johns Hopkins University, U.S. President Lyndon B. Johnson offered a hydroelectric scheme for the Mekong River that was quickly dubbed the TVA for the Mekong. It was rejected by Ho Chi Minh, and the Vietnam War, which was escalating at that time, led to massive bombing of parts of the country, destruction of much of the infrastructure of both North Vietnam and South Vietnam, and the defoliation of some parts of the jungle. Following the end of the war in 1975 and the nation's reunification in the following year, the country was desperately poor. In spite of this, heavy government investment in hydropower then results in it now accounting for 59.3 percent of the country's electricity production, with the rest coming from fossil fuels. Electricity production accounts for 25 percent of the carbon dioxide emissions in the country, with 38 percent from transportation and 30 percent from manufacturing and construction.

During the 1990s, Vietnam became a major tourist destination, and this has led to a significant rise in the rate of per capita carbon dioxide emissions, from 0.3 metric tons per person in 1990 to 1.18 metric tons per person by 2004. In 1998, 48 percent of carbon dioxide emissions in the country was from liquid fuels, 37 percent from solid fuels, 8 percent from gas flaring, and 7 percent from cement manufacturing.

The Vietnamese government of Vo Chi Cong took part in the United Nations Framework Convention on Climate Change, signed in Rio de Janeiro in May 1992. The Vietnamese government signed the Kyoto Protocol to the UN Framework Convention on Climate Change on December 3, 1998, which was ratified on September 25, 2002, with it entering into force on February 16, 2005.

SEE ALSO: Climate Change, Effects; Deforestation; Tourism.

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Villach Conference

THE CONFERENCE HELD in Villach, Austria, from October 9 to 15, 1985, was the result of the continuing work of several international entities. In some views, the background to the conference and the starting point for internationally cohesive attempts to understand the issues related to the stratospheric ozone layer depletion and climate change have been traced to the UN Conference on Human Development in Stockholm in 1972. The technical, scientific understanding of the possibility of human-induced effects on the ozone layer and of climate change developed in the diplomatic context as complementary efforts linked through a reliance on common research initiatives.

A World Climate Conference held in Geneva in 1979 continued the efforts of the 1972 UN Conference on Human Development and led to the World Climate Programme. The World Meteorological Organization, the UN Environment Programme, and the International Council of Scientific Unions collaborated to hold a series of workshops that have come to be known as the Villach Conference.

The UN Environment Programme Ad Hoc Working Group of Legal and Technical Experts for the Elaboration of a Global Framework Convention for the Protection of the Ozone Layer was established by decision of the UN Environment Programme Governing Council decision 12/14, part I. The first part of the fourth session of the working group was held at the Palais des Nations, Geneva, from October 22 to 26, 1984.

The Working Group was also informed of the collaborative effort of the UN Environment Programme, the World Meteorological Organization, and the International Council of Scientific Unions to hold a major scientific conference to assess the carbon dioxide/ozone and climate question in October 1985 at Villach, Austria, with the support of the government of Austria.

Located at the intersection of the ozone and climate change issues, the Villach Conference became immediately significant to the Working Groups of both UN endeavors and to the overall development of international initiatives to address atmospheric environmental issues. A workshop on chlorofluorocarbons at Villach initiated the processes that led to a protocol to the Vienna Convention, which had been signed earlier that year in March 1985. The same conference augmented the UN Environment Programme's role in determining the assessment of the greenhouse gas/climate issue. In this regard, the October 1985 Villach Conference was significant.

The participants at the Villach Conference were a small group of environmental scientists and research managers in nongovernmental organizations. The dominant contribution of these participants was their expertise in climate modeling. With accreditation from recognized scientific institutions such as the International Institute for Applied Systems Analysis and from Harvard University, the results of this series of workshops carried considerable weight internationally. Even before the conference, a majority of the scientists who attended had publicly advocated what they considered an imperative to respond to a perceived threat to planetary climate stability within a strategy that was consistent with sustainable development, which was eventually incorporated in the Brundtland Report. Through affiliations with nongovernmental institutions, the scientists had improved modeling techniques that they relied on and that led them to generally agree with the conclusions and recommendations of the conference.

It was at the Villach Conference that the scientific community present arrived at an initial consensus as to the technical features of greenhouse gases, the depletion of the stratospheric ozone layer, and the chemical reactions that were relevant.

The general conclusion of the scientists and participants at the conference was that they could anticipate an unprecedented rise of global mean temperature in the first half of the 21st century. The scale and actual increase in global mean temperature was expected to be higher than any rise in the record of the planet's history. To mitigate the perceived events, the participants recommended a strategy that relied on technical and science-based research to establish target emission or concentration limits. In doing so, they sought to regulate the rate of change of global mean temperature within specific parameters.

Another result of the work by the participants at Villach was the establishment of the Advisory Group on Greenhouse Gases in 1986. This group was established to ensure continued academic and public interest in the effect of rising levels of greenhouse gases on the ozone layer and on climate change. The Advisory Group on Greenhouse Gases was jointly sponsored by the World Meteorological Organization, the UN Environment Programme, and the International Council of Science Unions.

The Brundtland Report, published in 1987, popularized sustainable development and advocated the development of a low-energy economy. This publication included a section on energy authored by Professor Gordon Goodman, who was by then a prominent member of the Advisory Group on Greenhouse Gases.

Work by the Advisory Group on Greenhouse Gases subsequently led to the 1988 Conference on the Changing Atmosphere: Implications for Global Security in Toronto, Canada, which called for 20 percent reductions in CO_2 emissions. The Advisory Group followed that up by preparing the Meeting of Legal and Policy Experts in February 1989 in Ottawa, which recommended an umbrella consortium to protect the atmosphere. The 1988 Toronto Conference then led to the establishment of the Intergovernmental Panel on Climate Change, with the mandate for continuing international research on climate change phenomena.

SEE ALSO: Atmospheric Composition; Climate Change, Effects.

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Virginia

THE COMMONWEALTH OF Virginia is a southern Atlantic state on the eastern seaboard of the United States of America. Virginia is the 35th largest state in the United States, with an area of over 42,000 sq.

mi. (108,780 sq. km.) and an estimated population of about 7.6 million. Virginia's state capital is Richmond, located in central Virginia, and the largest city is Virginia Beach, on the coast. Cities in the commonwealth are considered independent and function in the same manner as counties. Virginia's geography is divided into six different regions, from the tidewater along Chesapeake Bay on the eastern coast, to the Appalachian Plateau in the West. Virginia's climate is considered mild for the United States but can be quite variable because of significant topographic differences across the state and the influence of the Atlantic Ocean. The regions east of the Blue Ridge, as well as the southern part of the Shenandoah Valley, are considered a humid subtropical climate (Koppen climate classification *Cfa*). In the mountainous areas between the Allegheny and Blue Ridge mountains in the west, the climate becomes humid continental (Koppen climate classification *Dfa*).

Virginia was founded on May 13, 1607, at Jamestown, the first permanent English settlement in North America, and is one of the original 13 colonies of the American Revolution. Virginia joined the Union on June 25, 1788, and was the 10th state to ratify the U.S. Constitution. More U.S. presidents (eight) have come from Virginia than from any other state. The current and 70th governor of Virginia is Democrat Tim Kaine, who assumed office in January 2006. Virginia's geography varies considerably across the state, including the Shenandoah Valley, bordered by the Allegheny and Blue Ridge mountains in the west; the rolling hills of the central piedmont; and the flat eastern coastal plain extending from the piedmont to the Atlantic Ocean. Elevations in Virginia range from sea level to nearly 6,000 ft. at the summit of Mt. Rogers.

The state is divided into six distinct geographical regions: the ridge and valley between the Blue Ridge Mountains to the east and the Appalachian and Allegheny plateaus to the west; the Shenandoah Valley, located within the ridge and valley; the Blue Ridge Mountains between the ridge and valley to the west and the piedmont region to the east; the foothills between the piedmont and the Blue Ridge Mountains; the piedmont between the Blue Ridge Mountains to the west and the tidewater region to the east; and, the tidewater between the fall line to the west and the Atlantic east, including the eastern shore.

The southern area of Virginia's Shenandoah Valley is considered a humid subtropical climate.

Virginia has five distinct climate regions: tidewater, piedmont, northern Virginia, western mountains, and southwestern mountains. Climate varies significantly across the state because of differences in topography, the influence of the Atlantic Ocean and the Gulf Stream in the east, and the complex pattern of rivers and streams. Much of the precipitation that Virginia receives results from storms associated with low-pressure (cyclone) frontal systems—warm and cold fronts that typically move from west to east across the state, curving northwestward as they reach the Atlantic Ocean. Virginia also experiences occasional tropical storm activity, most often in early August and September, and typically through the venue of the mouth of the Chesapeake Bay. The tropical storms can provide significant amounts of precipitation. In recent years, development trends in northern Virginia extending out from Washington, D.C., have created an urban heat-island effect characteristic of other large urban areas.

In Virginia, emissions of carbon dioxide, one of the primary greenhouse gases that alter the Earth's climate, have risen by over 30 percent since 1990, driven by economic growth, development patterns, and increased transportation trends. Human-induced climate change is expected to have many effects on Virginia's weather, wildlife, food production, and water supplies. Sea level in the mid-Atlantic region is estimated to rise several inches in the coming decades, threatening low-lying areas and coastal developments. Changes in precipitation and temperature regimes have the potential to disrupt agriculture and forestry. Although at present it is rare for a major hurricane to threaten the Virginia coast, hurricanes make the coastal area of Virginia vulnerable. Increased tropical storm activity that might result from climate change would carry the threat of damage to Virginia's communities.

Virginia has begun to address the issue of climate change in several ways. Virginia is one of several states to have completed, in 2007, a comprehensive Climate Action Plan, manifested as the Virginia Energy Plan. The process of developing a climate action plan includes identifying cost-effective opportunities by which a state may reduce emissions of the greenhouse gases that alter climate. However, unless clear policies are stipulated, climate action plans cannot ensure real reductions in emissions. Virginia adopted a voluntary renewable portfolio standard in 2007, and in May 2007, Governor Tim Kaine announced that Virginia had joined the Climate Registry, a state-sponsored initiative to standardize methods to record and measure greenhouse gas emissions.

SEE ALSO: Atlantic Ocean; Climate; Gulf Stream; United States.

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Volcanism

MEMBERS OF THE scientific community by and large concur that the Earth is undergoing a change in climate and that global warming is occurring at an increasing rate. In fact, scientific modeling suggests that Earth will experience an increase in temperature during the next 100 years at a pace up to four times greater than that in the previous 100 years. To a large extent this acceleration in the late 20th century is attributed to carbon dioxide (CO_2) emissions generated by human activity. Carbon dioxide acts like a glass barrier over the Earth, preventing heat from leaking into the environment, and thus creating a greenhouse effect. Human activity has counteracted global warming to a small degree by emitting aerosols in the environment, causing global cooling.

Volcanism is another contributing factor to climate change. Each volcano affects the climate based on its location and the nature and extent of an eruption.

Similar to human activity, volcanism leads to both global warming and cooling. The effect of volcanism on climate depends on the interaction between the sun's heat and the volcanic debris. In essence, scientists believe that ongoing volcanic eruptions have maintained the Earth's temperate climate for millions of years. Circumstantial evidence suggests that volcanism can influence short-term weather patterns in addition to having an effect on long-term climate change.

Volcanic dust blown into the atmosphere can remain for months and produce temporary cooling, the degree to which is dependent on the volume of dust, and the duration of which is dependent on the size of the dust particles. The strength of gases can vary greatly among volcanoes. Water vapor is typically the most abundant volcanic gas, followed by carbon dioxide and sulfur dioxide. Other principal volcanic gases include hydrogen sulfide, hydrogen chloride, and hydrogen fluoride.

Volcanoes that discharge great quantities of sulfur compounds affect the climate more significantly than those that release only dust. In fact, the greatest volcanic effect on the Earth's short-term weather patterns is caused by sulfur dioxide gas. Sulfur dioxide can form sulfuric acid aerosols that reflect the sun's heat and trigger cooling of the Earth's surface for as long as two years. Scientific literature frequently refers to the drop in global temperature after the eruption of Mount Pinatubo, Philippines, in 1991 and the very cold temperatures leading to crop failures and famine in North America and Europe for two years following the eruption of Mt. Tambora, Indonesia, in 1815 as examples of this effect. Furthermore, sulfuric dioxide can form acid rain, a combination of sulfuric acid and nitric acid. Acid rain, which is also caused by the burning of fossil fuels, is a critical environmental problem that can

Yasur volcano in Vanuatu is one of the world's most active volcanoes, erupting dozens of times a day for about 800 years.

injure lakes, streams, and forests and the inhabitants of these ecosystems.

In addition, volcanoes discharge water and carbon dioxide in large quantities in the form of atmospheric gases, and can absorb and retain in the atmosphere heat radiation emanating from the ground. Estimates suggest that water makes up to 99 percent of gas in volcanic expulsions. This short-term warming of the air leads the water to become rain within a matter of hours or days and the carbon dioxide to dissolve in the ocean or to be absorbed by plants. The majority of the heat energy connected to global warming exists in the ocean. If the oceanic depth at which heat is stored is decreased, then global temperature increases are expected to be greater than predicted.

Volcanic eruptions combined with man-made chlorofluorocarbons (CFCs) also can contribute to ozone depletion. CFCs were developed in the early 1930s and were used in industrial, commercial, and household applications, such as refrigeration units and aerosol propellants, because they were nontoxic and nonflammable and met a number of safety criteria. In February 1992, however, following evidence that CFCs contributed to depletion of the ozone layer, the United States announced the phase-out of the production of CFCs by December 1995. Members of the Montreal Protocol in 1992 followed suit and agreed to an accelerated phase-out by the end of 1995 as well.

The ozone layer, which rests in the stratosphere and begins at 7.5 mi. (12 km.) above the Earth, is a shield that protects living beings from ultraviolet-B (UV-B), the sun's most harmful UV radiation. In high doses, UV-B can lead to cellular damage in plants and animals. Scientists believe that global warming will lead to a weakened ozone layer, because as the Earth's surface temperature rises, the stratosphere will get colder, slowing the natural repairing of the ozone layer. Decreased ozone in the stratosphere results in lower temperatures.

Unlike ozone depletion created by man-made CFCs, which will take decades to repair, theories indicate that repair of damage to the ozone layer caused by volcanoes occurred as volcanic activity diminished. Recent mathematical models intimate that a volcanism in Siberia of great proportion significantly depleted the ozone layer.

Finally, hydrogen fluoride gas can concentrate in rain or on ash particles, contaminating grass, streams, and lakes with excess fluorine. Excess fluorine in grass and water supplies can poison the animals that eat and drink at contaminated sites, eventually causing fluorisis, which destroys bones.

SEE ALSO: Forced Climate Variability; Oceanic Changes; Stratosphere; Sulfur Dioxide.

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Von Neumann, John (1903–57)

JOHN VON NEUMANN is a Hungarian-born American mathematician who contributed important theories to all the different branches of the discipline. His discoveries influenced quantum theory, automata theory, economics, and defense planning. Von Neumann was one of the founders of game theory and, along with Alan Turing and Claude Shannon, was one of the conceptual inventors of the stored-program digital computer. He is mostly remembered in the field of global warming for his elaboration of general circulation models and for his 1955 article in *Fortune*, in which he stated that "microscopic layers of colored matter spread on an icy surface, or in the atmosphere above one, could inhibit the reflection-radiation process, melt the ice, and change the local climate." This is one of the earliest conceptualizations of the problem of global warming.

John Von Neumann was born János Neumann in Budapest, Hungary, on December 28, 1903, into a wealthy and completely assimilated Jewish family. His father was a banker, and his mother originally came from a family who made a fortune selling farm equipment. John was a child prodigy and was initially educated by private tutors in mathematics and foreign languages. In 1911, he entered Budapest's most prestigious school, the Lutheran Gymnasium. When Bela Kun established his revolutionary government, Von Neumann's family fled Hungary and briefly emigrated to Austria. Kun's government failed after only five months. Because it was mainly composed by Jews, Von Neumann's family, no matter how hostile to the regime, was blamed, together with many other Jews, for the brutality of the revolutionary government. In 1921, Von Neumann completed his education at the gymnasium and his father strongly advised him to take up a career in business and not in mathematics, where Von Neumann's talent was already obvious. His father was afraid that mathematics would not allow Von Neumann to lead a wealthy and comfortable existence. As a compromise, it was decided that Von Neumann would study both chemistry and mathematics. In spite of the strict quotas for Jewish entry to university, Von Neumann succeeded in attending the University of Budapest for mathematics and the University of Berlin for chemistry. He later switched to the Swiss Federal Institute in Zürich, from where he graduated with a degree in chemical engineering in 1925. The following year, he obtained a doctorate in mathematics from the University of Budapest.

Von Neumann quickly gained a reputation in set theory, algebra, and quantum mechanics. In particular, his paper "An Axiomatization of Set Theory" (1925) was read and appreciated by the famous mathematician David Hilbert. Because of Hilbert's interest, Von Neumann worked at the University of Göttingen in 1926 and 1927. Von Neumann was then employed as a *Privatdozent* ("private lecturer") at the Universities of Berlin (1927–29) and Hamburg (1929–30). At a time when Europe was characterized by political unrest and totalitarianism, he was invited to visit Princeton University in 1929 to lecture on quantum theory. He was then hired at Princeton as visiting professor the following year, although teaching was not one of his strongest assets, and when the Institute for Advanced Studies was founded there in 1933, he was appointed to be one of the original six professors of mathematics, a position he retained for the rest of his life. In 1930, Von Neumann married Mariette Koevesi. They had one child, Marina, who later became an economist. The couple separated amicably in 1937, and the following year Von Neumann married his childhood sweetheart Klara Dan, with whom he remained until his death. After his appointment at the Institute for Advanced Studies, Von Neumann resigned from all his German academic positions. Being a Jew, he could not work for a Nazi state. He prophetically stated that if Hitler remained in power, it would ruin German science for a long time.

During the World War II, Von Neumann worked for the Manhattan Project at the invitation of its director Robert Oppenheimer. His expertise in the nonlinear physics of hydrodynamics and shock waves was instrumental in the design of the Fat Man atomic bomb dropped on the Japanese port of Nagasaki. Von Neumann argued against dropping the bomb in Tokyo on the Imperial Palace. In the postwar years, Von Neumann continued to work as a consultant to government and industry. Starting in 1944, he contributed important insights for the development of the U.S. Army's ENIAC computer, initially designed by J. Presper Eckert, Jr., and John W. Mauchly. In a crucial contribution, Von Neumann modified the ENIAC to run as a stored-program machine. Von Neumann did not invent the computer itself, but he invented the software that made it run. The ENIAC machine was a combination of electronic hardware and punch-card software that allowed it to be employed for a variety of uses including weather forecast. Von Neumann then campaigned to build an improved and faster computer at the Institute for Advanced Study. The institute's machine, which began operating in 1951, used binary arithmetic where the ENIAC had used decimal numbers. Von Neumann's publications on computer design (1945–51) caused a clash with Eckert and Mauchly, who wanted to patent their contributions, and paved the way for the independent construction of similar machines around the world. Von Neumann's intuition for a single-processor, stored-program computer became the accepted standard.

As a consultant for RAND Corporation, Neumann was given the task of planning a nuclear strategy for the U.S. Air Force. In this capacity, he was a strong advocate of nuclear weapons, and he became one of President Dwight Eisenhower's top advisers on his nuclear deterrence policy. Von Neumann was diagnosed with bone cancer in 1955. In spite of his deteriorating health, he continued to work, and in 1956 he was honored with the Enrico Fermi Award. He converted to Roman Catholicism just before his death on February 8, 1957, in Washington, D.C.

SEE ALSO: Climate Models; Education.

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Vostok Core

RUSSIA'S VOSTOK STATION is located in east Antarctica. Vostok Station holds the record for lowest temperature ever recorded at minus 129 degrees F (minus 89 degrees C). Soviet researchers began deep drilling at the Vostok Station in 1980. The ice cores brought to the surface in segments provide information (chemistry, structure, inclusions) about climate conditions similar to tree ring samples. The information from air bubbles allows for measurement of the atmospheric concentration of greenhouse gases (carbon dioxide, methane, nitrogen, helium, sodium, and organic carbon). Besides presenting an extraordinary human effort spanning two decades in one of the most inhospitable places on earth, the drilling at Vostok has produced one of the richest scientific treasure troves of all time. Previously, analysis revealed tracking between carbon dioxide and temperature and that the magnitude of the carbon dioxide swings could account for the magnitude of the temperature swings.

The first hole drilling stopped in 1985 because of problems. A second hole drilled with French-Russian cooperation produced an ice core 2,083 m. long, or 1.33 mi. With a climate record of 160,000 years, drilling on this hole ended in 1990. A third hole was drilled with collaboration among Russia, France, and the United States. The drilling reached a depth of 2.25 mi. (3.6 km.) and in January 1998 produced the deepest ice core recovered at the time (now exceeded by the European Project for Ice Coring in Antarctica)—11,886 ft. (3,623 m.) deep, containing a climate record of 420,000 years, for a total of four climate cycles. Drilling stopped at this depth because the researchers were recovering accretion ice refrozen to the bottom of the glacier, indicating the presence of an underlying lake, and did not want to put themselves in danger from the release of pressurized lake water or risking contamination of the lake. Researchers have found microbes in the glacial ice from the Vostok core and four times more in the glacial-accretion ice transition, suggesting that the underground lake contains microbes and organic carbon.

Polar snowfall can be preserved in annual layers within an ice sheet to provide a climate record. These layers can be studied to develop an accurate picture of the climate history extending over the time periods (the deepest Vostok core extends over a 400,000 year time frame). Impurities (volcanic debris, sea salt, organic material, and interstellar particles) are also deposited with snow, making those layers distinctive.

Air bubbles trap gases in the ice and allow for testing to determine the air's composition at distinctive periods in the climate record. Water pockets may also become trapped the deeper the ice core is, and closer to the underlying rock or water. Researchers can determine the composition of water in comparison with heavy water isotopes to indicate environmental temperature; cold periods are those with moisture being removed from the atmosphere.

Studies on the second Vostok core showed a correlation between carbon dioxide and temperature over the past 160,000 years and provided evidence linking climate change with the greenhouse effect. The trapped air bubbles provided gas isotopes and, when compared with the temperature variations, matched up to show that greenhouse gases were the primary driver of climate change over time. The climate variation of ice ages also matched the solar records.

Initial Vostok studies, when combined with later research, provide an inclusive representation of the multiple factors involved in climate change by using a multidisciplinary approach to climate change research by using astronomical tables, chemistry, and physics. The Vostok ice cores indicate periods of ice ages, contain gases for comparison with temperature changes, and highlight the last ice age of 8 degrees F (4.4 degrees C) cooler than the present, taking place about 18,000 years ago.

Vostok's cores have provided significant evidence of greenhouse gas variations driving climate change and have provided information for the modeling of future climate changes in relation to greenhouse gas concentrations.The third Vostok core, recovered in 1998, provides additional confirmation and extends the historical record through the four most recent glacial cycles, showing that increased concentrations of greenhouse gases have forced the temperature higher and can be compared with the geological record of the same time frames.

The Vostok ice core has become the standard for creating timescales from cores recovered from other parts of the world. Researchers are able to plot the isotopes of their samples with similar isotope ratios of the known sample to provide an accurate time period reference.

SEE ALSO: Greenhouse Gases; Milankovitch, Milutin; Paleoclimates.

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Independent Scholar

Walker, Gilbert Thomas (1868–1958)

GILBERT THOMAS WALKER is the British physicist and statistician who first described the phenomenon of Southern Oscillation, a coherent interannular fluctuation of atmospheric pressure over the tropical Indo-Pacific region that produces wind anomalies. This was part of Walker's project to determine the connections between the Asian monsoon and other climatic fluctuations in the global climate in an effort to predict unusual monsoon years that cause drought and famine to the Asian sector. Although he was not a meteorologist by education, Walker greatly advanced the study of global climate with his discovery.

Gilbert Thomas Walker was born on June 14, 1868, in Rochdale, Lancashire. He was the eldest son and fourth child in a large family of eight. Soon after his birth, his family relocated to Croydon, where his father became the borough's chief engineer. From 1876 on, Gilbert attended Whitgift School, and in 1881 he won a scholarship to St. Paul's School. He already excelled in mathematics from these early years and passed the London matriculation in 1884. However, he did not stay in London for his degree, opting instead for Trinity College, Cambridge, where he enrolled in 1886, thanks to a scholarship. In 1891, he was elected a Trinity Fellow. He received an M.A. in 1893, and two years later, he was appointed a lecturer in mathematics. The heavy work necessary to attain these successes eventually took their toll on Walker's health, which broke down in 1890, forcing the mathematician to spend the next three winters in Switzerland. As a result of his precarious health, Walker did not publish many significant papers in the following years, but his 1899 work "Aberration and Some Other Problems Connected With the Electromagnetic Field" earned him the prestigious Adams Prize from Cambridge University. Walker was elected a fellow of the Royal Society in 1904, the same year that he received a Sc.D. from Cambridge University.

In the summer of 1903, Walker resigned his academic positions to become assistant to Sir John Eliot, who was the meteorological reporter to the government of India and director-general of Indian Observatories. The choice of Walker as special assistant was surprising, as Walker was not a meteorologist but a mathematician. At the end of 1903, Eliot retired, and Walker became the sole person responsible for the Indian Meteorological Department. He continued Eliot's quest for professional individuals to become members of his staff. He made prestigious appointments including J.H. Field, J. Patterson, and G.C.

Simpson, who later became directors of meteorological services in India, Canada, and the United Kingdom, respectively. From the beginning of his appointment, Walker devoted his research to the problems of monsoon and, in 1909, published his first meteorological papers. In 1908, Walker also gave lectures at the University of Calcutta, which were then published in 1910 by Cambridge University Press. Walker married May Constance Carter in 1908, and the couple had a son and a daughter.

Walker's interest in the monsoon resulted from the famine that the absence of rains had caused in India in 1899. Walker soon understood that he could not tackle meteorological problems through mathematical analysis and tried to develop more empirical techniques. He called his methodology seasonal foreshadowing, rather than weather forecasting, as the phrase indicated a vaguer prediction. Walker calculated statistical delay correlations between antecedent meteorological events both within and outside India and the subsequent behavior of the Indian monsoon. He was one of the first scientists to establish relationships between apparently separate events. The sets of relationships that he established, subsequently called Walker circulation in his honor, create a system resembling a global heat engine influencing the world's climate. The Walker circulation works like a swing in which warm, moist air rises in the western Pacific, becomes drier at high elevation, and displaces eastward, where heavy air sinks and returns westward. The phenomenon thus creates high air currents moving from the west to the east and, at the same time, east-to-west trade winds near the ocean surface. Global warming theorists have predicted that the rising temperatures will eventually slow down this mechanism.

Walker retired as director of the Indian Meteorological Department in 1924 and became a professor of meteorology at the Imperial College of Science and Technology in London. There, Walker continued his research into global weather and simultaneously carried out laboratory experiments in physics to study the convection of unstable fluids, particularly in its applications to cloud formations. He retired from Imperial College in 1934 and moved to Cambridge, where he lived until 1950. Although retired, Walker remained an active researcher and served as the editor of the *Quarterly Journal of the Royal Meteorological Society* from 1934 to 1941. He died in Coulsdon, Surrey, on November 4, 1958. Although he had only mixed success in his original goal, the prediction of monsoonal failures, Walker conceived theories that allowed his successors to move beyond local observation and forecasting toward comprehensive models of climate worldwide

Throughout his distinguished career, Walker was a member of prestigious societies and received numerous honors. He was elected a fellow of the Royal Meteorological Society in 1905 and served as president of the society in 1926 and 1927. He was also vice president of the society three times and was an ordinary member of council in 1925 and from 1935 to 1939. He was awarded the society's Symons Gold Medal in 1934. While working in India, Walker was the president of the Royal Society of Bengal and president of the Indian Science Congress. He became a Companion of the Order of the Star of India in 1911 and was knighted on the king's birthday in 1924. Walker was also an honorary fellow of Imperial College and a fellow of the Royal Astronomical Society.

SEE ALSO: Climate Models; Southern Oscillation.

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Walker Circulation

THE WALKER CIRCULATION is an atmospheric system of air flow in the equatorial Pacific Ocean. The trade winds across the tropical Pacific flow from east to west: air rises above the warm waters of the western Pacific, flows eastward at high altitudes, and descends over the eastern Pacific. A weaker Walker circulation (in the reverse direction) occurs over the Indian Ocean.

Sir Gilbert Walker assumed the post of director-general of the observatory in India following catastrophic famines in the late 1800s resulting from a general failure of the South Asian monsoon. In an effort to predict the monsoons, Walker undertook an investigation into the regional climate system. Over time, he recognized that the monsoonal system extended to a panoceanic scale. Walker observed that an inverse relation of atmospheric pressures at sea level generally existed between the two sides of the Pacific Ocean. A high-pressure phase in South America was usually accompanied by low pressure in the western Pacific and vice versa—the Southern Oscillation (SO). The generally accepted measure of the SO is the inverse relationship between surface air pressure at Darwin, Australia, and Tahiti (stations used by Walker); indeed, the SO is normally identified by the SO Index (SOI), that is, the difference in atmospheric pressure at sea level between these stations (Tahiti minus Darwin). The greater the SOI, the greater the intensity of the trade winds. Historically, the SO has exhibited a more or less cyclical pattern, in that it weakens or reverses every few years.

On the basis of data collection initiated during the International Geophysical Year in 1957 to 1958, in the 1960s Jacob Bjerknes of the University of California described the general nature of the mechanism linking the system. He extended the horizontal picture of the SO vertically by theorizing that to complete the system of the trade winds and atmospheric air pressure, there needed to be a countercirculation of air from west to east at high altitudes, descending over the eastern Pacific.

Atmospheric circulation is intimately coupled with the movement of water in the tropical Pacific. At the surface, the trade winds initiate a westward flow of surface water across the Pacific Ocean, producing an increase of sea level in the western Pacific of approximately 40 cm. The equatorial heating of this water produces high seasurface temperatures (SSTs) in oceanic waters near Indonesia. The resulting low atmospheric pressure and evaporation fuels the pan-Pacific upper-atmospheric circulation characterized by convection (low atmospheric pressure) in the west and subsidence (high atmospheric pressure) in the east. This is termed the Walker circulation in honor of Sir Gilbert.

The Walker circulation is closely connected to oceanic upwelling off the coast of South America. Fluctuations in the circulation are closely linked to El Niño and La Niña events—together termed the El Niño/SO system (ENSO). A weakening or reversal of the Walker circulation is closely linked with the El Niño phenomenon, with warmer-than-average SSTs in the eastern Pacific as upwelling diminishes. In contrast, the opposite phase, a particularly strong Walker circulation, produces a La Niña event, with cooler SSTs caused by increased upwelling. Interannular switches in the dipole are linked to global-scale changes in patterns of weather. Several explanations for the variation in the Walker circulation have been hypothesized, but the nature of the mechanisms initiating the change in phase has not been fully identified.

Evidence suggests that the Walker circulation may have been weakening since the mid-19th century. However, there is a high degree of uncertainty concerning the potential effects of climate change on the Walker circulation. Transient warming may dominate before the ocean has had a chance to reach equilibrium. In the short term, warming may occur more quickly in the western Pacific, thereby enhancing the circulation. In contrast, atmospheric models have indicated that climate change will, as part of a weakening of the entire tropical circulation, lead to a general decrease in the strength of the Walker circulation. The specific mechanisms involved are not fully known, and projections remain rather speculative and are a focus of intense research.

SEE ALSO: El Niño and La Niña; Pacific Ocean; Southern Oscillation; Trade Winds; Walker, Gilbert Thomas.

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Washington

WASHINGTON STATE IS 71,300 sq. mi. (184,666 sq. km.), with inland water making up 1,553 sq. mi. (4,022 sq. km.), coastal water making up 2,535 sq. mi. (6,565 sq. km.), and access to territorial water making up 666 sq. mi. (1,725 sq. km.). Washington's average elevation is 1,700 ft. (518 m.) above sea level, with a range in elevation from sea level on the Pacific Ocean to 14,410 ft. (4,392 m.) at the peak of Mt. Rainier. Western Washington lies on the Juan de Fuca Plate, with overriding by the North American Plate.

Washington is fairly warm and is kept that way by ocean currents including frequent rain and the rain shadow effect. Moist air streams up slopes of mountains, and rainfall or snowfall is increased. However, when the air, depleted of much of its moisture, begins to descend down the slopes, the temperatures warm, clouds dissipate, and very little precipitation falls. Western mountains take Pacific moisture that flows onshore all year long. The western slopes of the Olympic Mountains have a true rainforest, but the rain shadow on the eastern slope means it receives less than 15 in. of rain per year. The highest temperature recorded in the state is 118 degrees F (48 degrees C) in Ice Harbor Dam on August 5, 1961, and the lowest temperature recorded in the state is minus 48 degrees F (minus 44 degrees C) in Mazama and Winthrop on December 30, 1968. Mount St. Helens, an active volcano, spouted volcanic ash into the atmosphere in 1980. In 1993, the year of the flood in Iowa, Washington recorded the coolest summer on record in Spokane.

The state supports a population of over 6 million people. Major industries include agriculture, with the major products being apples, beef, milk, timber, and wheat; manufacturing computers, food, machinery, and paper products; and mining coal, gold, sand, and gravel.

The Columbia River is the second largest river in the country based on volume. The Grand Coulee Dam retains some water from spring runoff for summer use. It is the largest concrete structure at 55 ft. (16.7 m.) tall. It holds 24 generators supplying 65 mil-

Mount St. Helens in Washington is an active volcano, and had an enormous eruption at 8:32 in the morning on May 18, 1980. The debris blasted down nearly 230 sq. mi. (596 sq. km.) of forest and buried much of it beneath volcanic mud deposits.

lion kilowatts of electricity. This electricity is carried throughout the west and east to Chicago.

Commercial logging started in the 1800s and has claimed 90 percent of the forests that once grew in the Pacific Northwest. Logging in the national forests since World War II has divided mountainsides and river valleys into checkerboards of clear-cut and uncut forest, creating vulnerable areas to succumb to environmental pressures. More than half of the remaining untouched forest areas in Olympic National Forest are slated for cutting during the next 50 years, as is 69 percent of the old growth in Oregon's Siuslaw National Forest. In 1990, Congress voided all court injunctions brought to stop cutting of ancient trees on lands administered in Washington and Oregon by the Bureau of Land Management and the Forest Service and removed the right of citizen and conservation groups to seek further injunctions in any future cuts planned.

The Climate Impacts Group at the University of Washington is working to further understanding of the patterns and predictability of regional climate variability, the influence of climate variation on the Pacific Northwest, and providing strategies to prepare for climate change.

Washington is a member of the Western Regional Climate Action Initiative, along with Arizona, California, New Mexico, Oregon, Utah, and the Canadian provinces of British Columbia and Manitoba. This cooperative group works together to identify, evaluate, and implement ways to reduce greenhouse gas emissions on the regional level.

The effects of climate change that are already being experienced by Washington include weather changes, reduced summer water supply dependent on winter snowpack, and rising water levels along the coastline. Because of these effects, Washington is taking steps to prepare for climate change and reduce human-induced contributions to global warming. In February 2007, the governor signed an executive order establishing goals for reduction in climate pollution, increases in jobs, and reductions in expenditures on imported fuel. Because the United States has not ratified the Kyoto Protocol calling for greenhouse gas emission reduction, some states and regions have taken voluntary initiatives to reduce these emissions on their own. Washington's goal is to cut emissions by 20 percent by 2050, with reduced auto emissions, use of renewable fuels, green building standards, and energy efficiency; passing a clean renewable energy initiative; and adopting a CO_2 emissions performance standard for electric generating units.

Not only is Washington proactive on reduced emissions but they provide education and call for public support by using more energy-efficient transportation (public transportation, ride sharing, walking, or bicycling), improving home energy efficiency (insulation, energy-efficient appliances, and fluorescent lighting), and encouraging the planting of trees and plants.

Though climate models show no precipitation change, a change in temperature of 2 degrees to 3 degrees may mean less snowfall. An expected decrease this century of 60 percent in Cascade snowpack—even in the most reassuring of global warming scenarios—stands to have devastating consequences in the Pacific Northwest. The Columbia River's Grand Coulee Dam has made it possible for Washington, along with other Pacific and mountain states, to increase in population. A survey of nearly 600 snowfields in the Sierra Nevada, the Rocky Mountains, and the cascades of Washington and Oregon shows that 85 percent of them have lost volume since the 1950s. A higher incidence of wildfires resulting from increasing drought levels, as well as rising sea levels, could displace people from their homes.

The associated costs include those affiliated with fighting wildfires, flood damage, lost revenue from tourism, increase in water pricing because of shortages and drought conditions, and increased costs for healthcare related to poor air quality and increased infection.

With rising temperatures, variable precipitation, and rising sea levels, the quality of the water supply in Washington could be compromised, with an increasing risk of water-borne infections. The potential for agricultural disruption also could lead to risks of malnutrition, and increasing heat waves could cause more heat-related illness.

SEE ALSO: Deforestation; Drought; Floods; University of Washington; World Health Organization.

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Lyn Michaud
Independent Scholar

Washington, Warren (1936–)

WARREN WASHINGTON IS an African-American meteorologist and atmospheric scientist whose research focuses on the development of computer models that describe and predict the Earth's climate. Washington was one of the first developers of atmospheric computer models in the early 1960s at the National Center for Atmospheric Research in Boulder, Colorado. These computer models use the basic laws of physics to predict the future states of the atmosphere. Because these equations are extremely complex, it is almost impossible to solve them without a powerful computer system. Washington's book *An Introduction to Three-Dimensional Climate Modeling* (1986), coauthored with Claire Parkinson, is a standard reference for climate modeling. In his subsequent research, Washington worked with others to incorporate ocean and sea ice physics as part of a climate model. Such models now involve atmospheric, ocean, sea ice, surface hydrology, and vegetation components. Washington is the director of the Climate and Global Dynamics Division of the National Center for Atmospheric Research (NCAR), in Boulder, Colorado. He has advised the U.S. Congress and several U.S. presidents on climate-system modeling, serving on the President's National Advisory Committee on Oceans and Atmosphere from 1978 to 1984.

Washington was born in Portland, Oregon, in 1936. His father, Edwin Washington, Jr., wanted to be a schoolteacher, but in the 1920s, it was impossible for African Americans to be hired as teachers in Portland public schools. Thus, Edwin was forced to work as a waiter in Pullman cars to support his family. His wife Dorothy Grace Morton Washington became a practical nurse after Warren and his four brothers grew up. Washington's interest in scientific research was apparent from an early age, and he was encouraged by his high school teachers. When Washington had to choose what to do after high school, his counselor advised him to attend a business school rather than college. However, his ambition was to be a scientist, so he enrolled at Oregon State University, where he earned his bachelor's degree in physics in 1958. During his undergraduate years, Washington became interested in meteorology while working on a project at a weather station near the campus. The project involved using radar equipment to follow storms as they came in off the coast. Because of his growing interest in meteorology, Washington began a master's degree in meteorology at Oregon State, graduating in 1960. He then began a Ph.D. at Pennsylvania State University, graduating in 1964, thus becoming one of only four African Americans to receive a doctorate in meteorology.

Washington began working for NCAR in Boulder, Colorado, in 1963 and has remained associated with that institution throughout his career. His research at the center has attempted to describe patterns of oceanic and atmospheric circulation. Washington has contributed to the creation of complex mathematical models that include the effects of surface and air temperature, soil and atmospheric moisture, sea ice volume, various geographical traits, and other factors on past and current climates.

Washington's research has helped further our present understanding of the greenhouse effect. He has contributed to determining the process in which excess carbon dioxide in the Earth's atmosphere causes the retention of heat, thus leading to what is known

Warren M. Washington is the head of the Climate Change Research Section, National Center for Atmospheric Research.

as global warming. Washington's research also shed light on other mechanisms of global climate change. In interviews and statements, Washington has made it clear that he firmly believes that global warming is to the result of human actions: "For researchers in climate science, the question of whether or not climate change is attributable to human activity was put to rest several years ago with our DOE-supported simulations showing that the only way to duplicate the sharp increase of the global average temperature observed in the late 20th century was to include human generated greenhouse gases in the simulations. When the same simulation was run without the human-generated greenhouse gas increases, the model simulations show that the Earth would be in a slight cooling trend with the natural forcings of volcanic and solar activities. For us, that was the smoking gun for human-induced climate change." He has thus pleaded for climate science to rise in priority as a science problem for American administrations. He has also claimed that the Department of Energy has a particular responsibility to help find solutions for the global warming problem. According to Washington, "as the impacts of climate change become more apparent with increased severity of heat waves, droughts, water shortages, and more severe hurricanes, there will be more emphasis on understanding how we can better mitigate and adapt to the changes." The meteorologist has suggested that the Department of Energy study the carbon footprint and effect of various technology paths for the production of energy. He has also argued for an increased focus on what strategies to use to mitigate climate change and to find a long-term stabilization for carbon dioxide and other greenhouse gases in the atmosphere.

Throughout his career, Washington has published over 100 professional articles about atmospheric science, scientific textbooks, and an autobiographical volume. He has also served as a member and a director of prestigious institutes and commissions. Washington was appointed the director of the Climate and Global Dynamics Division at NCAR in 1987. In 1994, he was elected president of the American Meteorological Society. He is a fellow of the American Association for the Advancement of Science and a member of its board of directors, a fellow of the African Scientific Institute, a distinguished alumnus of Pennsylvania State University, a fellow of Oregon State University, and founder and president of the Black Environmental Science Trust, a nonprofit foundation that encourages African-American participation in environmental research and policymaking. From 1974 to 1984, Washington served on the President's National Advisory Committee on Oceans and Atmosphere. In 1995, he was appointed by President Bill Clinton to a six-year term on the National Science Board. In 1997, he was awarded the Department of Energy Biological and Environmental Research Program Exceptional Service Award for Atmospheric Sciences in the development and application of advanced coupled atmospheric-ocean general circulation models to study the effects of anthropogenic activities on future climates.

SEE ALSO: Climate Models; Education.

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Waves, Gravity

ATMOSPHERIC GRAVITY WAVES are generated by atmospheric disturbances such as storm fronts, strong wind shears, and flow over mountains and play a key role in coupling the lower and upper atmosphere, causing a redistribution of momentum and energy from the troposphere and lower stratosphere into the upper atmospheric regions of the middle stratosphere, mesosphere, and lower thermosphere. Gravity waves trigger convection and induce mixing and transport of atmospheric chemicals such as ozone. Gravity waves typically form within or near the back edge of a precipitation shield. The strongest upward motions of gravity waves occur just following the surface pressure trough and lead to maximum precipitation rates just ahead of the ridge.

Atmospheric gravity waves can occur at all altitudes in the atmosphere and are important for the transport of energy and momentum from one region of the atmosphere to another, to initiate and modulate convection and subsequent hydrological processes, and to inject energy and momentum into the flow. When the gravity wave breaks, the resulting turbulence mixes atmospheric chemicals. These wave-breaking processes occur globally and affect climate of the mesosphere and stratosphere.

These mesoscale–regional scale processes have global significance because of their accumulative effects from the global distribution of various wave sources. The primary challenges to observational, numerical, and analytical studies are how to better quantify gravity wave excitation as it is related to various tropospheric processes, the global distribution of the wave sources, their propagation and breaking, and the multiscale interactions involving gravity waves.

The difficulty in producing the observed Arctic climate change in models may be a result of not including gravity waves in the models. The most likely energy source mechanisms are latent heat release in deep convection and shear instability, in which waves can extract energy from the jet stream when vertical wind shear is sufficiently strong to reduce the Richardson number below 0.25. Alternatively, wave energy loss can be prevented by an efficient wave duct, which appears to be the most prevalent of the three mechanisms described.

Gravity waves are maintained by wave-ducting processes requiring a layer of static stability (the duct depth near the surface), no critical levels (wind moving in the direction of the wave at the same speed) in the lower stable layer that would absorb the wave's energy, and a reflecting layer above the stable layer to keep the wave from losing its energy.

Gravity waves can affect an existing cloud pattern in several ways as they propagate: through modulating the cloud pattern, with the development of wave cloud formations, the wave and cloud can propagate in tandem with little effect on the overall cloud pattern. Convection can generate a broad spectrum of waves, ranging from short-period waves excited by the development of convective cells along a thunderstorm gust front to large wavelength disturbances resulting from the release of latent heat in a thunderstorm complex.

The challenge of including gravity waves in global climate models stems from the resolution ability of computers; with increasing computer power, more complex equations over smaller distances can be resolved to examine gravity waves. Current models often use one of the available gravity wave drag parameters and assume a fixed gravity wave source for proper representation of turbulence on the small scale.

The vast spatial and temporal extent of gravity waves has important implications for the atmosphere from the mesoscale to the global scale and poses a stiff challenge to improving weather and climate predictions at all ranges.

An important part of the National Center for Atmospheric Research mission is to understand the coupling of the lower and upper atmosphere through dynamical, chemical, and radiative processes. Sudden stratospheric warming involves dynamical changes on vastly different scales from the troposphere to the lower thermosphere, and thus provides us an opportunity to understand the coupling process. Further wave source sensitivity studies and observations will help to define gravity wave sources and behavior.

SEE ALSO: Climate Models; Jet Streams; National Center for Atmospheric Research.

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Waves, Internal

AN INTERNAL WAVE is a wave that develops below the surface of a fluid along changes in density. With increased depth, this change may be gradual, or it may occur abruptly at the interface. Similar to the transmission of energy by wind along the surface of the ocean, the density interface beneath the ocean surface transmits energy to produce internal waves. The greater the difference in density between the two fluids, the faster the wave will move.

Internal waves may have a variety of causes, including the tidal pull of water, wind stress, and energy put into the water by moving vessels. Year-round internal waves caused by tidal forces carry between 30 and 50 percent of their energy away from their source. Seasonal (stormy winter months) internal waves caused by wind and storms carry at least 15 to 20 percent of the energy input from their source.

Internal waves reach greater highs (above 100 m., or 328 ft.) from a smaller energy input than do the waves resulting from large energy input at the ocean's surface. This is because they move along interfaces with less density difference than between the ocean surface and the atmosphere.

Internal waves eventually run out of energy and break, similar to surface waves. When they break in the deep ocean, they create turbulence. Where they create this turbulence, heat can be transferred from the upper ocean and stored in the deep ocean, with the exception of the Arctic Ocean, which is warmer in deeper water than on the surface. In the Arctic, turbulence transfers heat from the deep ocean to the surface.

Beneath the surface of the ocean exists a unique weather and climate resulting from the fluctuating currents driving wind in the atmosphere and from deep waves with similar patterns to those on the surface of the ocean—but unable to be seen from the surface—created by the ocean movement caused by the tides.

Internal tide is an internal wave created from the back-and-forth flows of water over geographic features at lower depths. These internal waves radiate away in the form of tide current carrying energy away from the source.

Internal waves are of special interest to climate modeling researchers because heat transfer is one of the roles of the ocean in regulating and changing climate. For example, the amount of heat transferred from the deep ocean in the Arctic will affect the amount of floating sea ice above. In the same way heat from the sun at the equator is transferred to the atmosphere, the upwelling of water enhances the global ocean circulation; otherwise, the depths of the ocean would be much colder and retain nutrients deeper down and away from supporting life or the ability for continuance of the carbon dioxide cycle absorption and release.

Internal waves occur beneath the water's surface. The reflection of light makes it possible to see them from high altitudes.

Internal waves mix and redistribute heat, salt, and nutrients in the oceans; mixing is accomplished more easily in water having uniform density. Most of this mixing occurs where internal waves break, overturning the density stratification of the ocean and creating patches of turbulence. Scientists have observed that the internal wave rates of dissipation and the redistribution of heat and nutrients is 10 percent less near the equator than at midlatitudes. This ocean dynamic would have to be accounted for in climate models.

Researchers are studying internal waves, as determining where internal wave energy might be high and where it might be low will help researchers distinguish between fluctuations in the data record originating from ocean currents and fluctuations resulting from internal waves/tides. Thus, oceanographic instruments can be deployed in oceanographically interesting locations where scientists can quantify the vertical redistribution of heat or assess the potential contribution to climate change and variability.

SEE ALSO: Ocean Component of Models; Oceanic Changes; Oceanography.

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Waves, Kelvin

KELVIN WAVES AFFECTING weather and climate occur in both the oceans and the atmosphere. These low-frequency, gravity-driven waves propagate vertically and parallel to boundaries (e.g., equator, coastline, air masses, and topography). Kelvin waves are nondispersive and carry energy from one point to another. The height or amplitude of a Kelvin wave is highest near the boundary where it propagates; the wave height decreases as the wave moves farther away from the boundary. In the Northern Hemisphere, the waves propagate anticlockwise, and in the Southern Hemisphere, the waves propagate clockwise. The flow of the Kelvin wave balances pressure perpendicular to the boundary by the forces of gravity and the Coriolis effect.

Kelvin waves in the ocean form as coastal waves or equatorial waves, both of which are caused by external forces—often a shift in the trade winds or resulting from temperature variations—and the water inside the Kelvin waves is usually a few degrees warmer than the surrounding water. Kelvin waves may be called external (or barotropic) Kelvin waves if the ocean is homogenous, and internal (or baroclinic) Kelvin waves if the ocean is stratified.

In the Northern Hemisphere, the equatorial waves propagate parallel to the equator and to the east, and the coastal Kelvin waves propagate in a counterclockwise direction, using the coastline for direction. These waves can be between 5 and 10 cm. high and hundreds of km. wide. Kelvin waves tend to move quickly, with a typical speed of approximately 250 km. (155 mi.)/day and can cross the Pacific in approximately 2 months.

The tidal cycles can cause Kelvin waves by the mechanism of a progressive tide wave moving from open ocean into and out of a narrowed body of water. Because of the Earth's rotation, resulting in an anticlockwise direction of current flow inside the channel, flood tides will be greater on the right side of the channel.

The effect on climate results from the Kelvin waves causing a variation in the depth of the oceanic thermocline (the boundary between warm waters in the upper ocean and cold waters in the deep ocean). Because of this variation, Kelvin waves can be used to predict and monitor El Niño activity. In comparison with Rossby waves, which carry water back toward the western Pacific and take as long as a decade to move from the eastern Pacific to the western Pacific, the faster-moving Kelvin waves carry warm water eastward in approximately 2 months.

In the atmosphere near the equator, Kelvin waves travel eastward and may propagate upward to higher altitudes. The formation of Kelvin waves is triggered by mountains, thunderstorm updrafts, and anything that interrupts the normal flow of stable air. The trigger forces the air upward, and the stable air sinks by gravity instead of just returning to normal; when air sinks farther, it causes the wave motion. Kelvin waves cannot happen in unstable air because the motion would just allow the movement of air to continue upward to higher altitudes.

Kelvin waves may propagate in the lower and upper stratosphere and mesosphere. In the lower stratosphere, the eastward-moving Kelvin wave is associated with periods of 10 to 30 days, and in the upper stratosphere, the Kelvin wave is associated with periods of 5 to 7 days. In the mesosphere, the Kelvin wave is associated with periods of 3 to 4 days. These Kelvin waves transport energy and eastward momentum upward and contribute to the maintenance of the eastward flow.

For predicting weather and future climate change, climate models including the COMMA-LIM model can reproduce the Kelvin waves to correlate with how the Kelvin wave acts in the atmosphere. The wave action can also interact with other wave types and the flow of air masses.

SEE ALSO: Climate Models; El Niño and La Niña; Waves, Gravity; Waves, Rossby.

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Waves, Planetary

PLANETARY-SCALE WAVES HAVE their origin relating to the Earth's shape and rotation; the waves are so large that some of them wrap around the whole Earth and can be observed in the atmosphere through the meandering of the jet stream. A long wave or planetary wave is a weather system that circles the world, with one to three waves forming a looping path around the Earth at any given time and displacing air north and south. Planetary waves have ridges (the high points) and troughs (the low points). Warmer upper air is associated with an increasing number of waves or stronger waves.

Planetary waves form in the lowest part of the atmosphere, called the troposphere, and propagate upward, transferring energy into the stratosphere and heating polar air between 9–18 degrees F (5–10 degrees C). Because of a larger landmass, with the majority of the highest mountains and land-sea boundaries in the Northern Hemisphere, planetary waves form more strongly in the Northern Hemisphere. Once the wave dissipates, the polar air begins to cool. In the Southern Hemisphere, landforms also produce planetary waves, although they are weaker there because there are fewer tall mountain ranges and vast open ocean surrounding Antarctica. The warming of the Arctic stratosphere suppresses ozone destruction. Ozone exists in the lower level of the stratosphere and is caused by sunlight splitting the oxygen molecules at cooler temperatures, with less ozone destruction at warmer temperatures.

The Himalayas and other land features create the planetary atmospheric waves that serve to decrease the formation of an ozone hole at the northern pole and therefore limit solar ultraviolet radiation exposure in the Arctic. Climate change could open ozone holes in the Arctic; in the spring of 1997, weak planetary waves created conditions that formed a small ozone hole over the Arctic. The chemistry of ozone destruction requires very cold air temperatures in the stratosphere, and because of planetary wave action, the Arctic stratosphere stays warmer than the Antarctic stratosphere.

In contrast, researchers announced in 1992 that El Niño weather changes and a large number of planetary waves in the atmosphere had caused shrinking of the Antarctic ozone hole, with the ozone hole in September 2002 being half the size it was in 2000. Large-scale weather patterns (similar to the semipermanent area of high pressure) generate more frequent and stronger planetary waves. If the waves are more frequent and stronger as they move from the surface to the upper atmosphere, they warm the upper air. Because ozone breaks down more easily with colder temperatures, the warmer the upper air around the "polar vortex," or rotating column of winds that reach into the upper atmosphere where the protective ozone layer is, the less ozone is depleted.

Researchers working in Esrange, Sweden, studied the main features of planetary waves and variability of the semidiurnal tide, with planetary wave periods observed by meteor radar. They focused observation on 5-, 8- to 10-, 16-, and 23-day planetary waves by meteor radar measurements in the mesosphere and lower thermosphere. In the winter, when the planetary waves are significantly amplified, a very strong periodic variability of the semidiurnal tide is observed as well. This result indicates that the most probable mechanism responsible for the periodic tidal variability during winter is in situ nonlinear coupling between tides and planetary waves. They established a correlation between the planetary wave and semidiurnal tide and secondary waves with frequency, phase, and vertical wavenumber (wavelength) correlation.

The influence of planetary waves on global system dynamics with airflow and temperature distribution include the indirect effect of upper air patterns on lower air patterns through feedback linking all layers of the atmosphere.

Planetary waves (also called Rossby waves) form in the ocean and affect ocean circulation over longer periods of time—from one to 10 years.

SEE ALSO: Waves, Gravity; Waves, Rossby.

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Waves, Rossby

NASA RESEARCHERS AT the Goddard Institute for Space Studies describe Rossby Waves as "slow-moving waves in the ocean or atmosphere, driven from west to east by the force of Earth spinning." These are naturally occurring phenomena first recognized in 1939 by a Swedish-American meteorologist named Carl-Gustav Rossby. These waves, which are found in both the atmosphere and the oceans, are important mechanisms for the redistribution of energy around the globe. In three sections, this essay describes the formation of atmospheric Rossby Waves, oceanic Rossby Waves, and the connection between Rossby Waves and global climate change.

ATMOSPHERIC ROSSBY WAVES

This eponymously named phenomenon was first identified as atmospheric oscillations that occurred in the mid-latitudes in the northern and southern hemispheres. In Europe and North America, people typically experience a Rossby wave as a large cold front plunging southward. The jet stream, guised as a tongue of cold air, dips southward as a large tropical air mass moves northward. The interaction between these air masses, affected by the coriolis affect that intensifies at lower latitudes, generates our changing weather on a day-to-day and week-to-week basis. During televised weather reports, we see North American Rossby waves as the large-scale oscillations of clouds moving from west to east across a continent.

OCEANIC ROSSBY WAVES

Scientists later identified a similar phenomenon at work in the water of all ocean basins. Researchers discovered that oceanic Rossby waves represent a mechanism by which the ocean responds to significant atmospheric "forcing" or wind-related disruption. Rossby waves disperse the atmospheric energy across ocean basins and can be measured through satellite imagery. Because of the impact of the earth's axial rotation and the Coriolis Effect, the oceanic Rossby waves tend to spiral away from the equator in both the northern and southern hemispheres.

ROSSBY WAVES AND CLIMATE CHANGE

Scientists are increasingly interested in Rossby Waves because of the possible connection between these atmospheric and oceanic waves and global warming. An understanding of atmospheric Rossby Waves enabled researchers to effectively study long term temperature fluctuations and provide concrete evidence that global warming was occurring.

Rossby waves can affect entire ocean basins. They also tend to move from the eastern part of the Pacific and Atlantic Oceans towards the west on either side of the equator. A complementary Kelvin wave moves in the opposite direction from west to east along the equator. The multiple axes along which the ocean moves has the ability to disrupt oceanic circulation. Researchers propose that global warming will generate stronger weather events with greater frequency. Because oceanic Rossby waves transmit atmospheric disruptions, the theory is that as storms occur more frequently, the wavelength and frequency of Rossby waves will also change—with a potentially disruptive impact on ocean currents such as the Gulf Stream. A disrupted Gulf Stream could cause cooling at higher latitudes in the North Atlantic.

Researchers also see a connection between changes in Rossby Waves and the intensity of El Niño and La Niña ocean surface water temperature fluctuations in the Pacific Ocean. Also known as the El Niño-Southern Oscillation (ENSO), sea surface temperature increases during El Niño events and decreases in La Niña events can alter or intensify the monsoonal rainfall and hurricane patterns in North and South America. The challenge for climatologists and oceanographers is to understand how disrupted Rossby waves are a cause and consequence of global warming. The broader point is that global climate change is a complex process that involves the interplay between large scale atmospheric and oceanic processes operating at multiple scales.

SEE ALSO: Coriolis Force; El Niño and La Niña; Jet Streams; Rossby, Carl-Gustav; Waves, Gravity; Waves, Kelvin.

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Weather

WEATHER IS THE physical condition or state of the atmosphere at any given time. It is what is happening in the atmosphere at any time or over any short period of time. If there were no atmosphere, there would be no weather. The principal elements of weather are temperature, pressure, winds, moisture, and precipitation. Thus, weather of any place is the sum total of its temperature, pressure, winds, moisture, and precipitation conditions for a short period of a day or a week. Temperature expresses intensity of heat. Unequal distribution of temperature over the Earth's surface causes differences in atmospheric pressure, which causes winds. Moisture is present in the atmosphere as water vapor, often condensed into clouds. It may be precipitated in the form of rain, hail, sleet, or snow. The capacity of air to gather and retain water vapor is largely dependent on its temperature. The higher the temperature, the greater the capacity of air to hold moisture. On cooling, the air is not able to retain all the moisture it gathers while warm. This leads to condensation and precipitation.

Weather is not synonymous with climate. Weather changes from day to day, whereas climate is something more stable, commonly defined as the average weather. Climate is the composite weather conditions over a considerable period of time. Weather conditions can change suddenly. Today may be warm and sunny, tomorrow may be cool and cloudy. Weather conditions include clouds, rain, snow, sleet, hail, fog, mist, sunshine, wind, temperature, and thunderstorms. Weather is driven by the heat stored in the Earth's atmosphere, which comes from solar energy. When heat is moved around the Earth's surface and in the atmosphere because of differences in temperature between places, this makes winds. Winds form part of larger weather systems, the most powerful of which is the hurricane. Other weather features like the thunderstorm also develop because of the movement of heat in the atmosphere. Some thunderstorms result in tornadoes. The Earth's water cycle plays an important role in the development of many weather features such as dew, fog, clouds, and rain.

Weather can be described using terms such as wet or fine, warm or cold, windy or calm. The science of studying weather is called meteorology. Meteorologists measure temperature, rainfall, air pressure, humidity, sunshine, and cloudiness, and they make predictions and forecasts about what the weather will do in the future. This is important for giving people advance notice of severe weather such as floods and hurricanes. Temperature is measured with a mercury thermometer in degrees Celsius. Temperature is the hotness or coldness of an object. Rainfall

Thunderclouds contain a great amount of energy, and the currents of air are strong enough to split apart the raindrops that are forming. This builds up an electric charge, released as lightning. The sound of thunder is the effect of the lightning strike on the air.

is usually measured by collecting what falls in rain gauges and is expressed as a depth of water that has fallen, in millimeters. Wind can be observed with a weather vane, but to measure its speed, more technical equipment is needed. Alternatively, the Beaufort scale can be used to make a judgment of the strength of the wind by observing how it affects objects outdoors, such as trees. The relative humidity and dew point temperature of the air can be determined by making measurements with a hygrometer and reading a table of numbers.

The purpose of a weather map is to give a graphical or pictorial image of weather to a meteorologist. As a forecasting tool, weather maps allow a meteorologist to see what is happening in the atmosphere at virtually any location on earth. Complex three-dimensional models of weather systems can be made by collecting weather data at multiple levels in the atmosphere. Computers then compile that information to produce the pictures that weather scientists analyze. In the early days of meteorology, these pictures were all drawn by hand.

WEATHER PREDICTION AND FORECASTING

Weather affects virtually everyone daily. Human beings live largely at the mercy of the weather. It influences our daily lives and choices and has an enormous effect on corporate revenues and earnings. Weather can be predicted to some degree by observing the state of the sky and the wind. Weather is measured, and forecasts are usually released and used to make important decisions about travels, timing, and so on. Weather forecasts can save lives, reduce damages to property, reduce damages to crops, and tell the public and the global community about expected weather conditions. A forecast is basically predicting how the present state of the atmosphere will change with time. This involves plotting weather information on special charts. Weather radar and satellites are now also used to help predict the weather. Weather forecasters measure the weather so they can forecast it. Temperature, rainfall, wind, clouds, sunshine, and air pressure are measured all over the country, and the information is plotted on special charts. These weather charts have been used by forecasters for many years to predict what the weather will do over the next few days. Weather presenters often show simplified charts on television. Sophisticated equipment is used to help forecast the weather: weather radar can help to show where it is raining over a country, whereas satellites are used to reveal cloud cover and the development of large weather systems. Procedures for collecting and taking the observations are determined by the World Meteorological Organization.

There are a variety of forecasting techniques. The easiest of the techniques is called persistence. In this technique, tomorrow's weather is said to be same as today's weather. Local factors that should be considered when forecasting include clouds and snow. Clouds during the day will decrease the maximum temperature expected. Without the clouds, higher maximum temperatures would be obtained. With snow, the surface stays colder during the day, as less short-wave radiation is absorbed. During the night, radiational cooling effectively cools the surface. If there is some wind, the wind could create mechanical turbulence, which will mix down warmer air to the surface. Hence, winds keep the minimum nighttime temperature warmer than in calm conditions. By looking at cloud movement at different levels, one can infer the type of temperature advection that may be occurring, and therefore atmospheric stability.

Synoptic weather analysis and forecasting began after the telegraph made instantaneous long-distance communications possible after 1850. The invention of radio allowed the extension of the weather observation net over the oceans, and this was one of its first important uses. Every ship became a weather station, radioing reports at regular intervals to a central office. This great advance occurred by 1915, and weather prediction was of great service in Would War I. Significant theoretical advances were made during the middle of the 20th century, especially in the properties of the upper atmosphere, elucidated by such indirect methods as sound propagation and meteor trails.

THE SUN, THE AIR, AND THE WEATHER

The state of the air is important in weather studies. The elements of weather are air temperature, precipitation, cloud cover and sunshine, wind speed and direction, and air pressure. The air in the atmosphere is a mixture of gases consisting of nitrogen, oxygen, water vapor, carbon (IV) oxide, and some rare gases. The amount of water vapor is very important, as it gives us clouds and rain. Clouds are seen in the sky every day. They come in all shapes and sizes and bring with them all sorts of weather. A cloud is simply a visible mass of tiny water droplets that have formed because the air has become too cold at that height to store all its water as invisible vapor. This usually happens when warmer air near the ground is cooled down by rising higher in the atmosphere.

Different types of clouds can be described as they are viewed from the ground, using different terms. A cloud's name generally reflects the height at which it forms, as well as its general shape. The three main types of clouds are cirrus, cumulus, and stratus. Cirrus clouds are wispy in appearance and resemble horsetails. They are formed almost entirely of tiny ice crystals. Cumulus clouds look like fluffy balls of cotton wool. These can sometimes grow much larger, becoming cumulonimbus clouds, which bring heavy bursts of rain during thunderstorms. Cumulus clouds are clouds of vertical development and may grow upward dramatically under certain circumstances. Another type of cumulus cloud is the altocumulus cloud, which sometimes resembles fish scales. They sometimes have dark, shadowed undersides. Stratus clouds are layer clouds that form near the ground and make the weather very grey and dreary, and sometimes rainy. Stratus clouds form flat layers or uniform sheets. Only a fine drizzle can form from stratus clouds because there is no vertical development.

Air usually contains some water in the form of moisture called dew. The water is hardly seen, as it is like a gas. Humid air contains more moisture than dry air, but when the temperature of air falls, its ability to hold moisture decreases. If the temperature drops low enough, air can become saturated, even if it was originally much drier at the warmer temperature. At this point, excess moisture begins to condense, forming small water droplets on the ground called dew. As an air mass cools, it can hold less and less water vapor. If it cools down enough, it reaches a point at which the water vapor present in the air mass represents the amount needed to saturate an air mass at the lower temperature. The temperature at which saturation occurs is the dew point. The dew point depends on the amount of water vapor in the air. In winter, the temperature may fall below freezing. If dew has formed on the ground, it will freeze, forming white crystals called frost.

When the temperature of air close to the ground falls low enough, dew will form. If a larger layer of air is cooled, the condensation of excess moisture in the air forms a mist of tiny water droplets known as fog. Fog is common in the autumn and winter and usually forms when there is little or no wind to disturb it. It is also more common in hollows and valleys, where the air tends to be a little colder because it is heavier and sinks down into these places. Fog is least likely on hilltops, unless low clouds have descended to cover them.

The major driving force behind the weather is the sun. Energy from the sun is stored in the atmosphere as heat. When this heat is moved around, it makes the weather. The equator is much hotter than the poles because it receives much stronger sunlight. There is more heat stored in the atmosphere nearer the equator. Heat, however, likes to flow from warm to cold temperatures. More heat is also stored nearer the ground. This makes the air lighter than that above it, and it rises. When air rises, its temperature falls, which makes weather features such as clouds and rain.

SEVERE WEATHER

The greater part of Europe often experiences bad weather, particularly in winter. Bad weather usually comes in from the Atlantic Ocean with weather systems called depressions—regions of low pressure, strong winds, and rain. In the tropics, bad weather is much less common, but when it strikes, it can be devastating. Large tropical storms, which usually develop toward the end of summer, are called hurricanes. The most common place for hurricanes to form is in the Caribbean. Here, seawater temperature is high because the sunlight is strong, and a lot of heat is stored there. Under the right conditions, a storm will develop, which, with sufficient energy, will become a hurricane. Viewed from a satellite, a hurricane appears almost circular, with clouds spiralling out from a small center. On the ground, the weather in the center may be fairly calm, with clear skies, but as the hurricane moves over, the weather can become very nasty, with winds of over 100 mi. (161 km.) per hour that are strong enough to tear roofs off houses.

Heavy rain, dark black clouds, and lightning are evidence of a thunderstorm. Thunderstorms are not nearly as strong as hurricanes, but they can be damaging, particularly if large hailstones fall out from their clouds. Thunderclouds are known scientifically as cumulonimbus clouds. Thunderstorms are more common in summer because they need a lot of energy to form. The energy comes from the heating of the ground and the surface air by the sun. If this heating is strong enough, air heated near the ground will rise up a long way into the atmosphere because it is lighter than the air around it. Warmer air is lighter than colder air. As the air rises up, it becomes colder. Moisture in the air begins to condense out as clouds, in the same way as fog forms on a calm, cool night. In thunderclouds, however, the energy is much greater, and the currents of air are strong enough to split apart the raindrops that are forming. This builds up an electric charge, which, when released, is seen as lightning. The sound of thunder is the effect of the lightning strike on the surrounding air. When rain or hail begins to fall from a thundercloud, it is usually very heavy, but it generally lasts no more than 30 minutes. Sometimes, however, the death of one thunderstorm may lead to the development of another, and the bad weather may continue for several hours.

A rapidly spiralling column of air is called a tornado. Large thunderstorms develop because there is an awful lot of energy stored in the atmosphere. Some large thunderstorms give birth to tornadoes. The tornado is usually very small in comparison to the thunderstorm, but it can wreak terrible havoc across the small area over which it moves. At a distance, a tornado is seen as a rapidly rotating funnel or spout of air, usually colored grey because of clouds and earth debris caught up inside it. The strongest tornadoes can have wind speeds of over 250 mi. (402 km.) per hour—and sometimes over 300 mi. (483 km.) per hour.

Most water on earth is in the oceans. A little, however, is contained by air in the atmosphere. The water in the atmosphere is usually not seen except when it rains, as it is in the form of moisture or vapor. Water enters the atmosphere by evaporating from the surface of the oceans, lakes, and other liquid water bodies. At higher levels in the atmosphere, the air is colder, and moisture begins to condense out as fine droplets, which we see as clouds. When conditions are right on the ground, the same process forms fog. Eventually, water in clouds forms rain, hail, sleet, or snow, which falls back to the ground. This movement of water from the earth to the atmosphere and back again is called the water cycle. The water cycle is responsible for much of the world's weather.

SEE ALSO: Atmospheric Composition; Clouds, Cirrus; Clouds, Cumulus; Clouds, Stratus Rain; Thunderstorms.

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Weather World 2010 Project

DEVELOPED BY THE Department of Atmospheric Sciences (DAS) at the University of Illinois Urbana-Champaign (UIUC), the Weather World 2010 project (WW2010) is a WWW framework for integrating current and archived weather data with multimedia instructional resources, using new and innovative technologies. The project focuses on many different manifestations of global warming such as hurricanes, clouds and precipitation, and El Niño. The accuracy of the instructional resources on the website has been reviewed by professors and scientists from the DAS at the UIUC and at the Illinois State Water Survey.

Weather World 2010 is the result of a long process dating back to January 1993, when Dr. Mohan Ramamurthy and programmer John Kemp created the Weather Machine. This resource allowed users to view weather images through a gopher server. At the same time, Steve Hall started to devise instructional modules in HyperCard for use by the educationally motivated Collaborative Visualization (CoVis) Project, a project that strives to promote project-based science learning. The advent of the first Web browser Mosaic marked the birth of a new medium for the exchange of information on the internet. As a result, efforts were made to place both weather and educational resources into HTML format. This conversion transformed the original Weather Machine products into the Daily Planet, which was created in 1994. This first attempt to realize a World Wide Web product was a success, and it soon became a popular site for many to browse.

Meanwhile, Mythili Sridhar and Steve Hall converted the HyperCard-based educational modules to HTML so that they could be used on the Web. The people working on the project soon became aware of the necessity of integrating weather data with explanatory and educational material. This led to the creation of the CoVis-sponsored Electronic Textbook, later named the Online Guide to Meteorology, in 1995. This server became an extremely useful location for users to learn about weather with archived data for examples. The CoVis also provided the Geosciences Web Server, a useful resource allowing users large collections of links to all sorts of weather information, as well as educational material.

In the summer of 1995, the team of researchers released the Weather Visualizer, which became one of the most successful attempts to integrate real-time weather and instructional material. It allowed users to customize their own weather maps and to get explanations about difficult or technical terms. Seeing the rising popularity of HTML and newer technologies such as Java, fall 1995 witnessed the creation of the Image Animator and the Interactive Weather Report—a couple of the first Java weather tools on the Web. Thanks to real-time instant access to weather data using Java applets, these tools allowed an increased level of educational interactivity.

The first discussions of a dynamic framework for hypermedia and CD-Web interactivity started to take place in the early months of 1996. Such discussion was prompted by the difficulties experienced by CoVis teachers in accessing the large volume of information within the educational modules. Often, their connections were too slow to effectively use the resources in their classrooms. The desire to improve and redesign the existing resources, including developing better graphical interfaces and navigation systems, prompted Steve Hall and Dave Wojtowicz to begin the construction of the early form of Weather World 2010 in May 1996. This project soon grew into a much larger task than was initially conceived: rather than a simple improvement, this new project was to provide a new framework to support the preexisting modules and allow users access to weather data and information. In October 1996, the project was presented to the students, faculty, and staff of the Department of Atmospheric Sciences at the University of Illinois. The project drew on the different expertise of the many volunteers that it managed to involve, and in return, it provided them with a chance to learn HTML. Since October 1996, nearly 20 people have volunteered for a variety of tasks: writing scripts to generate image products, developing helper sections to describe images and fundamental concepts, creating instructional modules, and participating in design input and performance testing.

Initially, the team of WW2010 spent considerable time browsing the internet, finding the most appealing features of available websites, and incorporating some of these features into the server. Although Java and other new technologies are opening up exciting possibilities, the researchers of WW2010 remain concerned with allowing easy access to large sets of data and instructional materials and efficient navigation. WW2010 is an example of how new and innovative technologies can be used to visualize some of the effects of climate change and global warming on our lives.

SEE ALSO: Climate Change, Effects; Global Warming; University of Illinois; Weather.

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Western Boundary Currents

WESTERN BOUNDARY CURRENTS are intense jet currents at the western periphery of large-scale oceanic gyres in the World Ocean. As was shown in the pioneer paper of Henry Stommel in 1948, they are the result of two causes: the so-called β-effect (this term has arisen from traditional representation of Coriolis force, f, in the following form: $f = f_0 + \beta y$, where f_0 is a Coriolis parameter at a definite latitude; in other words, the β-effect is to the result of the spherical form of the Earth turning around its axis), and low conservation of absolute vortex for the oceanic motions.

Oceanic gyres are forced by horizontally inhomogeneous large-scale wind fields (or wind vorticity). For instance, in the North Atlantic Ocean, anticyclonic subtropical gyre is situated under northeastern trade wind and midlatitude westerly wind as a result of clockwise wind vorticity, whereas north tropical cyclonic gyre is a result of anticlockwise wind vorticity between the Intertropical Convergence Zone and the northeastern trade wind. Currents in the western part of each gyre are more intense than in the eastern part because this is dictated by low conservation of absolute (relative plus planetary) vortex.

Each particle moving northward (southward) gets an additional (loses) planetary vorticity as a result of the spherical form of the Earth. In the clockwise gyre, this should be compensated for by the increasing relative negative vorticity, that is, by the intensification of clockwise rotating. In the anticlockwise gyre, this should be compensated by the increasing of relative positive vorticity, that is, by the intensification of anticlockwise rotating. In both cases, this leads to intensification of currents in the western periphery of the basin. In the eastern part of gyres, all particles move in the opposite direction, in comparison with the western part. It leads to the weakening of circulation in the eastern gyres' end.

The β-effect may be also understood in terms of Rossby waves. Actually, long, nondispersive Rossby waves carry (kinetic) energy from the east to the west within each gyre. After their reflection from the western boundary of the basin, the short dispersive Rossby waves are generated and move to the east. However, the short Rossby waves are dissipated in the relatively narrow vicinity of the near-coastal zone as a result of their shortness and dispersive properties, which lead to more affective realization of dissipative processes. Thus, the kinetic energy of the planetary Rossby waves is accumulated in the vicinity of the western periphery of the gyres.

In fact, western boundary currents (especially in the Atlantic Ocean) are also controlled by thermohaline factors. The β-effect affects thermohaline circulation and causes the intensification of the thermohaline currents in the western part of the basin. Deep thermohaline currents in the North Atlantic Ocean (generating in the region of sinking of Deep Atlantic Ocean Water and spreading at the depths between 1.5 and 2.5 mi., or 2.5 and 4 km.) are southward, whereas compensative thermohaline currents in the upper baroclinic layer (between the surface and 0.6 and 1.2 mi., or 1 to 2 km.) are northward. As a result, the wind-driven northward Western Boundary Currents in the clockwise gyres intensify, and southward ones in the anticlockwise gyres weaken as a result of meridional thermohaline circulation.

The most intense Western Boundary Currents in the Northern Hemisphere are the Gulf Stream, Labrador Current, North Brazil Current (Atlantic Ocean), Kuroshio (Pacific Ocean), and Somali Current (Indian Ocean). The velocity in these currents' axes reaches or even exceeds 6.5 ft. (2 m.) per second. Detailed analysis of the structure and origins of Western Boundary Currents (e.g., the Gulf Stream) was done by Henry Stommel in 1958 and 1966.

Western boundary currents in the North Atlantic Ocean carry up to about 100 Sv (1 Sverdrup = 10^6 cu. m. per second) of water in the upper baroclinic layer. The wind vorticity accounts for about 30 to 60 Sv (30–60 multiplied by 10^6 cu. m. per second). The average power of source of Deep Atlantic Ocean Water is about 20 Sv (20 multiplied by 10^6 cu. m. per second). So, the joint effect of wind vorticity and meridional thermohaline circulation can explain up to 80 percent of observed transport of the western boundary currents in the North Atlantic Ocean.

Western boundary currents are meandered jets that generate the intense mesoscale eddies, the so-called rings. The typical horizontal size of rings is about 62 mi. (100 km.), and orbital velocity is 3.3 to 6.5 ft. (1 to 2 m.) per second. Rings trap the water in their central part and carry it with a typical speed of about a few centimeters per second. The lifetime of the rings may reach 4 years. Thus, mesoscale eddies account for a significant portion of volume transport in the vicinity of Western Boundary Currents. Recirculation of the Gulf Stream is one of the integral manifestations of mesoscale effects.

SEE ALSO: Coriolis Force; Gulf Stream; Intertropical Convergence Zone; Kuroshio Current; Stommel, Henry; Thermohaline Circulation; Waves, Planetary; Waves, Rossby; Wind-Driven Circulation.

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Western Regional Climate Center

THE WESTERN REGIONAL Climate Center (WRCC), based in Reno, Nevada, and inaugurated in 1986, is one of six regional climate centers in the United States. The regional climate center program is administered by the National Oceanic and Atmospheric Administration. Specific supervision is provided by the National Climatic Data Center of the National Environmental Satellite, Data, and Information Service.

The mission of the Western Regional Climate Center is to disseminate climate data and information of the highest standards pertaining to the western United States; promote better use of this information in policymaking; carry out applied research related to climate issues; and improve the coordination of climate-related activities at the state, regional, and national levels. The center receives queries from lawyers, media, insurance companies, different businesses, teachers and students, contractors, the Forest Service, state and local government, and individuals interested in weather observation.

The data collected by the center include daily climate observations for a digital period of record (6,781 stations, about 2,608 now active), summarized monthly climate data (5,240 stations), hourly precipitation data (1,937 stations), upper air soundings recorded twice a day (about 50 stations), surface airway hourly observations (over 1,800 stations nationwide). In addition, the center provides access to these databases: remote automatic weather station, historic lightning data though 1996, access to Natural

Resources Conservation Service SNOTEL (SNOwpack TELemetry), and other western databases.

The WRCC coordinates the work of federal resource management agencies and western committees and commissions. It liaises with other centers and programs such as the National Climate Data Center in Asheville, North Carolina; regional climate centers; state climatologists and state climate programs; the Climate Analysis Center, Washington D.C.; and the National Weather Service. Its main areas of research include the effects of climate variability in the western United States, the quality control of western databases, the relation of El Niño/Southern Oscillation to western climate, the climatic trends and fluctuations in the West, geographic information systems, and remote sensing. It is also the home of the regional climatologist.

Although the WRCC is concerned with some of the most evident phenomena of global warming, such as the effect of El Niño on western climate, the climatologists at the center do not agree on a single definition of global warming. For example, in July 2007, Jim Ashby, one of the WRCC climatologists, challenged the credibility of weather data collected by weather stations, as they are often moved. Even moving the weather station just few hundred yards could make a difference in temperature and moisture, Ashby maintained, creating a situation in which data belonging to different areas are compared. This comparison of inhomogeneous data would be, according to Ashby, the same as comparing apples and oranges. Ashby has also stressed that even stations that remain in the same place can have changing circumstances that alter weather readings.

Atmospheric readings can be altered by the surroundings (the presence of trees favors cooler temperatures, whereas new buildings and more roads and rooftops retain more heat). Ashby takes Reno, where the Western Regional Climate Center is situated, as a classic example of a place where weather is being changed by urbanization. Average low temperatures in town have risen about 10 degrees (5 degrees C) in the last 20 years. "Most of the warming is due to the fact Reno is growing like a weed," Ashby argued. "The weather station used to be out in a field somewhere. Now it's surrounded by asphalt." This line of reasoning comes dangerously close to that of global warming contrarians, who say that all the moves and changes at weather stations have affected the validity of the climate record.

Another climatologist at the center, Kelly Redmond, has instead pointed out the visible effects of global warming on the vegetation of the region. Western states are heavily dependent on snowpack for their flora. Melting snow provides three-fourths of the water in streams. Over the past 35 years, temperatures across the region have risen from 1–3 degrees F (0.5–1.6 degrees C), causing the snow to melt as much as three weeks earlier and leading to widespread droughts.

SEE ALSO: Climate Change, Effects; Nevada; Weather.

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West Virginia

WEST VIRGINIA HAS the 37th largest population of America's 48 contiguous states and is the 20th largest emitter of carbon dioxide. The past century has seen an average temperature increase of 1.1 degrees F (degrees C) in Charleston, the state's capital, and an average precipitation increase of 10 percent across the state. Scientists predict that if the climate continues to rise, there could be an increase in the number of thunderstorms and extremely hot days. By 2100, average temperatures in winter, spring, and summer could be 3 degrees F (1.6 degrees C) warmer than at present, and autumn temperatures could be 4 degrees F (2.2 degrees C) higher. Precipitation could also be significantly higher.

Rising temperatures have the potential to alter the state's natural environment, particularly the topography of its forests. The exact effect of a warmer climate on forests, which constitute 97 percent of the state's land mass, is unknown. If average rainfall decreases in the coming years, forests could shrink by as much as 10 percent, and grassland will appear where trees once stood. In contrast, a combination of warmer temperatures and increased rainfall could support the growth of tree species that thrive in such conditions, such as oaks and pines, and create much denser forests. Changes to the state's forests would have significant implications for the plant and animal species that rely on forests for their survival. Hares, red squirrels, and the northern flying squirrel are particularly at risk, as their habitats are concentrated in mountain forests, thus making it impossible for them to move to higher altitudes. Significant climate change over the next century could potentially eradicate some or all of West Virginia's high-altitude forests. The state's most expansive forest, the Monongahela Forest, is one such example.

The state's water supply, much of which originates from groundwater such as lakes and rivers, could also be affected by hotter weather. Much of the state lies at a high altitude, and an earlier spring would cause water levels to rise as a result of melting snow. Higher water levels may cause problems such as flooding, property damage, and erosion. Summer droughts, which already have an effect on water supplies, could cause rivers and lakes to dry up entirely, cutting off water to a substantial portion of the state's population. At present, nearly all the rural population and around half the urban population are supplied by groundwater. Receding water reserves could exacerbate problems such as acid and sludge drainage from abandoned coal mines and increase concentrations of bacteria and feces in the water supplied to homes and businesses. Low water supplies would also affect the tourist industry by limiting the opportunities for sports such as white-water rafting.

A warmer climate in West Virginia could also change patterns of farming and agriculture. Less rainfall would reduce soil moisture and create the need for irrigation—a practice that would divert water from homes and communities. Alternatively, it could push agriculture to the northern reaches of the state. More sun and less rain could increase yields of hay, the state's main crop, by as much as 30 percent, but at the same time it would destroy arable pasture used for livestock grazing. In turn, livestock farming would be less profitable, because animals would not yield as much meat.

If climate change continues, it will create health risks for the inhabitants of West Virginia. Heat-related deaths and illnesses would likely increase, particularly among elderly people living alone. The increase in ground-level ozone that would result from warmer temperatures could potentially lead to more incidences of respiratory illnesses such as asthma and impaired lung function. Ticks and certain species of insect would be more able to thrive and spread diseases such as dengue fever in a warmer climate. Mosquitoes would be especially adept at surviving and would likely spread malaria, a disease that does not naturally exist in the state, and California encephalitis, a lethal disease that causes neurological damage. Higher rainfall, another possible consequence of climate change, could facilitate the transmission of water-borne illnesses such as giardia, crypto-sporidia, and bacterial gastroenteritides.

The state faces specific policymaking challenges to address the possible consequences of climate change.

SEE ALSO: Agriculture; Forests; Rain; Rainfall Patterns.

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Wind-Driven Circulation

WIND-DRIVEN CIRCULATION (WDC) refers to ocean currents initiated and propelled by winds blowing across the surface of the ocean. Wind-driven circulation is part of the complex system of energy and heat redistribution that helps to draw tropical heat away from equatorial regions to moderate the earth's climate.

WIND GENERATION

Wind is caused by the uneven solar heating of the Earth's surface, which creates areas of high and low atmospheric pressure. Pressure differentials cause air to circulate from areas of high to low pressure. Solar heating is greatest near the equator, causing a region of low pressure. Rising air moves northward as cooler air from high pressure, mid-latitude regions moves towards the equator. The Coriolis Effect, the rotational action of the earth spinning on its access, deflects the winds towards the east north of the equator and to the west south of the equator. This explains why prevailing winds in the midlatitude northern hemisphere come from the west.

OCEANIC CIRCULATION

An understanding of wind generation helps to explain the operation of ocean currents. There are two general types of ocean circulation and both result from solar heating: (1) WDC, and (2) thermohaline circulation (THC). Differential solar heating generates wind. Wind blowing across the surface of the ocean causes the water to move. The direction of the ocean current is determined in part by the direction of the prevailing winds at a given latitude. WDC is responsible for currents near the ocean's surface.

THC drives deep-water ocean currents and vertical movement of water. THCs occur as water density increases, either through cooling as water moves towards the poles, or because of increased salinity. In both cases, the THC is responsible for carrying warmer surface water to the ocean depths.

There is an interplay, then, between the WDCs and THCs that is exemplified in the Gulf Stream that moves warm water from the Caribbean in a northeasterly direction, along the eastern seaboard of North America, towards northern Europe. As WDCs carry water away from the tropics, the water cools and becomes more saline. It consequently becomes more dense, which causes it to sink along a THC. This mechanism whereby warm surface water is transported towards the poles, descends as it becomes cooler, to be re-circulated southward as cool deepwater currents is sometimes referred to as the North Atlantic conveyor.

GLOBAL WARMING AND THE INTERPLAY OF WDCS AND THCS

The Gulf Stream starts as a WDC because it gets its initial energy from the trade winds. Global warming could affect the Gulf Stream in two ways. The first, and more widely reported mechanism occurs because global warming could melt arctic ice, decreasing sea salinity. This will in turn hinder the ability of the water to descend as part of the THC. The end result is the cooling of northern latitudes.

Global warming could also affect the initial forcing of the Gulf Stream. Some researchers suggest that global warming will disrupt and weaken the trade winds. Diminished trade winds means less energy driving the Gulf Stream northward, also contributing to a cooler climate at high latitudes. This could cause dramatic cooling in northern Europe which needs the North Atlantic Conveyor to moderate its climate. The paradox is that global warming could ultimately cause regional cooling in some parts of the world by affecting both the THCs and WDCs.

SEE ALSO: Coriolis Force; El Niño and La Niña; Jet Streams; Trade Winds; Winds, Easterlies; Winds, Westerlies.

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Winds, Easterlies

WINDS ARE DEFINED by their origins. The "easterly" descriptor refers to winds with an easterly zonal component (coming from the east). These include northeasterly and southeasterly winds. Easterly winds occur at all atmospheric scales, including local and synoptic. However, the term "easterly winds" generally refers to large-scale belts of winds operating within the global circulation of the atmosphere.

In the atmosphere's general circulation, two distinct bands of easterly winds exist: the trade winds and the polar easterlies. They are found at low and high latitudes, respectively, and arise from the dynamics of air flow among pressure systems.

Among the most consistent winds on earth, the trade winds (or trades) are part of the Hadley cell circulation found from approximately 0 degrees to 30 degrees north and south of the equator. Air rises near the equator as a result of a combination of convection spurred by intense solar radiation and the low-level convergence of wind in a circumpolar zone called the Intertropical Convergence Zone. As the rising air approaches the tropopause, it turns. At approximately 30 degrees, the air subsides, or sinks, resulting in the belt of persistent subtropical highs. Air diverges out of these anticyclones and flows toward the equatorial low. This outflow of air gives rise to the trades. As the air moves toward the equatorial low, it is deflected as a consequence of the Coriolis force (or effect). This deflection results in northeasterly trade winds in the Northern Hemisphere and southeasterly trades in the Southern Hemisphere. The trade winds are also referred to as tropical easterlies, particularly when the associated vertical wind shear is large.

The polar easterlies, a belt of winds found from approximately 60–90 degrees in each hemisphere, constitute another component of the general circulation. These winds originate from dynamics similar to those of the Hadley cell. Thermally driven high pressure exists at the poles; similarly, a circumpolar zone of low pressure is found near 60 degrees. As air flows from the polar high to the subpolar low (as a result of the presence of a pressure gradient), it is deflected. This deflection leads to a belt of easterly winds in both Northern and Southern hemispheres.

Rising air over the western tropical Pacific, with sinking air over the eastern tropical Pacific, comprises the Walker air current. The trades, as part of the Walker circulation, push warm surface waters toward the west.

Any weakening of the trades, then, would disrupt this oceanic transport of water. This dynamic is similar to an El Niño, in which the trade winds slow and even break down. Recent research suggests that climate changes, specifically global warming, would weaken or slow the trade winds. Indeed, the Walker circulation has already diminished by 3.5 percent since the 1800s. This slowing is projected to continue, and much of this change is attributed to anthropogenic activity.

The culprit in the slowing trade winds is the balance between evaporation and precipitation. To maintain a balance, the atmospheric absorption of moisture must be balanced by its release by precipitation. Water vapor, transported west by the trade winds, is precipitated out over the western Pacific. Warmer temperatures, then, spur the absorption of additional water vapor by enhancing evaporation rates. However, precipitation rates increase more slowly. To balance these processes, wind flow must decrease.

Weakened trade winds would result in numerous consequences, including the disruption of normal weather and climate patterns, as well as suppressed oceanic upwelling and potentially reduced biological productivity. The latter would have important economic ramifications, particularly for the Pacific fishing industries.

SEE ALSO: El Niño and La Niña; Walker Circulation; Winds, Westerlies.

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Winds, Westerlies

THE WESTERLIES ARE the prevailing winds in the middle latitudes blowing from the subtropical high pressure toward the poles. The westerlies originate as a result of pressure differences between the subtropical high-pressure zone and the subpolar low-pressure zone. The westerlies curve to the east because of the Coriolis effect, caused by the Earth's rotation. In the Northern Hemisphere, the westerlies blow predominantly from the southwest, whereas in the Southern Hemisphere, they blow predominantly from the northwest. The equatorward boundary is fairly well defined by the subtropical high-pressure belts, whereas the poleward boundary is more variable. The westerlies can be quite strong, particularly in the Southern Hemisphere, where less land causes friction to slow them down. The strongest westerly winds typically occur between 40 degrees and 50 degrees latitude.

Winds transport heat from warmer areas to cooler areas and help the Earth to maintain equilibrium of its thermal environment. In the midlatitude, the westerlies play a big role in the weather and atmospheric circulation in the middle latitudes. They transport warm, moist air to polar fronts and are also responsible for the formation of extratropical cyclones. In winter, they collect warm, moist air from over the oceans, move it to the cooler continents, and bring heavy rainfall to the areas like the northwest coast of the United States. In summer, they collect hot, drier air from over the continents and move it to the oceans.

Does global warming influence westerlies? A recent study of westerlies in the Southern Hemisphere shows that the westerlies are shifting southward, toward Antarctica. No conclusion has been made yet, however. Some scientists believe that recent observations are related to global warming, but others think of them as a part of natural variations. North Atlantic Oscillation (NAO) is one indicator that shows the relationship between global warming and westerlies. NAO is calculated by the difference in pressure between the permanent low-pressure system located over Iceland (Icelandic Low) and the permanent high-pressure system located over the Azores (Azores High). Global warming can reduce the difference in pressure between the two places. At a high NAO index, a large pressure difference between the two places induces stronger westerlies flow. Storm tracks advance northward, and Europe experiences milder winters but more frequent rainfall in central Europe and nearby. At a low NAO index, with suppressed westerlies, storm tracks move more toward the Mediterranean, which results in colder winters in Europe and southern Europe and in North Africa receiving more storms and higher rainfall.

El Niño–Southern Oscillation (ENSO) is another indicator. In winters of El Niño years, the polar jet stream in the Northern Hemisphere moves farther poleward and brings warmer winter weather to the northeastern part of the United States. In the winter of 2006 to 2007, the warming induced was about 9 degrees F (5 degrees C), which was as much as five times the typical air temperature increase compared with a warming in a typical El Niño year. Changes in both surface and upper-level westerlies resulting from El Niño patterns can also influence the development, intensity, and track of hurricane over the tropical Atlantic Ocean. In fall 2006, El Niño strengthened the upper-level westerlies, increased wind shear, and discouraged tropical cyclogenesis over the tropical Atlantic. Whether or not global warming is behind these stronger El Niño patterns is still being researched. A recent climate model (Joellen L. Russell et al., 2007) indicates that westerlies influence the temperature of the Southern Ocean. According to the model, the southward movement of the Southern Hemisphere westerlies in recent years transfers more heat and carbon dioxide into the deeper waters of the Southern Ocean. This poleward shift of the westerlies has intensified the strength of the westerlies near Antarctica. The pattern could slow down global warming somewhat but also induce ocean levels to rise in Antarctica.

How global warming influences the westerlies still remains in question. The recent observation, however, suggests that global warming brings noticeable change in the westerlies.

SEE ALSO: Climate Change, Effects; Winds, Easterlies.

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Wisconsin

WISCONSIN IS 65,498 sq. mi. (169,639 sq. km.) in size, with inland water making up 1,830 sq. mi., (4,740 sq. km.), and Great Lakes Coast water of 9,358 sq. mi., (24,237 sq. km.). Wisconsin's average elevation is 1,050 ft., (320 m.) above sea level, with a range in elevation from 579 ft., (176 m.) above sea level on Lake Michigan to 1,951 ft., (595 m.) at Timms Hill. Wisconsin is customarily divided into two major natural regions: the Central Lowland (low-lying area and swings in a broad belt across the southern two-thirds of Wisconsin) and the Superior Upland (higher elevation, forest cover, and numerous small glacial lakes). A low-lying and partially swampy plain, known as the Lake Superior Lowland, occupies the areas along the southern shore of Lake Superior. Wisconsin's rivers drain into either the Mississippi River system or the Great Lakes–St. Lawrence system. The Mississippi River forms part of the border with Minnesota and the entire border with Iowa. Wisconsin has many lakes and a few reservoirs.

Weather in Wisconsin varies greatly from winter to summer, with bitter cold and lots of snow in winter and warm and humid summers. This type of climate is called temperate continental. Three different types of air masses affect Wisconsin. The continental polar air masses from the northwest bring bitter cold, dry weather in winter. The maritime tropical gulf air mass from the Gulf of Mexico brings high humidity and heat in summer. The maritime polar Pacific air mass can bring more moderate weather straight from the west any time during the year. Wisconsin's weather is also affected by the Great Lakes on its northern and eastern sides by their moderating of the weather in the coastal areas, which are warmer in winter and cooler in summer than the rest of the state. Residents of shoreline cities get lake-effect snow (perhaps several inches, while 30 mi. (48 km.) inland, the sky is sunny and nobody needs to shovel). The annual precipitation is 31 in (79 cm.). The southern counties get about 30 in. (76 cm.) of snow each winter, and the annual snowfall in Iron County to the north can be as much as 100 in. (254 cm.). The highest temperature recorded in the state is 114 degrees F (45.5 degrees C) on July 13, 1936, and minus 55 degrees F (13 degrees C), on February 4, 1996, is the lowest temperature recorded in the state.

Wisconsin is a Corn Belt state, and corn is its major crop. Other leading crops are soybeans, hay, sweet corn, potatoes, cranberries, and oats. Major industries include dairy products, corn, hay, and beef. Wisconsin takes advantage of Lake Michigan for commercial fishing, though it is only a small industry in the state. Important species are whitefish, lake trout, perch, chub, alewife, and carp. Forestry is a minor industry, with most hardwood cut going to plywood and veneer manufacture; the pulp and paper industry consumes much of the softwood harvest. Wisconsin's mineral output is limited to stone, sand and gravel, copper, lime, lead, and talc.

Canadian geese seeking refuge in the comparatively warm water temperature during -20°F weather in Mequon, Wisconsin.

Wisconsin experienced a sample of possible effects of climate change with the Great Flood of 1993, when rain and snow runoff raised the Mississippi River along with other rivers and small streams. Madison reported 21.49 in. (54.5 cm.) of rain. Signs of global warming are apparent throughout the Great Lakes. Over the past 150 years, the average extent of ice cover on many of Wisconsin's lakes has continuously declined.

Although climate models vary on the amount of temperature increase during the 21st century, ranging from 8–7 degrees F (4.4–3.8 degrees C), the average summer water level in the Great Lakes could drop 1.5–8 ft. (0.4–2.4 m.) by the end of the century, and extreme 100-year floods (named because they happen once every 100–200 years) could begin to occur on a much more frequent basis. With extreme floods and higher temperatures, Wisconsin could experience more drought conditions as a result of increased evaporation, and reduced soil moisture may force farmers to rely more on irrigation.

Possible effects from increased temperatures include decreased water supplies; changes in food production, with agriculture improving in cooler climates and decreasing in warmer climates (Wisconsin farmers could see an increase in demand for corn-based ethanol); changes in rain pattern to downpours, with the potential for flash flooding and health risks of certain infectious diseases from water contamination or disease-carrying vectors such as mosquitoes, ticks, and rodents; warmer temperatures can cause heat-related illnesses and lead to higher concentrations of ground-level ozone pollution causing respiratory illnesses, especially in cities with smog, like Milwaukee.

On the basis of energy consumption data from EIA's State Energy Consumption, Price, and Expenditure Estimates, released June 1, 2007, Wisconsin's total CO_2 emissions from fossil fuel combustion in 2004 were 107.05 million metric tons, made up of contributions from commercial (5.67 million metric tons), industrial (16.67 million metric tons), residential (10.02 million metric tons), transportation (30.57 million metric tons), and electric power (44.13 million metric tons).

Wisconsin established the Task Force on Global Warming in April 2007 to understand emissions impacts, determine modeling scenarios, and define the sensitivities that will need to be run to establish reasonable ranges of outcomes for confident decision making by Wisconsin legislators. Wisconsin joined the Climate Registry, a voluntary national initiative to track, verify, and report greenhouse gas emissions, with acceptance of data from state agencies, corporations, and educational institutions beginning in January 2008.

Wisconsin lawmakers have enacted a minimum renewable electricity standard that requires utilities to provide 22 percent of the state's power from renewable sources by 2011. To meet this goal, the Wisconsin Public Service Corporation installed 14 wind turbines in Kewanee County that are expected to provide enough electricity for 3,600 homes and generate tax revenue. The National Renewable Energy Laboratory also estimates Wisconsin as having the solar potential to provide electricity generation.

The Wisconsin Department of Natural Resources is the agency responsible for carrying out state conservation programs. Reforestation, soil erosion, and wildlife management are the principal concerns of conservationists in Wisconsin.

SEE ALSO: Climate Change, Effects.

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THE WOODS HOLE Oceanographic Institution (WHOI), a world-renowned private, not-for-profit organization founded in 1930, is the largest independent oceanographic research institution in the United States. WHOI is committed to higher education and scientific research that furthers the understanding of the world's oceans and their role within the Earth's ecosystem as a whole. In addition, WHOI disseminates its research findings and information to the public and policymakers to foster understanding and decisionmaking for the greater good of society. At any given moment, more than 350 projects are in progress around the world, representing a wide range of scientific inquiries, in which collaboration and creativity are highly valued and encouraged.

WHOI recruits distinctly qualified scientists, engineers, staff, and students and provides an interdisciplinary and flexible setting in which students, as future scientists and engineers, can thrive. The research activities of the WHOI are centered in five departments: applied ocean physics and engineering, encompassing ocean acoustics, observation systems, and immersible vehicles; biology, with specialties in biooptical studies, pollution effects in the sea, and the behavior of marine animals; marine chemistry and geochemistry, focusing on chemical analyses and modeling of ocean processes; physical oceanography, including the examination of the geography and physics of the ocean currents; and geology and geophysics, including the study of the oceans' role in past climate change.

WHOI's research efforts are enhanced by four ocean institutes, established in 2000, which address the concerns of members of the general public and policymaking bodies and make research findings available as expeditiously as possible. The Coastal Ocean Institute encourages pioneering, interdisciplinary experiments, and field missions to increase knowledge and understanding about basic ocean processes. The Ocean Life Institute sponsors studies of the oceans' organisms and processes to understand the evolution of life and adaptability of species to their natural surroundings.

The Ocean and Climate Change Institute, among other undertakings, supports research about the effect of greenhouse gases on the ocean and the effect of ocean dynamics that may cause large, sudden climate shifts. WHOI's interest in research and technology that focus on the possible regional and global effects of changes in the Arctic on circulation and climate, including the effects on fisheries and ecosystems beyond the Arctic, was advanced in 2006 with the receipt of a grant to establish the Clark Arctic Research Initiative. The initiative is intended to make resources available to support individual and collaborative focused research based in the Arctic region through 2007.

The WHOI's fourth institute, the Deep Ocean Exploration Institute, encourages multidisciplinary research endeavors throughout WHOI and advocates the development of deep-sea technology, including vehicles such as *Alvin*, the Deep Submergence Vehicle owned by the U.S. Navy and operated by WHOI. In addition to *Alvin,* the National Deep Submergence Facility, funded by the federal government and located at WHOI, oversees the operation of the remotely operated vehicle *Jason/Medea* and the robotic underwater vehicle *ABE.* The year 2008 will be one of significant change as the *ABE* is replaced by the *Sentry,* which can dive to greater depths and has longer deployment capability than its predecessor.

Of even greater note is the anticipated retirement in 2008 of *Alvin*, which carries two scientists and a pilot as deep as 3 mi. (4.8 km.) for 6- to 10-hour dives. The submersible vehicle, which has made more than 4,000 dives since 1964, can reach almost two-thirds of the ocean's floor, moving at speeds up to 1.5 m.p.h. *Alvin* has remained a state-of-the-art vehicle because it has been disassembled, inspected, and reassembled every 3 to 5 years. Every part of *Alvin* has been replaced at least once in the vehicle's lifetime, but additional refurbishing will unlikely enable the sub to do more than it does now. *Alvin's* replacement vehicle will be funded by the National Science Foundation and will reach greater depths than *Alvin*, reaching almost the complete ocean floor. WHOI has indicated that operating both submergence vehicles is cost-prohibitive. *Alvin* leaves behind a rich history that has included locating a lost hydrogen bomb in the Mediterranean Sea, photographing the Titanic, and exploring deep-sea hydrothermal vents, where it gathered information about 300 life-forms that were previously unknown.

The WHOI's research fleet, which in addition to its submergence vehicles includes one of the United States' newest research vessels, the Navy-owned *Atlantis*, among its ships, provides students in the joint program offered by WHOI and the Massachusetts Institute of Technology (MIT) incomparable opportunities at research and learning. The MIT/WHOI Joint Program ranks among the leading graduate marine science programs in the world. In addition, WHOI 's Geophysical Fluids Dynamic (GFD) Program offers eight to 10 new graduate fellows each year the unique experience of participating in an intensive 10-week interdisciplinary research program. The students present a lecture and prepare a written report for inclusion in the GFD Proceedings Volumes.

Students who have fulfilled the requirements of a Ph.D. program may be awarded one of several postdoctoral appointments: the scholar, fellow, or investigator. Postdoctoral scholarships are awarded for 18 months in the fields of oceanography, biology, chemistry, engineering, geology, geophysics, mathematics, meteorology, physics, and biology. In addition, professionals in law, social sciences, or natural sciences may apply for Marine Policy Fellowships, which focus on the examination of maritime conflicts. The WHOI also appoints postdoctoral investigators to positions that fall within the parameters of existing research contracts or grants.

In addition to its premier graduate and postdoctoral programs, WHOI provides opportunities for undergraduate students to gain experience through its Summer Student and Minority Fellowship programs, working in partnership with scientists and engineers on a wide range of scientific topics.

WHOI also grants a limited number of undergraduate students and certain advanced high school students the chance to participate in WHOI's education programs as Guest Students for up to 1 year. Middle school teachers benefit from participation in profession development workshops presented by WHOI scientists and engineers at the WHOI Exhibit Center, which highlights the institution's research programs and vessels.

The WHOI, in partnership with the Marine Biological Laboratory (MBL), an international research center for biology, biomedicine, and ecology, makes a critical contribution to the everyday operation of the MBLWHOI Library. The library, acclaimed for having one of the world's largest collections, both print and electronic, in biomedicine, oceanography, marine biology, and ecology, meets the daily needs of WHOI and MBL scientists and associated researchers. Researchers and students affiliated with the MIT/WHOI Joint Program, the Boston University Marine Program, the Sea Education Association, the National Marine Fisheries Service, the National Ocean and Atmospheric Administration, and the United States Geological Survey also make use of the library's services and resources.

The MBLWHOI Library houses the Data Library and Archives, which, through a wide-ranging collection of administrative records, oral papers and histories, personal papers and diaries, photographs, film, video, instruments, and other documents, makes the history of the WHOI accessible to WHOI's scientific community. The library encourages access to the collection by other institutions and researchers, but its services are restricted to those compatible with the needs of WHOI and MBL. The MBLWHOI Library offers an impressive collection of online resources including the *Alvin* dive log database, the *Alvin* ocean floor photos, digital photos from the WHOI archives, a searchable database of nearly 4,000 films and videotapes in the library's collection, WHOI oral history project, a database providing links to data files from research cruises, and images and descriptions about WHOI ships.

The WHOI receives funding from private contributions and endowment income, but the majority of its funding is generated by peer-reviewed grants and contracts from government agencies, including the National Science Foundation.

In August 2007, a joint venture led by WHOI and including the Scripps Institution of Oceanography at the University of California, San Diego, and Oregon State University's College of Oceanic and Atmospheric Sciences, was awarded a $97.7 million contract by the Joint Oceanographic Institutions in support of the National Science Foundation's Ocean Observatories Initiative. Charity Navigator, an independent evaluator of charities in the United States, assigned its highest ranking of four stars to WHOI—one of 1,300 charities to be recognized as outperforming most charities in its cause. Evaluations are based on annual financial information each charity provides to the U.S. Internal Revenue Service.

SEE ALSO: Massachusetts Institute of Technology; Navy, U.S.; Oceanic Changes; Oceanography.

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Rotary International Archives

World Bank

THE WORLD BANK (or the Bank) was established on December 27, 1945, following the ratification of the Bretton Woods agreement. The World Bank was conceived of in July 1944 at the United Nations Monetary and Financial Conference to provide development assistance to facilitate the reconstruction of Europe following World War II. Since then, the Bank has provided financial assistance to developing countries following natural disasters and humanitarian emergencies to facilitate postconflict rehabilitation and economic liberalization and development.

The organization of the World Bank consists of two agencies of the five that make up the World Bank Group (WBG): the International Bank for Reconstruction and Development (IBRD) and the International Development Association (IDA). The Bank consists of 185 member countries, all of whom are shareholders, represented by a board of governors—the ultimate policymakers of the Bank. The board of governors consists of member countries' ministers of finance or development, and it meets annually. The governors delegate specific duties to 24 on-site executive directors.

The five largest shareholders—France, Germany, Japan, the United Kingdom, and the United States—each appoint one executive director, and the remaining member countries are represented by 19 other executive directors, thus making up the 24. The president of the Bank, currently Robert B. Zoellick, is responsible for chairing the meetings of the board of directors and for overall management of the Bank. The president of the Bank serves a renewable five-year term. The president is, by tradition, a U.S. citizen nominated by the president of the United States—the bank's largest shareholder. The presidential nominee is confirmed by the board of governors.

The World Bank's activities are focused on the reduction of global poverty, especially on the achievement of the Millennium Development Goals (MDGs), goals calling for the elimination of poverty and the implementation of sustainable development. The constituent parts of the Bank, the IBRD and the IDA, achieve their aims through the provision of low- or no-interest loans and grants to countries with little or no access to international credit markets. The Bank is a market-based, nonprofit organization, using its high credit rating to make up for the low interest rate of loans.

MISSION AND FUNDING

The Bank's mission is to aid developing countries and their inhabitants achieve the MDGs through the alleviation of poverty by developing an environment for investment, jobs, and sustainable growth, thus promoting economic growth, and through investment in and empowerment of the poor to enable them to participate in development. The World Bank focuses on four key factors necessary for economic growth and the creation of a business environment: capacity building (strengthening governments and educating government officials), infrastructure creation (implementation of legal and judicial systems for the encouragement of business, the protection of individual and property rights and the honoring of contracts), development of financial systems (the establishment of strong systems capable of supporting endeavors from micro credit to the financing of larger corporate ventures), and combating corruption (eradicating corruption to ensure optimal effect of actions).

The Bank obtains funding for its operations primarily through the IBRD's sale of AAA-rated bonds in the world's financial markets. Although this does generate some profit, the majority of the IBRD's income is generated from lending its own capital. The IDA obtains the majority of its funds from 40 donor countries, who replenish the bank's funds every 3 years, and from loan repayments, which then become available for relending.

The Bank offers two basic types of loans: investment loans and development policy loans. The former are made for the support of economic and social development projects, whereas the latter provide quick disbursing finance to support countries' policy and institutional reforms. Although the IBRD provides loans with a low interest rate (between 0.5 and 1 percent for a standard Bank loan), the IDA's loans are interest free. The project proposals of borrowers are evaluated for their economical, financial, social, and environmental aspects to ensure that they are viable before any amount of money is distributed.

The Bank also distributes grants for the facilitation of development projects through the encouragement of innovation, cooperation between organizations, and participation of local stakeholders in projects. IDA grants are predominantly used for debt burden relief in the most indebted and poverty-struck countries, amelioration of sanitation and water supply, support of vaccination and immunization programs for the reduction of communicable diseases such as HIV/AIDS and malaria, support to civil society organizations, and the creation of initiatives for the reduction of greenhouse gases.

THE WORLD BANK AND CLIMATE ISSUES

With respect to its work addressing issues of global warming, the World Bank has created and funded a number of climate-related partnerships and programs with other agencies and national governments, including the United Nations Framework Convention on Climate Change (UNFCCC), the Global Environment Facility (GEF), Carbon Finance, the Energy Sector Management Assistance Program (ESMAP), the Asia Alternative Energy Program (ASTAE), the Global Facility for Disaster Reduction and Recovery (GFDRR), the Vulnerability and Adaptation Resources Group (VARG), and the Global Gas Flaring Reduction partnership (GGFR).

The UNFCCC is an international treaty through which countries consider ways to reduce global warming and cope with inevitable temperature increases. The World Bank is an observer to the UNFCCC and also takes part in a number of technical discussions conducted by the UNFCCC Secretariat, such as by the Subsidiary Body for Implementation and the Subsidiary Body for Scientific and Technological Advice.

The GEF is the financing mechanism for the UNFCCC, as well as other key international environmental agreements. As a GEF-implementing agency, the World Bank helps identify, prepare, and implement projects that reduce poverty and benefit the local and global environment. Climate change was the second most active focal area of the GEF active portfolio at the end of fiscal year 2006.

The World Bank's Carbon Finance Unit offers a means of leveraging new private and public investment into projects that serve to mitigate climate change by reducing greenhouse gas emissions, while promoting sustainable development. Projects relate to rural electrification, renewable energy, energy efficiency, urban infrastructure, waste management, pollution abatement, forestry, and water resource management.

The atrium of the World Bank in Washington, D.C. It has funded a number of climate-related partnerships and programs.

ESMAP, cosponsored by the World Bank and the United Nations Development Programme, is a global technical assistance program that provides policy advice on sustainable development issues to the governments of developing countries and economies in transition. ESMAP also contributes to technology and knowledge transfer in energy sector management and, since its creation in 1983, has operated in 100 different countries through some 450 different activities. Recently, a new window in ESMAP has opened to support the goals of the Clean Energy Investment Framework.

The ASTAE program, established in 1992, aims at mainstreaming renewable energy and energy efficiency in the World Bank's lending operations in the power sector in Asia. The World Bank is cooperating actively with the GFDRR, which aims at integrating hazard risk reduction strategies in development processes at local and national levels. The potential exacerbation of extreme climatic events as climate changes suggests significant overlap between the areas of adaptation to climate change and disaster risk reduction.

The VARG is an informal network of multi- and bilateral development institutions that aim to facilitate the integration of adaptation to climate change in the development process. The World Bank is one of 19 organizations that are partnering in this open-knowledge network.

The GGFR partnership, a World Bank–led initiative, facilitates and supports national efforts to use currently flared gas by promoting effective regulatory frameworks and tackling the constraints on gas utilization, such as insufficient infrastructure and poor access to local and international energy markets, particularly in developing countries. Launched at the World Summit on Sustainable Development in August 2002, GGFR brings around the table representatives of governments of oil-producing countries, state-owned companies, and major international oil companies, so that together they can overcome the barriers to reducing gas flaring by sharing global best practices and implementing country-specific programs.

THE SUSTAINABLE DEVELOPMENT NETWORK

Another World Bank initiative is the Sustainable Development Network, a part of which includes a Climate Change Team within the Environment Department of the Bank. The Climate Change Team provides resources and expertise for the World Bank's participation in international climate change negotiations under the UNFCCC and provides technical advice to the World Bank's GEF Program on the preparation of GEF climate change mitigation projects in energy efficiency and renewable energy and on the development of strategic initiatives with the GEF. The team also is leading the Bank's efforts related to climate change vulnerability and adaptation issues for its client countries.

The Bank recognizes that achieving objectives related to climate change is a long-term process requiring the integration of the greenhouse gas (GHG) mitigation and the vulnerability and adaptation agendas into mainstream operational work. These instruments include planning, policy dialogue, generation and dissemination of knowledge, and investment lending, all of which are primarily aimed at promoting national development priorities. Bank support to clients for better managing climate change occurs in three key areas: mitigation of GHG emissions, reduction of vulnerability and adaptation to climate change, and capacity building. In the area of GHG mitigation, the bank promotes policy and regulations, as these tend to have large and sustainable effects on improving the efficiency of resource use and, consequently, reduction of GHG emissions. In the context of these reforms, the Bank mobilizes resources from the GEF and the Prototype Carbon Fund to support GHG abatement measures that simultaneously address poverty reduction and sustainable development goals.

In areas of vulnerability and adaptation, where the decision on UNFCCC support is pending, the Bank will mobilize donor financing for a Vulnerability and Adaptation Facility to better prepare for climate change. Over the medium term, the Bank will focus on improving the understanding of the potential effects of climate change and on identifying and implementing no-regrets measures to reduce vulnerability to current climate and to climate change. Finally, the Bank will assist clients in building the capacity needed to deal with GHG abatement and with vulnerability and adaptation.

As part of its work in climate change, the World Bank has developed a variety of resource and training materials addressing the fundamental issues underlying climate change, examples of successful mainstreaming of climate change concerns into project work or underlying analysis, and basic tools for accurately identifying the climate change effects of projects, baselines, and alternatives. The climate risk screening toolkit is referred to as ADAPT (Assessment and Design for Adaptation to Climate Change), which is a prototype tool that will screen proposed development projects for potential risks posed by climate change and variability. The Bank has also developed a variety of tools and examples to help its staff and clients more readily address the methodological, technical, and economic issues underlying the incorporation of GHG issues in project development and economic analysis. In the area of renewable energy, the Renewable Energy Toolkit comprises a range of tools to help Bank staff and country counterparts improve the design and implementation of renewable energy projects. It aims at providing practical implementation needs at each stage of the project cycle and also helps project staff determine sustainable business models, financing mechanisms, and regulatory approaches.

SEE ALSO: Climate Change, Effects.

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World Business Council for Sustainable Development

THE WORLD BUSINESS Council for Sustainable Development (WBCSD), based in Geneva, Switzerland, is a global association of businesses focused on market-oriented solutions to sustainable development and is appropriately structured along the lines of a chief executive officer (CEO)–led business. The WBCSD's mission statement asserts its purpose: "Our mission is to provide business leadership as a catalyst for change toward sustainable development, and to support the business license to operate, innovate and grow in a world increasingly shaped by sustainable development issues." The WBCSD arose from ideas forwarded at the United Nations Conference on Environment and Development (UNCED), also known as the Rio de Janeiro Earth Summit of 1992, where Swiss businessman Stephan Schmidheiny was appointed chief adviser for business and industry to the secretary general of the UNCED. Schmidheiny created a forum called Business Council for Sustainable Development that eventually published the book *Changing Course*, in which the phrase eco-efficiency—doing more with less—was first used. The WBCSD was constituted in its current form when it merged (1995) with the World Industry Council for the Environment.

The WBCSD has approximately 60 national and regional business councils and has its North America office in Washington, D.C. Only companies committed to sustainable development are invited, by the executive council, to join the association.

General Motors, DuPont, 3M, Deutsche Bank, Coca-Cola, Sony, Oracle, BP, and Royal Dutch/Shell are among approximately 200 member companies from 35 countries representing 20 industrial sectors. Members make their knowledge, experience, and some limited human resources available to the WBCSD and are asked to base their business development within the parameters of economic, social, and environmental sustainability. Member company CEOs act as executive council members, cochair working groups, and promote the objectives of the WBCSD within their companies.

OBJECTIVES OF THE COUNCIL

The council's objectives are to be a leading business advocate on sustainable development, participate in policy development to create the right framework conditions for business to make an effective contribution to sustainable human progress, develop and promote the business case for sustainable development, demonstrate the business contribution to sustainable development solutions and share leading-edge practices among members, and contribute to a sustainable future for developing nations and nations in transition. To achieve these objectives the WBCSD has four focus areas (FAs): energy and climate, development, the business role, and ecosystems.

The WBCSD initiated its Energy and Climate FA in 1999 by creating and promoting ways for business to prosper while being socially and environmentally conscious within a sustainable development framework that prepares business for the carbon-constrained future necessary for the planet to counter anthropogenic (human-induced) global warming and climate change. This required innovation, education, and dialogue seeks to create an efficient approach to energy sustainability and climate change through changing and adapting policy frameworks, business plans and markets, advancing technologies, and the interaction between business, government, and economies regionally, nationally, and globally. One focus of this initiative was/is the large greenhouse gas (GHG) emitters (United States, China, India, and Russia). The WBCSD interacts with the UN Environment Programme (UNEP), the UNEPs Intergovernmental Panel on Climate Change (IPCC), and the UN Framework Convention on Climate Change, and also focuses on the development of a post-2012 flexible Kyoto mechanism. Energy and climate became the primary WBCSD FA in 2005.

WBSCDs *Facts and Trends to 2050* (2004) and *Pathways to 2050* (2005) proposed potential pathways to GHG stabilization and to creating a low GHG economy. Its *Policy Directions to 2050: A Business Contribution to the Dialogues on Cooperative Action* (2007) promotes these goals and the averting of a climate change catastrophe through the coordinated and sustained actions of governments, businesses, and consumers. The WBCSD's Greenhouse Gas Protocol Initiative joint initiative with the World Resources Institute attempts to standardize all GHG accounting.

The WBCSD contends that stable and sustainable societies cannot and must not tolerate poverty among their citizens and that businesses, economies, governments, and societies must work together to ensure open and fair access to all markets and opportunities. The WBCSD supports this focus through its Sustainable Livelihoods project, which advocates the changes in societal, policy, and business frameworks necessary to achieve this focus while promoting business-led development targeting the long-term alleviation of poverty.

The WBCSD Business Role FA began in 1992 with the publication of the book *Changing Course*, the basic premise of which was that the only solution to the challenges of environmental deterioration and climate change is the active participation of business. The WBCSD tried to ignite a discussion on the role that business should or might play in any future economic, social, and environmental sustainable society with its

2006 publication of *From Challenge to Opportunity: The Role of Business in Tomorrow's Society*. The WBCSD secretariat and its FA Core Team (FACT), composed of 11 member companies led by two cochairs, creates and implements the WBCSD Action Plan seeking to provide platforms for discussion and debate among business leaders, facilitate future thinking on how business might support sustainable development, use the available WBCSD resources more appropriately, and shape the message of the WBCSD to the business world.

Ecosystems became a WBCSD FA in March 2007 and, as a FA, is built on the WBCSD's Sustaining Ecosystems Initiative created in November 2005 to rally and direct business to address the ecosystem opportunities and challenges outlined in the July 2005 *Millennium Ecosystem Assessment* that the WBCSD partially authored. The goal is to encourage business to address the risks inherent in the accelerating degradation of the ecosystem and the loss of ecosystem services and to adopt mitigation and market-based strategies for enhancing sustainable management and ecosystems use. The WBCSD began addressing these issues by demonstrating how business could integrate these strategies into management systems when the WBCSD and the World Conservation Union (IUCN) jointly produced (1997) two reports on business and biodiversity: *A Guide for the Private Sector* and *A Handbook for Corporate Action*. The WBCSD and the IUCN continued to promote the benefits of integrating biodiversity into business after they partnered with the World Conservation Union to host a workshop on the subject in Bangkok, Thailand, in November 2004.

SEE ALSO: Climate; Climate Change, Effects; Developing Countries; Ecosystems; Greenhouse Gases; Intergovernmental Panel on Climate Change (IPCC); Sustainability; United Nations Environmental Programme (UNEP); World Resources Institute (WRI).

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World Climate Research Program

THE WORLD CLIMATE Research Program (WCRP) is sponsored by the International Council for Science (ICSU), the World Meteorological Organization (WMO), and the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO). The program brings together the intellectual and structural potentialities related to climate and climate change of more than 185 countries. The program thus aims to work as an international forum to share scientific discoveries and facilities to advance the understanding of the phenomena that influence climate. The two underlying objectives of the WCRP are to determine the predictability of climate and to assess the effect of human activities on it.

These two objectives stem from the needs identified by the UN Framework Convention on Climate Change. To achieve its objectives, the WCRP adopts a multidisciplinary approach, organizes extensive observational and modeling projects, and encourages researches on aspects of climate too large and complex to be addressed by any one nation or single scientific discipline. The WCRP is not open exclusively to scientists. On the contrary, it aims to involve different subjects such as policymakers, information end-users, and sponsors in a scientifically accurate debate on climate change and variability.

The WCRP was established in 1980. It was initially joint-sponsored by the ICSU and the WMO. Since 1993, the IOC of UNESCO has also become a sponsor of the program. Since its establishment, the WCRP has contributed to the advancement of climate science. Thanks to WCRP researchers, climate scientists can monitor, simulate, and project global climate with improved accuracy so that climate information can be used for governance, in decision making, and in support of a wide range of practical applications. In 2005, after 25 years of serving science and society, the WCRP launched its Strategy Framework 2005–2015, which expresses the program's commitment to working efficiently and effectively toward strengthening knowledge and increasing capabilities with regard to climate variability and change. Titled the Coordinated Observation and Prediction of the Earth System, the framework aims "to facilitate analysis and prediction of Earth system variability and change for use in an increasing range of practical applications of direct relevance, benefit and value to society." The WCRP is thus devoted to provide a larger series of products and services to an ever-increasing group of users. The WCRP intends to reach this goal through the integration of observations and models to generate new understanding and improve climate predictions.

Today, the WCRP covers studies of the different parts of the Earth's climate system: global atmosphere, oceans, sea and land ice, the biosphere, and the land surface. The major core projects, diverse working groups, various cross-cutting activities, and many cosponsored activities of the WCRP all aim to improve scientific understanding of processes that can enable better forecasts.

The Global Energy and Water Cycle Experiment (GEWEX) project studies the dynamics and thermodynamics of the atmosphere, the atmosphere's interactions with the Earth's surface (especially over land), and the global water cycle. GEWEX uses suitable models to represent and forecast the variations of the global hydrological regime and its effect on atmospheric and surface dynamics. GEWEX also focuses on variations in regional hydrological processes and water resources and their response to changes in the environment, such as the increase in greenhouse gases. GEWEX projects are divided into three focus areas corresponding to the key elements in the global energy and water cycle: radiation, hydrometeorology, and modeling and prediction.

The Climate Variability and Predictability (CLIVAR) project, set up in 1995, specifically targets climate variability. Its mission is to observe, simulate, and predict the Earth's climate system, with a focus on ocean-atmosphere interactions. CLIVAR seeks to develop predictions of climate variations on seasonal to centennial timescales and to refine the estimates of anthropogenic climate change. CLIVAR also includes a Working Group on Seasonal to Interannual Prediction, which oversees development of improved models, assimilation systems, and observing system requirements for seasonal prediction.

The section of WCRP dealing with the Stratospheric Processes and Their Role in Climate (SPARC), founded in 1993, carries out research on the chemistry of the climate system. In particular, it focuses on the interaction of dynamic, radiative, and chemical processes. SPARC's projects include the construction of stratospheric reference climatology and the improvement of understanding of trends in temperature, ozone, and water vapor in the stratosphere. SPARC also studies gravity wave processes, their role in stratospheric dynamics, and how these may be represented in models.

The Climate and Cryosphere (CliC) project, founded in 2000, measures the effects of climatic variability and change on components of the cryosphere and their consequences for the climate system. CliC is also charged with the task of improving the management of data and information relating to the cryosphere and climate, and with making data more readily available for use by the broader scientific community. To this end, CliC has established a Web-based Data and Information Service for CliC.

The Surface Ocean–Lower Atmosphere Study aims to quantify the key biogeochemical-physical interactions and feedbacks between the ocean and the atmosphere. WCRP cosponsors the project jointly with the Commission on Atmospheric Chemistry and Global Pollution, the International Geosphere-Biosphere Programme and the Scientific Committee on Oceanic Research. The project investigates biogeochemical interactions and feedbacks between ocean and atmosphere, exchange processes at the air-sea interface and the role of transport and transformation in the atmospheric and oceanic boundary layers, and air-sea fluxes of carbon dioxide and other long-lived radiatively active gases.

The Working Group on Surface Fluxes was established in 2007 to review the requirements of the different WCRP schemes for surface sea fluxes including biogeochemical fluxes, to coordinate the various related research initiatives, and to encourage research and facilitate operational activities on surface fluxes.

SEE ALSO: Carbon Dioxide; Climate; Climate Models.

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World Health Organization

THE WORLD HEALTH Organization (WHO), established in 1948 by the United Nations (UN), has a mission to promote international cooperation for improved health conditions of all peoples. The headquarters for WHO are in Geneva, Switzerland. Operations fall under the World Health Assembly (the policymaking body holds annual meetings), an executive board of health (specialists elected for three-year terms by the assembly) and a secretariat with regional offices and staff throughout the world. Financing for the services provided by WHO comes from member governments based on ability to pay and, since 1951, from an allocation from the technical assistance program of the UN.

The auspices of the WHO include providing a central clearinghouse for information and research as relates to health, sponsoring measures for the control of disease, and strengthening and expanding the public health administrations of member nations.

Overall health depends on potable water for drinking and washing, sufficient nutrition, and shelter and protection from weather extremes. Increased temperatures, rising sea levels, and changing weather patterns are factors affecting food, water, and shelter. Excellent health services and living conditions would have a protective or palliative effect on those populations. Substandard health services and living conditions would have a negative effect on populations in poverty or in disaster situations.

For prevention and preparedness, the WHO coordinates review of scientific evidence on the links between climate, climate change, and health. On the basis of the information available, WHO established a list of possible health effects resulting from rapid climate change, especially in vulnerable populations. The effect of warmer temperatures would increase the incidence of heat-related illnesses and lead to higher concentrations of ground-level ozone pollution, causing respiratory illnesses (diminished lung function, asthma, and respiratory inflammation). Flooding associated with storms and rising sea levels could increase the risk of contracting certain infectious diseases from water contamination or disease-carrying vectors, especially for the malnourished.

WORLD HEALTH PROGRAMS AND ACTIVITIES

WHO supports actions to reduce human influence on the global climate while still recognizing the effect past emissions and human action have on the likelihood of warming and more variable climate for at least several decades. To alleviate this issue as well as reduce health vulnerability to future climate change, WHO supports programs for combating infectious diseases, improving water and sanitation, and ensuring response to natural disasters. In addition, research and effort are being put into building the capacity of health services and information to help adapt to climate changes.

Primary prevention includes actions to prevent the onset of disease from environmental disturbances in an otherwise unaffected population (mosquito nets, vector control, early weather-watch warning systems). Secondary prevention includes early-response action (disease surveillance). Tertiary prevention includes diagnosis and treatment to lessen the morbidity or mortality caused by disease.

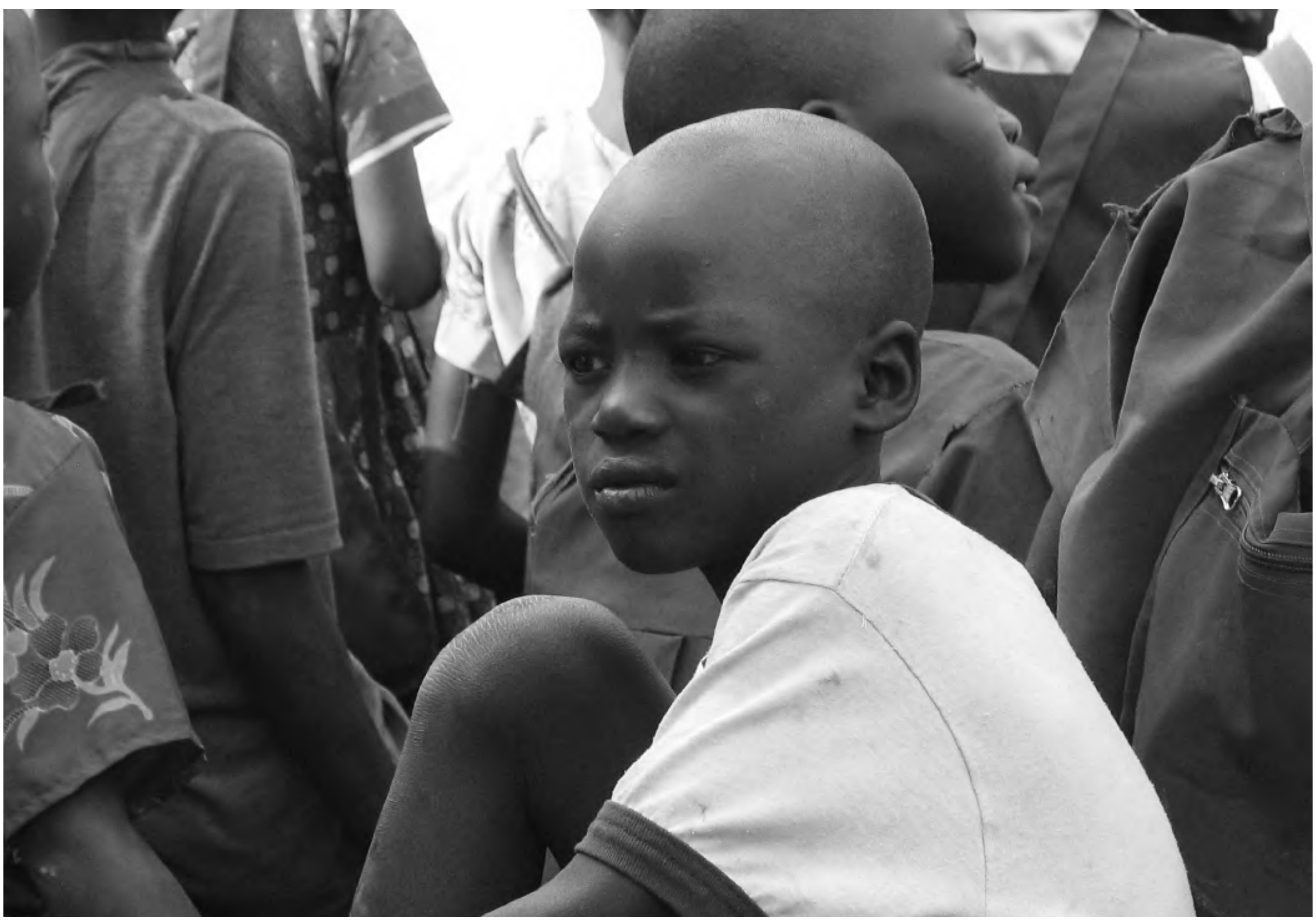
Adaptation refers to actions taken to lessen the effects of the anticipated changes in climate. The ultimate goal of adaptation interventions is the reduction, with the least cost, of diseases, injuries, disabilities, suffering, and death from climate change. Public health programs should anticipate the health effects of climate change such as, for instance, those on infectious diseases. For example, surveillance systems could be improved in sensitive geographic areas. Such regions include those bordering areas of current distribution of vector-borne diseases that could themselves experience epidemics under certain climatic conditions. Vaccination programs could be intensified, and pesticides for vector control and drugs for prophylaxis and treatment could be stockpiled.

To prepare for climate change, the WHO encourages and fosters international cooperation through collaborating with partners (UN agencies and other international organizations, donors, civil society, and the private sector). WHO provides support to countries to implement programs using best technical guidelines and practices and helping to establish health priorities and strategy.

To prepare appropriately for climate change, climate and environmental monitoring are essential. To be most effective, health professionals must interact with the environmental sectors to evaluate the changing climate and assess risks. Researchers and monitoring organizations interested in health impact assessment have requested assistance from health researchers to ensure an accurate risk assessment. Health researchers must also be encouraged to access environmental data or be given the tools necessary to find the information on air and water pollution levels. Additional monitoring should include food contamination and identification of emission sources or contamination sites. The WHO/ECEH (European Centre for Environment and Health) is developing a Health and Environment Geographic Information System (HEGIS) to identify areas and issues of priority for the environment and health. With an initial focus on demographics and air quality, the information system has the potential for expansion to include climate change data and health effects.

The agenda of WHO includes promoting development of health-promoting activities, fostering health security, strengthening health systems, and collecting and disseminating research information.

Health development is directed by the ethical principle of equity: access to lifesaving or health-promoting interventions should not be denied for unfair (economic or social) reasons. Despite how health has become a



Children in Uganda: The World Health Organization coordinates review of scientific evidence on the links between climate change and health. Increased temperatures, rising sea levels, and changing weather patterns would affect food, water, and shelter.

standard factor in perception of social and economic progress, as well as receiving additional resources and funding, poverty and poor health are still widespread around the world. WHO activities are aimed at health development and at making health outcomes in poor, disadvantaged, or vulnerable groups a priority. The organization's agenda is to focus on the prevention and treatment of chronic disease in all populations and to research and address tropical diseases as part of their Millennium Development goals.

WHO intends to foster health security even for vulnerable populations by demanding action from the international community in addressing preventable diseases. Forty percent of the global population is very poor, many suffer from water shortages, more than a billion lack safe drinking water, and water-related diseases cause between 2 and 5 million deaths each year. Public health and preventive measures are available, and action is justified, including vaccination or control measures such as improved sanitation and temperature control of foods. In addition there is the risk of outbreaks from emerging and epidemic-prone disease.

Such outbreaks are occurring in increasing numbers, fuelled by such factors as rapid urbanization, environmental mismanagement, the way food is produced and traded, and the way antibiotics are used and misused. The threat of climate change also demands action for building capacity and adaptabilities to climate change. WHO provides workshops in vulnerable countries and works with policymakers to ensure adequate healthcare is available for treatment. These activities have a twofold benefit: action taken now both improves current health conditions and provides a foundation for additional adaptation measures in the future to address climate changes.

As an ultimate measure for ensuring adequate health care not only in the future but in the present as well, health systems around the world must be strengthened. To function as a method for reducing poverty, health services must be available to all populations, including those that are now underserved because of economic reasons. WHO works with countries to ensure an adequate number of trained professional and additional staff to meet the healthcare needs, funding to provide services, and access to medication and supplies as well as the technology to provide appropriate care.

For collecting and disseminating research information, the WHO maintains a searchable database on the Web on a broad range of health subjects including links to journal articles, research undertaken, and recommendations. As mentioned before, the WHO/ECEH also is developing a HEGIS to identify areas and issues of priority for environment and health. With an initial focus on demographics and air quality, the information system has the potential for expansion to include climate change data and health effects.

SEE ALSO: Food Production; Population; United Nations.

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World Meteorological Organization

THE WORLD Meteorological Organization (WMO) is a specialized agency of the United Nations (UN). It is the UN voice on the state and behavior of the Earth's atmosphere, its interaction with the oceans, the climate it produces, and the resulting distribution of water resources. The WMO has a membership of 188 member states and territories. It originated from the International Meteorological Organization, which was founded in 1873. Established in 1950, WMO became the specialized agency of the United Nations in 1951 for meteorology (weather and climate), operational hydrology, and related geophysical sciences. It is based in Geneva, Switzerland.

The WMO seeks to provide the framework for an international cooperation regarding climate matters. The organization points out that weather, climate, and the water cycle know no national boundaries, so international cooperation at a global scale is essential for the development of meteorology and operational hydrology. Since its establishment, the WMO has devised programs and services attempting to contribute to the preservation of the environment and the welfare of humanity. The National Meteorological and Hydrological Services have sought to protect life and property against natural disasters, to preserve the environment, and to encourage the economic and social well-being of all sectors of society in areas such as food security, water resources, and transport.

The WMO supports cooperation to establish networks for meteorological, climatological, hydrological, and geophysical observations, as well as for the exchange, processing, and standardization of related data. It also provides technology transfer, training, and research and fosters collaboration between the National Meteorological and Hydrological Services and its members. The organization sponsors the application of meteorology to public weather services, agriculture, aviation, shipping, the environment, water issues, and the mitigation of the effects of natural disasters.

WMO aids the free exchange of data and information, products, and services in real- or near-real-time on topics relating to safety and security of society, economic welfare, and the protection of the environment. It contributes to policymaking in these areas at national and international levels. In the specific case of disasters related to weather, climate, and water, which represent nearly 90 percent of all natural catastrophes, WMO's programs try to provide advance warnings that save lives and reduce damage to property and the environment. The organization is also committed to reducing the effects of human-induced disasters, such as those associated with chemical and nuclear accidents, forest fires, and volcanic ash. Thus, the WMO is central in international efforts to monitor and protect the environment. In collaboration with other UN agencies and the National Meteorological and Hydrological Services, the WMO supports the implementation of a number of environmental conventions and is instrumental in providing advice and assessments to governments on related issues. The organization claims that its activities contribute toward ensuring the sustainable development and well-being of nations.

Global warming is a major WMO concern. The organization supports intergovernmental legal agreements on major global environmental concerns such as ozone-layer depletion, climate change, desertification, and biodiversity. WMO also coordinates the observing systems that provide the necessary data to assess atmospheric-ocean processes and interactions, such as El Niño/La Niña, and water-resources availability. Most significantly for global warming, the WMO lists, among its programs, the Global Atmosphere Watch (GAW). The WMO's interest in a program of atmospheric chemistry and the meteorological aspects of air pollution dates back to the 1950s. This included assuming responsibility for standard procedures for uniform ozone observations and establishing the Global Ozone Observing System during the 1957 International Geophysical Year.

In the late 1960s, the Background Air Pollution Monitoring Network was set up and was subsequently consolidated with the Global Ozone Observing System into the current GAW in 1989. The GAW monitoring scheme includes a coordinated global network of observing stations along with supporting facilities. GAW provides data for scientific measurements of changes in the chemical composition and related physical characteristics of the atmosphere that may negatively affect our environment. The priorities of the scheme have been identified in greenhouse gases for possible climate change, ozone and ultraviolet radiation for both climate and biological concerns, and certain reactive gases and the chemistry of precipitation.

GAW is intended to provide accessible, high-quality atmospheric data to the scientific community. These components include measurement stations, calibration and data-quality centers, data centers, and external scientific groups for program guidance. Support for these components is obtained, largely, by individual WMO member countries that directly participate in the program. Additional resources come from international funding and the WMO secretariat's internal budget.

SEE ALSO: Climate; Global Warming; Weather.

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World Resources Institute

THE WORLD RESOURCES Institute (WRI) is a nonpartisan and nonprofit environmental organization that tries to find practical applications for theoretical research on the protection of the Earth and the improvement of people's lives. WRI supplies information and proposals for policies that promote a sustainable development both in environmental and social terms. WRI is based in Washington, D.C., and has a staff of more than 100 scientists, economists, policy experts, business analysts, statistical analysts, mapmakers, and communicators.

The institute takes as its point of departure for action the fact that the shift to low-carbon technology will only occur by persuading owners and shareholders of its profitability. To WRI, business investors are instrumental in solving the climate crisis. WRI produces a highly respected biennial publication, the *World Resources* report, which supplies data and in-depth analysis on current environmental issues, including, for example, the importance of efficient ecosystem management for rural poverty relief. The report is a collaborative product of WRI with the World Bank, United Nations Environment Programme, and UN Development Programme. *World Resources* was launched in 1986 to bridge the gap in information about the conditions of the world's natural resources.

GOALS AND ACTIVITIES

The activities of the institute are structured around four key areas and goals. In the field of people and ecosystems, the institute aims to reverse the process of rapid degradation of ecosystems and guarantee their ability to provide humans with needed goods and services. Regarding access to information, WRI attempts to improve public knowledge about decisions on natural resources and the environment. In the area of climate protection, energy, and transport, WRI is active in the protection of the global climate system from further harm caused by emissions of greenhouse gases. The institute is also committed to help humanity and the natural world adapt to the climate change that is already taking place. As for markets and enterprise, WRI seeks to promote an economic development that will increase social opportunities and, at the same time, protect the environment. WRI has worked with the private sector to find profitable solutions that have both economic and environmental benefits. WRI also created the accounting system which companies all over the world use to account for their greenhouse gas emissions.

WRI was founded in June 1982 by American lawyer and environmental activist James Gustave Speth. Speth, a former chairman of the U.S. Council on Environmental Quality and later professor of law at Georgetown University, also acted as WRI's first director. He held this position until January 1993, when he became director of the UN Development Programme and was then succeeded by Jonathan Lash, senior staff attorney at the Natural Resources Defense Council from 1978 to 1985. The institute was created thanks to the John D. and Catherine T. MacArthur Foundation of Chicago, which provided $15 million to help finance the first five years of WRI. The institute was organized as a nonprofit Delaware corporation that could receive tax-deductible contributions under the U.S. Internal Revenue Code. WRI was founded not as an activist environmental membership organization but as an independent institution that should carry out scientifically sound research and suggest viable policies.

In 1985, WRI was one of the first research centers to organize an international meeting on the rising emissions of carbon dioxide and other greenhouse gases into the atmosphere. During its over two decades of activity, WRI has attracted other centers that have decided to merge with the institute, including the North American office of the International Office for Environment and Development and the Management Institute for Environment and Business. In 1990, the UN Development Programme commissioned WRI with a study that eventually resulted in the creation of the Global Environment Facility. Throughout the 1990s, WRI played a key role in initiatives aimed to contain the phenomenon of global warming. In 1992, the institute made important contributions to the development of the Convention on Biological Diversity, which was then signed at the Earth Summit in Rio de Janeiro.

In 1999, WRI committed to stopping its own emissions of carbon dioxide. The institute has also created several important networks such as the Global Forest Watch, which monitors the conditions of forests; the Access Initiative, a global forum of civil society organizations committed to improving citizen access to information and favor their participation in decisions that affect the environment;

and the Green Power Market Development Group, a partnership of Fortune 500 companies devoted to establishing corporate markets for renewable energy. WRI has also been responsible, in partnership with Mexico City, for the creation of the Bus Rapid Transit Corridor, a system of transport designed to reduce environmental damages. The institute is collaborating with metropolises such as Shanghai, Hanoi, and Istanbul for the creation of similar systems.

SEE ALSO: Carbon Dioxide; Carbon Emissions; Climate Change, Effects; Global Warming; Population.

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World Systems Theory

AN UNDEREXAMINED ASPECT of global warming is the geographic separation between the people who generate greenhouse gases and the people who are most likely to be hurt by global warming. This article explains how World Systems Theory (WST) can help us understand how climate change is both a cause and a consequence of existing social and regional inequalities. This essay begins by explaining the basic concepts of WST. It then uses WST to explain how geopolitical structures in the global economy ensure that the benefits and costs of burning fossil fuels are not shared equally.

WST evolved to counter free-market economists such as Walter Rostow, who argued that countries were poor because of deficiencies within those countries. Less developed countries could advance by emulating wealthy countries, which had moved through several stages of development.

DEPENDENCY THEORY

A chorus of critics challenged this view because, from their perspective, adherents to the stages of development view blamed the poor countries for their poverty. In response, critics argued that the lack of development in places such as South America was a result of the economic and political structures imposed by wealthy countries through colonial and lingering postcolonial relationships. Foremost among these scholars was Andre Gunder Frank.

His dependency theory argued that as capitalism diffused outward from the economic core of Western Europe over the past 500 years, it transformed the places at the periphery that were drawn into the growing capitalist world system. These new territories in Africa and Latin America were thrust into a subordinate role, and their economies were restructured to suit the needs of the colonial powers in Europe. Frank summarized this subordination as the "development of underdevelopment." Capitalist penetration into new regions underdevelops or undermines the economic potential of these places. Frank wanted to shift the blame for poverty away from the processes within poor countries and to place responsibility for poverty on the structural relationships imposed by colonial, and later, neocolonial, core powers.

Building on dependency theory, scholars such as Immanuel Wallerstein proposed WST to provide more historical context into the processes leading to the development of inequality. WST sorts the countries of the world into three broad categories according to the type of economic processes that predominate in those countries. Countries in the periphery are largely dependent on agriculture and other forms of natural resource extraction. Social inequality is high because most jobs are typically low skill and low wage. Core countries have diverse economies based on manufacturing, services, and information technology. An intermediate category called the semiperiphery includes countries that are more economically diverse than peripheral countries but that have invested less in manufacturing and other tertiary sectors. Hence the level of development is less than that of core countries.

WST improves on the rigid core-periphery dichotomy of dependency theory by adding the semiperipheral category. This modification helps to explain the historical reality of peripheral countries such as Korea ascending to core status, or how the global economy can relegate former colonial powers such as Portugal to semiperipheral status. WST tells us that the international division of labor creates a system of unequal exchange and income inequality between core, semiperipheral and peripheral countries. Peripheral countries extract raw materials and ship them largely unprocessed to the semiperipheral and core countries for processing. The finished goods are then shipped back to the peripheral countries at much higher prices. This system of unequal exchange is perpetuated by protectionist international trade agreements; copyright and patent laws, which limit the diffusion of processing technology to the periphery; the role of multinational corporations, which repatriate profits to the core that were earned by extracting resources in the periphery; and the role of wealthy local elites in poor countries, who benefit from the status quo relationships between the core and periphery.

The creation and perpetuation of global economic and political inequality has direct implications for understanding the effects of global climate change. As noted above, countries in the periphery are far more reliant on agriculture than are countries in the core. Countries in the core are much more invested in manufacturing. As a consequence, they produce disproportionately large amounts of greenhouse gases. That means that there is a geographic separation between the largest producers of greenhouse gases and the regions that will suffer the most harm from global warming. In short, climate changes will have a disproportionately negative impact on the economies and communities in the periphery. The fact that countries at the periphery have the fewest resources to adapt to climate change makes matters even worse. WST is a useful counterbalance to traditional neoclassical discussions of market-based solutions to greenhouse gas reductions because it brings a geopolitical perspective to our understanding of climate change.

SEE ALSO: Developing Countries; Economics, Cost of Affecting Climate Change.

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Worldwatch Institute

THE WORLDWATCH INSTITUTE is "dedicated to fostering the evolution of an environmentally sustainable and socially just society, where human needs are met in ways that do not threaten the health of the natural environment or the prospects of future generations." It describes itself as "an independent, globally focused environmental and social policy research organization" with a "unique blend of interdisciplinary research and accessible writing." Worldwatch is essentially a think tank, with its closest environmental movement analogues being Resources for the Future, the World Resources Institute, and the Earth Policy Institute. The latter is headed by Lester Brown, who founded Worldwatch in 1974 and served as its president through 2000. Its current president is Christopher Flavin.

Worldwatch prides itself on its accessible writing style and its fact-based analysis of critical global issues. It focuses on the underlying causes of these issues and seeks, through education and dissemination of information, to inspire people to act in positive ways. A search of its website produces large numbers of publications regarding climate change, which it has addressed in its publications since at least 1984. *Worldwatch Papers*, one of its signature publications, has sought to educate the public regarding "pressing economic, environmental, and social issues" since 1975. Worldwatch has published *State of the World*, a widely read and widely influential annual report, beginning in 1984. Although Worldwatch does not lobby Congress directly, this comprehensive report is read by legislators as well as world leaders, students, and ordinary individuals and has been translated into

25 languages. In 1992, *Vital Signs: The Trends That Are Shaping Our Future* came into being—an annual series designed to be even more accessible, with its "brief, digestible glimpses into more than 50 issues affecting the world each year." The group publishes a bimonthly magazine, *World Watch,* and has moved to Web-based education recently with *Vital Signs Online*. It also produces an occasional series of books on specialized issues.

Worldwatch is not a one-issue organization, having written about a very wide range of environmental issues including energy, water pollution and availability, soil erosion and other agricultural concerns, population, biodiversity, materials recycling and conservation, forests, toxic materials, and so on. However, it seeks to foster recognition that these issues are inextricably tied to issues of social justice and peace. It began paying consistent attention to the relationship between social and environmental issues, particularly in international settings, much earlier than most environmental organizations. It began calling attention to the need for a sustainable society in at least 1982, five years before "sustainability" began to gain widespread attention with the publication of the Brundtland Commission report, *Our Common Future*. One of the features of its website is an item entitled "Natural Disasters and Peacemaking." A premise is that natural disasters can serve as a means of breaking down social and political barriers, leading to opportunities for peace.

A desire to inspire change in societal attitudes and actions from a grassroots perspective is a hallmark of this organization. It seeks to effect change not by force from the top but by educating the public and thereby inspiring them to demand change.

Worldwatch spends 78.4 percent of its overall budget to pay for the programs and services it exists to provide. Its administrative expenses use 6.7 percent of its budget, and fundraising accounts for another 14.7 percent. Worldwatch spends $0.19 to raise each dollar it earns. Christopher Flavin's compensation for fiscal year 2005 was $95,000, which amounted to 3.38 percent of the group's total budget—a larger percentage (though a smaller amount) than the leaders of many other environmental organizations such as World Resources Institute, Environmental Defense, or the Natural Resources Defense Council.

SEE ALSO: Developing Countries; Resources for the Future (RFF); Sustainability; World Resources Institute.

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World Weather Watch

THE WORLD WEATHER Watch is the central program of the World Meteorological Organization (WMO), the United Nations' agency for cooperation among national weather bureaus, founded in 1950. The Fourth World Meteorological Congress approved the idea of the program in 1963, and the WMO, which has 188 member countries and territories, subsequently established the World Weather Watch to make available an integrated worldwide weather-forecasting system.

The World Weather Watch includes the Tropical Cyclone Program, the Antarctic Activities Program, an Emergency Response Activities Program for environmental emergencies, and the Instruments and Methods of Observation Program to ensure the quality of the observations that are vital for weather forecasting and climate monitoring.

Through the World Weather Watch, a system is in place for countries around the world to obtain daily weather forecasts. The core components of the World Weather Watch—the Global Observatory System (GOS), the Global Telecommunications System (GTS), and the Global Data-Processing and Forecasting System (GDPFS)—enable the World Weather Watch to provide basic meteorological data to the WMO and other related international organizations.

The GOS allows for observing, documenting, and communicating data about the weather and climate for the creation of forecast and warning services. Monitoring the climate and the environment is a priority of the WMO, and the GOS is critical to the effective and efficient operations of the WMO. Long-term objectives of the GOS include the standardization of observation practices and the optimization of global observation systems.

The GTS consists of land and satellite telecommunication links that connect meteorological telecommunication centers. The GTS provides efficient and reliable communication service among the three World Meteorological Centers in Melbourne, Moscow and Washington, and the 15 Regional Telecommunication Hubs that make up the Main Telecommunication Network. The six Regional Meteorological Telecommunication Networks, covering Africa, Asia, South America, North America, Central America and the Caribbean, South–West Pacific, and Europe, ensure the collection and distribution of data to members of the WMO. The National Meteorological Telecommunication Networks make it possible for the National Meteorological Centers to collect data and to receive and disseminate weather information on a national level.

The primary aim of the GDPFS is to prepare and provide meteorological analyses to members in the most cost-effective manner possible. The GDPFS is organized to implement functions at international, regional, and national levels through the World Meteorological Centers, the Regional Specialized Meteorological Centers, and the National Meteorological Centers. Real-time functions include preprocessing and postprocessing of data and the preparation of forecast products. Non-real-time functions include long-term storage of data and the preparation of products for climate-related analysis.

Increasingly, the World Weather Watch provides support for developing international programs related to global climate and other environmental issues and to sustainable development. The entire continent of Africa has only 1,150 World Weather Watch stations—one per 26,000 sq. km., (10,038 sq. mi.)—even though the continent's land mass is as large as North America, Europe, Australia, and Japan put together. This represents coverage eight times lower than the WMO's recommended minimum level. The changing climate of Africa necessitates greater capacity building on the part of institutions prepared to address the likely crises that lie ahead. The World Weather Watch is vital in developing that capacity.

The World Weather Watch and its parent organization, the WMO, through the development of a permanent global weather data network, have proven critical to defining global warming as a given. As a consequence, the political and policymaking debates about climate change and its very real consequences, such as those facing Africa, have moved to a new arena. Although the World Weather Watch cannot compel individual governments to act on its findings, it can and has framed the issue of climate change on a truly global scale.

SEE ALSO: Climate; United Nations.

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World Wildlife Fund

ALTHOUGH THE WORLD Wildlife Fund around the world has changed its name to the World Wide Fund for Nature, the original name remains the official one in the United States and Canada. As an international nongovernmental organization, it was founded in 1961 in Switzerland to help with the conservation, research, and restoration of the natural environment, changing its name in 1986, although still keeping its initials (WWF) around the world.

Although over many years the WWF became famous for its protection of endangered fauna—its symbol remains a panda bear—it has also been keen to preserve natural environments, seeing its role as helping endangered flora as much as fauna, with the change in its name reflecting this. Indeed the WWF now recognizes that the single biggest threat to the environment today comes from global warming, and as a result it has campaigned for companies and individuals to reduce their greenhouse gas emissions.

In December 2007, the World Wildlife Fund issued a report titled "Antarctic Penguins and Climate Change."

The major area where the WWF initially concentrated its energies was in reducing deforestation, especially in Brazil, Central Africa, and the Russian Far East. This has seen U.S. experts from the WWF-U.S. taking part in projects in these regions, and also in other parts of the world. They have been involved in recording the level of deforestation, and in many cases illegal logging, and notifying the relevant governments as well as bringing extreme levels of deforestation to world attention.

Traditionally, the WWF has organized throughout the United States at a city, town, and village level, with the education of young people being at the forefront of its approach. This means that the WWF has devoted much of its time and energy to encouraging students to gain a greater interest in the environment and the threat of global warming through the provision of resource kits, booklets, and lectures. Many of these items have been available free of charge, or heavily subsidized, with many schoolchildren becoming interested in the world of the WWF through television documentaries and other media sources such as the internet.

This has seen the developing of educational problems to allow more students to plan ways of reducing carbon dioxide emissions. Among the children who have been involved in WWF projects have been some of those displaced by Hurricane Katrina, who have been better able to understand the problems leading to the hurricane. To that end, the WWF hosts the Southeast Climate Witness Program, which allows students to attend a Climate Camp in June 2008 and to take part in the Youth Summit in Washington, D.C., in the following month. Many schools around the United States also raise money for the WWF that is used for the campaign against climate change.

Although it has long been a community movement, the WWF has also started working heavily with businesses. This change has seen the WWF and some of its partners collaborating with 12 prominent companies including the Collins Companies, IBM, Johnson & Johnson, Nike, Polaroid, and Sony. These large corporations have agreed to work toward reducing their carbon dioxide emissions by over 10 million tons each year, which, as a result, has led to many smaller companies becoming aware of their effect on the generating of greenhouse gases and working to reduce their emissions. The WWF has also tried to get, with less success, the energy utility companies to reduce the emissions of their operations.

SEE ALSO: Animals; Climate Change, Effects; Deforestation; Economics, Cost of Affecting Climate Change.

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Wyoming

WYOMING IS 97,819 sq. mi. (253,350 sq. km.) with inland water making up 714 sq. mi. (1,849 sq. km.). The Continental Divide (the separation mark of the Pacific and Atlantic watersheds) passes through Wyoming, making Wyoming a source for the Missouri-Mississippi, the Great Basin, the Columbia, and the Colorado drainage systems.

The climate in Wyoming is relatively cool and depends on the elevation; for example, the summers are moderately warm at lower elevations. Early freezes and a late spring provide long winters and a short growing season (from approximately 80 days in the northwest to 120 days in the plains). Precipitation also varies with elevation. Snow falls from November to May—the yearly snowfall can be as little as 10 in. or less in the basins and 15 to 20 in. in the Plains to over 60 to 70 in. at the higher elevations.

Wyoming has 22 state parks, Grand Teton and Yellowstone national parks, and national forests set aside for preservation. The largest aquifer in the world, Ogallala Aquifer lies underground beneath eight states including Wyoming. Major industries include agriculture (most of the agricultural land is used for grazing, though dryland wheat and some irrigated crops are grown) and mining for coal, natural gas, and petroleum. Industries that are important to Wyoming's economy include petroleum refining, chemical industries, food processing, industrial machinery, and wood products.

Although climate models vary on the amount of temperature increase possible, potential risks include having decreased water supplies; increased risk for wildfires; changes in food production, with agriculture improving in cooler climates and decreasing in warmer climates; change in rain pattern to downpours, with the potential for flash flooding and health risks of certain infectious diseases from water contamination or disease-carrying vectors such as mosquitoes, ticks, and rodents, and heat-related illnesses.

Wyoming may benefit from changing climate. Shorter, milder winters could mean longer growing seasons and increasing crop yields, though higher temperatures may mean changing crops produced to those that are better adapted to a warmer climate and that are more drought resistant. The milder climate could attract more tourists. Taking advantage of sun and wind to produce electricity could provide economic benefits. The effect of climate change on agriculture will be mixed, and some crops such as potatoes and wine grapes could be negatively affected by rising temperatures, decreasing yields. By comparison, the orchard crops will mature more quickly at height temperatures, with increased quality and market-share value. Some areas may need to change crops for those with higher drought resistance and adaptability to a warmer climate.

Wyoming's glaciers are melting at a rapid pace because of milder temperatures brought on by global warming. Warmer temperatures also mean less snowpack in the mountains and earlier snowmelt, leading to more winter runoff and reduced summer flows in many Wyoming streams. Snowpack also stores much of Wyoming's clean water supply for drinking, agriculture, and wildlife. Any reduction in snow would increase pressures on this valuable and scarce resource.

On the basis of energy consumption data from Energy Information Administration's State Energy Consumption, Price, and Expenditure Estimates, released June 1, 2007, Wyoming's total CO_2 emissions from fossil fuel combustion for 2004 was 63.54 million metric tons, made up of contributions from commercial (0.86 million metric tons), industrial (10.12 million metric tons), residential (0.86 million metric tons), transportation (8.07 million metric tons), and electric power (43.62 million metric tons).

Wyoming's current incentive programs and tax breaks targeted at reducing carbon emissions are designed to encourage energy efficiency and the use of renewable energy sources such as wind and solar power. New laws enacted in 2007 include authorizing a clean-coal task force and providing funding for the clean-coal research, extending a tax benefit for an additional four years (until 2012) for renewable power generation facilities such as wind farms, and improved funding for the Wyoming Game and Fish Department—the state's agency for managing both game and nongame species of wildlife. In addition, the legislature approved project money drawn on the interest in the Wyoming Wildlife and National Resources Trust Fund, established in 2005, to enhance aspen and sage on the Bates Creek watershed and aspen, sage, bitterbrush, and sumac near Lander, both for wildlife foraging.

SEE ALSO: Climate Models; Greenhouse Gases.

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Yemen

LOCATED IN THE southern region of the Arabian Peninsula, the Republic of Yemen has a land area of 203,849 sq. mi. (527,968 sq. km.), with a population of 22,389,000 (2006 est.) and a population density of 104 people per sq. mi. (40 people per sq. km.). Only 3 percent of the land in Yemen is arable, with 13 percent of that area being under permanent cultivation. In addition, 34 percent of the country is used as meadows or pasture, and 8 percent of the country is forested.

Yemen has a very low rate of per capita carbon dioxide emissions, being 0.8 metric tons per person in 1991, rising gradually to 1.03 metric tons in 2004. The entire electricity production in the country comes from fossil fuels, with liquid fuels being responsible for 96 percent of Yemen's carbon dioxide emissions. In terms of the sector producing the carbon dioxide in the country, 48 percent comes from transportation, with 20 percent from electricity and heat production, 20 percent from residential use, and 7 percent from manufacturing and construction.

The effect of global warming and climate change has already been dramatic in Yemen, with the alienation of some marginal arable land. The rise in temperature has made it harder to grow crops in arid parts of the country, and there has been extensive bleaching of coral reefs along the Red Sea coastline and the Socotra Archipelago.

The Yemen government of Ali Abdullah Saleh took part in the United Nations Framework Convention on Climate Change, signed in Rio de Janeiro in May 1992, and accepted the Kyoto Protocol to the UN Framework Convention on Climate Change on September 15, 2004, with it entering into force on February 16, 2005.

SEE ALSO: Climate Change, Effects; Drought.

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Younger Dryas

MARKING THE BOUNDARY between the Holocene and Pleistocene epochs, the Younger Dryas, a period of glacial conditions between 12,900 and 11,500 years ago, is named for *Dryas octopetala*, a flower that is adapted to the cold. *Dryas*' pollen is found in abundance in strata of this age. *Dryas*' pollen is also found in older strata, necessitating the term Younger Dryas to distinguish this time from older periods in which *Dryas*' pollen is abundant. Locked in an ice age, earth had finally warmed and the glaciers had begun to retreat 15,000 years ago. Counteracting this warming trend, the Younger Dryas reduced temperatures 50 degrees F in only a decade. Glaciers once more advanced in North America and Europe. Rainfall diminished, and frigid winds carried dust from central Asia throughout Europe.

Climatologists have identified three causes of the Younger Dryas, though it is uncertain whether all three operated at the same time. The fact that the Southern Hemisphere cooled before the Northern Hemisphere suggests that some mechanism cooled the south, whereas no mechanism was then operating in the north. The rapid change in climate that was the Younger Dryas may have caused the extinction of large mammals in North America and the collapse of the first Native American culture. In western Asia, the Younger Dryas may have prompted humans to invent agriculture. The end of the Younger Dryas ushered in the modern climate.

The Younger Dryas was part of the Cenozoic Ice Age, which locked the world in glaciers 100,000 years ago. The climate was particularly cold as recently as 18,000 years ago. From these frigid conditions, the climate gradually warmed until 15,000 years ago, the glaciers began to retreat. The Younger Dryas interrupted this warming trend, restoring glacial conditions to earth.

Climatologists have advanced three causes of the Younger Dryas. The leading explanation focuses on ocean currents. The Gulf Stream brings warm water from the tropics to the North Atlantic Ocean, warming the Atlantic coasts of North America and Europe. The Gulf Stream remained undisturbed as the North American glacier began to retreat north 15,000 years ago. In the initial centuries of retreat, the ice sheet emptied its water down the Mississippi River and into the Gulf of Mexico. By 12,900 years ago, however, the North American glacier had retreated to the Great Lakes. Melted water no longer flowed south down the Mississippi River but now went east along the St. Lawrence River to the Atlantic Ocean. This cold water shut down the Gulf Stream, robbing North America and Europe of its warmth and returning the climate to glacial conditions.

Climatologists have identified a second cause in the impact of an asteroid near the Great Lakes 12,900 years ago. Upon impact, the asteroid ejected enormous amounts of debris, dust, and ash into the atmosphere, blocking out sunlight and cooling the Earth. A third cause might have been the sudden, and unexplained, cessation of El Niño. Every two to seven years, warm water from the western Pacific Ocean and Indian Ocean flows east, warming the west coasts of South and North America. Without El Niño, these continents cooled, returning them to glacial conditions. Possibly more than one cause initiated the Younger Dryas.

The Younger Dryas ended as abruptly as it had begun, when temperatures rose 50 degrees F (28 degrees C) in just 10 years. Glaciers retreated to Antarctica, Greenland, and the North Pole, and rainfall again became abundant. The Cenozoic Ice Age, having cooled the Earth for 100,000 years, finally ended with the close of the Younger Dryas. Forests returned to Scandinavia, Germany, and North America. The return of warmth and rainfall, along with the invention of agriculture, allowed humans to settle in communities. With some exceptions, humans were no longer nomads. The end of the Younger Dryas initiated the modern climate. Although temperatures fluctuated in modernity, the retreat of glaciers has so far been permanent. Perhaps glaciers will return one day, though there is no evidence that they will come soon.

SEE ALSO: Climate; Cretaceous Era; Greenhouse Effect; Greenhouse Gases.

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Zambia

THE REPUBLIC OF Zambia lies in the interior of southern Africa and shares its borders with the Democratic Republic of Congo, Angola, Zimbabwe, and five other countries. From 1924, the country was known as Northern Rhodesia and was administered as a British protectorate by the United Kingdom. It achieved independence in 1964 and was renamed the Republic of Zambia for the Zambezi River.

Zambia is a landlocked country with a tropical climate. Most of the country consists of flat plateau with altitudes of 3,281–4,921 ft. (1,000–1,500 m.), which contributes to a milder climate. Average maximum temperatures during the hot, rainy season (November to March) range from 79–95 degrees F (26–35 degrees C); the cooler, dry season (April to August) brings high temperatures of 77–82 degrees F (25–28 degrees C). Annual rainfall ranges from 750 mm. in the south to more than 1,300 mm. in the north.

Rising temperatures and erratic rainfall are the primary symptoms of climate change. The most significant risks of climate change include water scarcity, reduced agricultural productivity, spread of vector-borne diseases such as malaria, risk of forest fires, reduced fish and wildlife stocks, and increased flooding and droughts. Farmers, rural households, and communities that depend on natural resources for their livelihoods are the most vulnerable to the effects of climate change. The government has embarked on a National Adaptation Programme for Action, with support from the United Nations Development Programme.

With declining per capita food production, food security is already a grave concern. Food-insecure people requiring humanitarian assistance number roughly one million. Food security may be further threatened by the effects of climate change, especially declining rainfall, and is exacerbated by the existing challenges of chronic poverty, HIV/AIDS, and an ineffective food distribution system. Northern Zambia is prone to flooding, whereas the south is increasingly dry.

Maize is an extremely important crop—the cornmeal-based *nshima* is served with nearly every meal—but maize is highly vulnerable to drought. Shorter rainy seasons, later start of rains, and declining rainfall are associated with reduced productivity of maize and other crops. Some farmers have switched to earlier-maturing, drought-resistant crops such as sweet potatoes as an adaptation strategy, but many are reluctant to pass up government maize subsidies and the steady demand for cornmeal.

Deforestation is a continuing problem, and the clearing of forests for agriculture, construction, and industrialization is likely to increase the risks of climate change. Forests protect watersheds, provide erosion control, and absorb carbon that would otherwise contribute to global warming. Deforestation rates are estimated between 200,000 and 300,000 hectares per year. Extensive forest exploitation is related to the production of charcoal, which contributes to carbon monoxide emissions. Eighty-three percent of urban households use charcoal for cooking fuel.

Miombo woodlands provide an important source of timber and nontimber forest products. Although Miombo woodlands require regular burning, rising temperatures and declining rainfall may lead to increases in wildfires. Wildfires and deforestation threaten traditional bark-hive beekeeping and the reproductive capacity of Mophane caterpillar products, an important source of nutrition and income for rural households.

SEE ALSO: Climate Change, Effects; Current; Deforestation; Drought.

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Zimbabwe

A LANDLOCKED COUNTRY located in southern Africa, Zimbabwe (formerly Rhodesia) has a land area of 150,871 sq. mi. (390,757 sq. km.), with a population of 13,349,000 (2006 est.) and a population density of 85 people per sq. mi. (33 people per sq. km.). Its economy has been heavily reliant on agriculture, with 7 percent of the country being arable, 13 percent being used as meadows or pasture, and 62 percent being forested.

In Zimbabwe, some 53.3 percent of electricity generation comes from fossil fuels, with 46.7 percent from hydropower. This extensive use of hydropower, much of it from the Kariba Dam, as well as the declining economy in the country, has led to Zimbabwe having a low rate of per capita carbon dioxide emissions—1.6 metric tons per person in 1990, falling to 0.81 metric tons in 2004. In 1999, electricity production contributed 55 percent of Zimbabwe's carbon dioxide emissions, with manufacturing and construction making up 23 percent and transportation a further 20 percent. In terms of the source of carbon dioxide emissions, 86 percent were from solid fuels, with 10 percent from liquid fuels, and most of the remainder from gaseous fuels. Problems with electricity supplies in the country have led to many people reverting to the use of private generators. The economy has also been badly damaged by a decline in the demand for tobacco—the most important single export in the country.

The effects of global warming on the country have been a steady alienation of marginal arable land, which, together with a general decline in the economy, has seen widespread impoverishment. The rise in temperature has also affected the productivity of fish farms. The Zimbabwean government of Robert Mugabe took part in the United Nations Framework Convention on Climate Change, signed in Rio de Janeiro in May 1992, but the government has so far not expressed an opinion on the Kyoto Protocol to the UN Framework Convention on Climate Change. However C. Madova, co-vice president of the African Region at the World Bank addressed the Fifth World Bank Conference on Environmentally and Socially Sustainable Development in Washington, D.C., in December 1997, supporting measures to reduce world emissions.

SEE ALSO: Carbon Dioxide; Climate Change, Effects.

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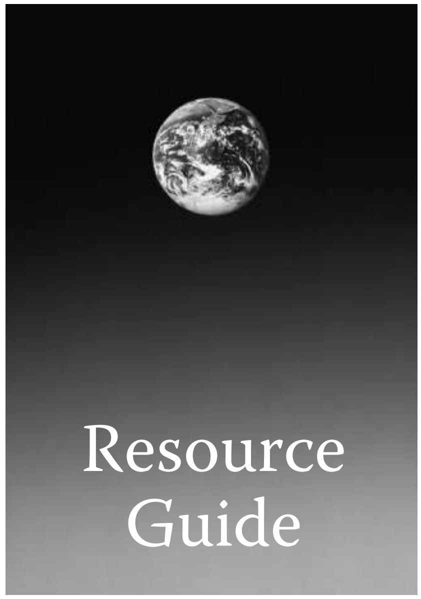

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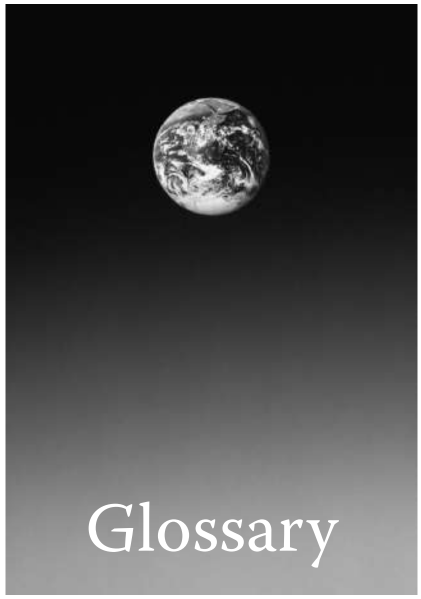

Glossary

A

Acid Deposition

Acidic aerosols in the atmosphere are removed from the atmosphere by wet deposition (rain, snow, fog) or dry deposition (particles sticking to vegetation). Acidic aerosols are present in the atmosphere primarily due to discharges of gaseous sulfur oxides (sulfur dioxide) and nitrogen oxides.

Aerosol

A collection of airborne solid or liquid particles, with a typical size between 0.01 and 10 micrometers (μm) and residing in the atmosphere for at least several hours. Aerosols may be of either natural or anthropogenic origin. Aerosols may influence climate in two ways: directly through scattering and absorbing radiation, and indirectly through acting as condensation nuclei for cloud formation or modifying the optical properties and lifetime of clouds.

Afforestation

The planting of new forests on land which historically had been covered by forest.

Albedo

The fraction of solar radiation reflected by a surface or object, often expressed as a percentage. Most snow-covered surfaces have a high albedo; the albedo of soils ranges from high to low; vegetation covered surfaces and oceans have a low albedo. The Earth's albedo varies mainly through varying cloudiness, snow, ice, leaf area, and land cover changes.

Alleroed

A village in Denmark whose name is used for a warm period at the end of the last glacial.

Alliance of Small Island States (AOSIS)

The group of Pacific and Caribbean nations who call for relatively fast action by developed nations to reduce greenhouse gas emissions. The AOSIS countries fear the effects of rising sea levels and increased storm activity predicted to accompany global warming. Its plan is to hold Annex I Parties to a 20 percent reduction in carbon dioxide emissions by 2005.

Allometric Equation

An equation that uses known growth measurements to estimate related unknown growth measurements.

Alternative Energy

Energy derived from nontraditional sources (e.g., compressed natural gas, solar, hydroelectric, wind, and others).

Annex I Parties

Industrialized countries that, as parties to the Framework Convention on Climate Change, have pledged to reduce their greenhouse gas emissions by the year 2000 to 1990 levels. Annex I Parties consist of countries belonging to the Organisation for Economic Co-operation and Development (OECD) and countries designated as Economies-in-Transition.

Anthropogenic

Made by people or resulting from human activities. Usually used in the context of emissions that are produced as a result of human activities.

Atmosphere

The gaseous envelope surrounding the Earth. The dry atmosphere consists almost entirely of nitrogen (78.1 percent volume mixing ratio) and oxygen (20.9 percent volume mixing ratio), together with a number of trace gases, such as argon (0.93 percent volume mixing ratio), helium, radiatively active greenhouse gases such as carbon dioxide (0.035 percent volume mixing ratio), and ozone. In addition the atmosphere contains water vapor, whose amount is highly variable but typically 1 percent volume mixing ratio. The atmosphere also contains clouds and aerosols. The atmosphere can be divided into a number of layers according to its mixing or chemical characteristics, generally determined by its thermal properties (temperature). The layer nearest the Earth is the troposphere, which reaches up to an altitude of about about 5 mi. (8 km) in the polar regions and up to nearly 11 mi. (17 km) above the equator. The stratosphere, which reaches to an altitude of about 31 mi. (50 km.) lies atop the troposphere. The mesosphere which extends up to 50–56 mi. (80–90 km.) is atop the stratosphere, and finally, the thermosphere, or ionosphere, gradually diminishes and forms a fuzzy border with outer space.

Atmospheric Lifetime

The lifetime of a greenhouse gas refers to the approximate amount of time it would take for the anthropogenic increment to an atmospheric pollutant concentration to return to its natural level (assuming emissions cease) as a result of either being converted to another chemical compound or being taken out of the atmosphere via a sink. This time depends on the pollutant's sources and sinks as well as its reactivity. The lifetime of a pollutant is often considered in conjunction with the mixing of pollutants in the atmosphere; a long lifetime will allow the pollutant to mix throughout the atmosphere. Average lifetimes can vary from about a week (sulfate aerosols) to more than a century (chlorofluorocarbons [CFCs], carbon dioxide).

B

Baseline Emissions

The emissions that would occur without policy intervention (in a business-as-usual scenario). Baseline estimates are needed to determine the effectiveness of emissions reduction programs.

Berlin Mandate

A ruling negotiated at the first Conference of the Parties (COP 1), which took place in March, 1995, concluding that the present commitments under the Framework Convention on Climate Change are not adequate. Under the Framework Convention, developed countries pledged to take measures aimed at returning their greenhouse gas emissions to 1990 levels by the year 2000.

Biogeochemical Cycle

The chemical interactions that take place among of key chemical constituents essential to life, such as carbon, nitrogen, oxygen, and phosphorus.

Biomass

Organic nonfossil materials that are biological in origin, including organic material (both living and dead) from above and below ground, for example, trees, plants, crops, roots, and animals and animal waste.

Biomass Energy

Energy produced by combusting renewable biomass materials such as wood. The carbon dioxide emitted from burning biomass will not increase total atmospheric carbon dioxide if this consumption is done on a sustainable basis (i.e., if in a given period of time, regrowth of biomass takes up as much carbon dioxide as is released from biomass combustion). Biomass energy is often suggested as a replacement for fossil fuel combustion, which has large greenhouse gas emissions.

Biome
A naturally occurring community of flora and fauna (or the region occupied by such a community) adapted to the particular conditions in which they occur (e.g., tundra).

Biosphere
The region of land, oceans, and atmosphere inhabited by living organisms.

Black Carbon
Operationally defined species based on measurement of light absorption and chemical reactivity and/or thermal stability; consists of soot, charcoal, and/or possible light-absorbing refractory organic matter.

Borehole
Any exploratory hole drilled into the Earth or ice to gather geophysical data. Climate researchers often take ice core samples, a type of borehole, to predict atmospheric composition in earlier years.

Bubble
A system that lets several countries meet a reduction target together while having different individual targets.

C

Capital Stocks
The accumulation of machines and structures that are available to an economy at any point in time to prune goods or render services. These activities usually require a quantity of energy that is determined largely by the rate at which that machine or structure is used.

Carbon Cycle
The global scale exchange of carbon among its reservoirs, namely the atmosphere, oceans, vegetation, soils, and geologic deposits and minerals. This involves components in food chains, in the atmosphere as carbon dioxide, in the hydrosphere, and in the geosphere.

Carbon Dioxide (CO_2)
The greenhouse gas whose concentration is being most affected directly by human activities. CO_2 also serves as the reference to compare all other greenhouse gases. The major source of CO_2 emissions is fossil fuel combustion. CO_2 emissions are also a product of forest clearing, biomass burning, and non-energy production processes such as cement production. Atmospheric concentrations of CO_2 have been increasing at a rate of about 0.5 percent per year and are now about 30 percent above preindustrial levels.

Carbon Equivalent (CE)
A metric measure used to compare the emissions of the different greenhouse gases based upon their global warming potential (GWP). Greenhouse gas emissions in the United States are most commonly expressed as "million metric tons of carbon equivalents" (MMTCE). Global warming potentials are used to convert greenhouse gases to carbon dioxide equivalents.

Carbon Sequestration
The uptake and storage of carbon. Trees and plants, for example, absorb carbon dioxide, release the oxygen and store the carbon. Fossil fuels were at one time biomass and continue to store the carbon until burned.

Carbon Sinks
Carbon reservoirs and conditions that take in and store more carbon (carbon sequestration) than they release. Carbon sinks can serve to partially offset greenhouse gas emissions. Forests and oceans are common carbon sinks.

Chlorofluorocarbons and Related Compounds
This family of anthropogenic compounds includes chlorofluorocarbons (CFCs), bromofluorocarbons (halons), methyl chloroform, carbon tetrachloride, methyl bromide, and hydrochlorofluorocarbons (HCFCs). These compounds have been shown to deplete stratospheric ozone, and therefore are typically referred to as ozone-depleting substances. The most ozone-depleting of these compounds are being phased out under the Montreal Protocol.

Clean Development Mechanisms (CDM)
Article 12 of the Kyoto Protocol provides for the CDM whereby developed countries are able to invest in emissions-reducing projects in developing countries to obtain credit to assist in meeting their assigned

amounts. The details of the CDM have yet to be negotiated at the international level.

Climate
The average weather for a particular region and time period. Climate is not the same as weather, but rather, it is the average pattern of weather for a particular region. Climatic elements include precipitation, temperature, humidity, sunshine, wind velocity, phenomena such as fog, frost, and hail storms, and other measures of the weather.

Climate Change
The term *climate change* refers to all forms of climatic inconsistency. Climate change has been used synonymously with the term *global warming*.

Climate Change Action Plan
Unveiled in October 1993 by President Clinton, the CCAP is the U.S. plan for meeting its pledge to reduce greenhouse gas emissions under the terms of the Framework Convention on Climate Change (FCCC). The goal of the plan was to reduce U.S. emissions of greenhouse gases to 1990 levels by 2000.

Climate Feedback
An atmospheric, oceanic, terrestrial, or other process that is activated by the direct climate change induced by changes in radiative forcing. Climate feedbacks may increase (positive feedback) or diminish (negative feedback) the magnitude of the climate change.

Climate Lag
The delay that occurs in climate change as a result of some factor that changes only very slowly.

Climate Model
A quantitative way of representing the interactions of the atmosphere, oceans, land surface, and ice.

Climate Modeling
The simulation of the climate using computer-based models.

Climate Sensitivity
The equilibrium response of the climate to a change in radiative forcing; for example, a doubling of the carbon dioxide concentration.

Climate System (or Earth System)
The five physical components (atmosphere, hydrosphere, cryosphere, lithosphere, and biosphere) that are responsible for the climate and its variations.

Cloud Condensation Nuclei
Airborne particles that serve as an initial site for the condensation of liquid water and which can lead to the formation of cloud droplets.

CO_2 Fertilization
The enhancement of plant growth as a result of elevated atmospheric CO_2 concentrations.

Coalbed Methane
Coalbed methane is methane contained in coal seams, and is often referred to as virgin coalbed methane, or coal seam gas. For more information, visit the Coalbed Methane Outreach program site.

Coal Mine Methane
Coal mine methane is the subset of CBM that is released from the coal seams during the process of coal mining. For more information, visit the Coalbed Methane Outreach program site.

Cogeneration
The process by which two different and useful forms of energy are produced at the same time. For example, while boiling water to generate electricity, the leftover steam can be sold for industrial processes or space heating.

Compost
Decayed organic matter that can be used as a fertilizer or soil additive.

Conference of the Parties (COP)
The supreme body of the United Nations Framework Convention on Climate Change (UNFCCC). It comprises more than 180 nations that have ratified the Convention. Its first session was held in Berlin, Germany, in 1995 and it is expected to continue meeting on a yearly basis. The COP's role is to promote and review the implementation of the Convention.

Cryosphere
One of the interrelated components of the Earth's system, the cryosphere is frozen water in the form

of snow, permanently frozen ground (permafrost), floating ice, and glaciers. Fluctuations in the volume of the cryosphere cause changes in ocean sea level, which directly impact the biosphere.

D

Deforestation

Those practices or processes that result in the change of forested lands to nonforest uses. This is often cited as one of the major causes of the enhanced greenhouse effect for two reasons: (1) the burning or decomposition of the wood releases carbon dioxide; and (2) trees that once removed carbon dioxide from the atmosphere in the process of photosynthesis are no longer present and contributing to carbon storage.

Desertification

The progressive destruction or degradation of existing vegetative cover to form desert. This can occur due to overgrazing, deforestation, drought, and the burning of extensive areas.

Diurnal Temperature Range

The difference between maximum and minimum temperature over a period of 24 hours.

E

Economic Potential

The portion of the technical potential for GHG emissions reductions or energy-efficiency improvements that could be achieved cost-effectively in the absence of market barriers. The achievement of the economic potential requires additional policies and measures to break down market barriers.

Eddy Mixing

Mixing due to small scale turbulence processes (eddies). Such processes cannot be explicitly resolved by even the finest-resolution atmosphere-ocean general ciculation models currently in uses and so their effects must be related to the larger-scale conditions.

El Niño

A climatic phenomenon occurring irregularly, but generally every three to five years. El Niños often first become evident during the Christmas season (El Niño means Christ-child) in the surface oceans of the eastern tropical Pacific Ocean. The phenomenon involves seasonal changes in the direction of the tropical winds over the Pacific and abnormally warm surface ocean temperatures. The changes in the tropics are most intense in the Pacific region; these changes can disrupt weather patterns throughout the tropics and can extend to higher latitudes.

Emission Permit

A nontransferable or tradeable allocation of entitlements by a government to an individual firm to emit a specific amount of a substance.

Emission Quota

The portion or share of total allowable emissions assigned to a country or group of countries within a framework of maximum total emissions and mandatory allocations of resources or assessments.

Emissions

The release of a substance (usually a gas when referring to climate change) into the atmosphere.

Emission Standard

A level of emission that under law may not be exceeded.

Energy Intensity

Ration of energy consumption and economic or physical output. At the national level, energy intensity is the ratio of total domestic primary energy consumption or final energy consumption to gross domestic product or physical output.

Enhanced Greenhouse Effect

The natural greenhouse effect has been enhanced by anthropogenic emissions of greenhouse gases. Increased concentrations of carbon dioxide, methane, and nitrous oxide, CFCs, HFCs, PFCs, SF_6, NF_3, and other photochemically important gases caused by human activities such as fossil fuel consumption and adding waste to landfills trap more infrared radiation, thereby exerting a warming influence.

Equilibrium Response

The steady state response of the climate system (or a climate model) to an imposed radiative forcing.

Evapotranspiration
The sum of evaporation and plant transpiration. Potential evapotranspiration is the amount of water that could be evaporated or transpired at a given temperature and humidity, if there was water available.

F

Fluorocarbons
Carbon-fluorine compounds that often contain other elements such as hydrogen, chlorine, or bromine. Common fluorocarbons include chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs), and perfluorocarbons (PFCs).

Forcing Mechanism
A process that alters the energy balance of the climate system, i.e., changes the relative balance between incoming solar radiation and outgoing infrared radiation from Earth. Such mechanisms include changes in solar irradiance, volcanic eruptions, and enhancement of the natural greenhouse effect by emissions of greenhouse gases.

G

Geosphere
The soils, sediments, and rock layers of the Earth's crust, both continental and beneath the ocean floors.

Glacier
A multiyear surplus accumulation of snowfall in excess of snowmelt on land and resulting in a mass of ice at least 0.1 km2 in area that shows some evidence of movement in response to gravity. A glacier may terminate on land or in water. Glaciers are found on every continent except Australia.

Global Warming
Global warming is an average increase in the temperature of the atmosphere near the Earth's surface and in the troposphere, which can contribute to changes in global climate patterns. Global warming can occur from many causes, both natural and human induced.

Global Warming Potential (GWP)
Defined as the cumulative radiative forcing effects of a gas over a specified time horizon resulting from the emission of a unit mass of gas relative to a reference gas. The GWP-weighted emissions of direct greenhouse gases in the U.S. inventory are presented in terms of equivalent emissions of carbon dioxide, using units of teragrams of carbon dioxide equivalents.

Greenhouse Effect
Trapping and buildup of heat in the atmosphere (troposphere) near the Earth's surface. Some of the heat flowing back toward space from the Earth's surface is absorbed by water vapor, carbon dioxide, ozone, and several other gases in the atmosphere and then reradiated back toward the Earth's surface. If the atmospheric concentrations of these greenhouse gases rise, the average temperature of the lower atmosphere will gradually increase.

Greenhouse Gas (GHG)
Any gas that absorbs infrared radiation in the atmosphere. Greenhouse gases include, but are not limited to, water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), ozone (O_3), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6).

H

Halocarbons
Compounds containing either chlorine, bromine, or fluorine and carbon. Such compounds can act as powerful greenhouse gases in the atmosphere. The chlorine and bromine containing halocarbons are also involved in the depletion of the ozone layer.

Hydrocarbons
Substances containing only hydrogen and carbon. Fossil fuels are made up of hydrocarbons.

Hydrochlorofluorocarbons (HCFCs)
Compounds containing hydrogen, fluorine, chlorine, and carbon atoms. Although ozone-depleting substances, they are less potent at destroying stratospheric ozone than chlorofluorocarbons (CFCs). They have been introduced as temporary replacements for CFCs and are also greenhouse gases.

Hydrologic Cycle
The process of evaporation, vertical and horizontal transport of vapor, condensation, precipitation, and the flow of water from continents to oceans. It is a

major factor in determining climate through its influence on surface vegetation, the clouds, snow and ice, and soil moisture. The hydrologic cycle is responsible for 25 to 30 percent of the midlatitudes' heat transport from the equatorial to polar regions.

Hydrosphere
The component of the climate system comprising liquid surface and subterranean water, such as oceans, seas, rivers, freshwater lakes, underground water.

I

Ice Core
A cylindrical section of ice removed from a glacier or an ice sheet in order to study climate patterns of the past. By performing chemical analyses on the air trapped in the ice, scientists can estimate the percentage of carbon dioxide and other trace gases in the atmosphere at a given time.

Infrared Radiation
Radiation emitted by the Earth's surface, the atmosphere and the clouds. It is also known as terrestrial or longwave radiation. Infrared radiation has a distinctive range of wavelengths longer than the wavelength of the red color in the visible part of the spectrum.

Intergovernmental Panel on Climate Change (IPCC)
The IPCC was established jointly by the United Nations Environment Program and the World Meteorological Organization in 1988. The purpose of the IPCC is to assess information in the scientific and technical literature related to all significant components of the issue of climate change. With its capacity for reporting on climate change, its consequences, and the viability of adaptation and mitigation measures, the IPCC is also looked to as the official advisory body to the world's governments on the state of the science of the climate change issue.

L

Landfill
Land waste disposal site in which waste is generally spread in thin layers, compacted, and covered with a fresh layer of soil each day.

Longwave Radiation
The radiation emitted in the spectral wavelength greater than 4 micrometers corresponding to the radiation emitted from the Earth and atmosphere.

M

Methane (CH_4)
A hydrocarbon that is a greenhouse gas with a global warming potential most recently estimated at 23 times that of carbon dioxide (CO_2). Methane is produced through anaerobic (without oxygen) decomposition of waste in landfills, animal digestion, decomposition of animal wastes, production and distribution of natural gas and petroleum, coal production, and incomplete fossil fuel combustion.

Metric Ton
Common international measurement for the quantity of greenhouse gas emissions. A metric ton is equal to 2,205 lbs. or 1.1 short tons.

Mount Pinatubo
An active volcano located in the Philippine Islands that erupted in 1991. The eruption of Mount Pinatubo ejected enough particulate and sulfate aerosol matter into the upper atmosphere to block some of the incoming solar radiation from reaching Earth's atmosphere.

N

Natural Gas
Underground deposits of gases consisting of 50 to 90 percent methane (CH_4) and small amounts of heavier gaseous hydrocarbon compounds such as propane (C_3H_8) and butane (C_4H_{10}).

Nitrogen Oxides (NOx)
Gases consisting of one molecule of nitrogen and varying numbers of oxygen molecules. Nitrogen oxides are produced in the emissions of vehicle exhausts and from power stations. In the atmosphere, nitrogen oxides can contribute to formation of smog, can impair visibility, and have health consequences.

Nitrous Oxide (N_2O)
A powerful greenhouse gas with a global warming potential of 296 times that of carbon dioxide (CO_2). Major sources of nitrous oxide include soil cultivation

practices, especially the use of commercial and organic fertilizers, fossil fuel combustion, nitric acid production, and biomass burning.

O

Oxidize

To chemically transform a substance by combining it with oxygen.

Ozone (O_3)

Ozone, the triatomic form of oxygen (O_3), is a gaseous atmospheric constituent. In the troposphere, it is created both naturally and by photochemical reactions involving gases resulting from human activities (photochemical smog). In high concentrations, tropospheric ozone can be harmful to a wide range of living organisms. Tropospheric ozone acts as a greenhouse gas. In the stratosphere, ozone is created by the interaction between solar ultraviolet radiation and molecular oxygen (O_2). Stratospheric ozone plays a decisive role in the stratospheric radiative balance. Depletion of stratospheric ozone, due to chemical reactions that may be enhanced by climate change, results in an increased ground-level flux of ultraviolet (UV-) B radiation.

Ozone-Depleting Substance (ODS)

A family of man-made compounds that includes chlorofluorocarbons (CFCs), bromofluorocarbons (halons), methyl chloroform, carbon tetrachloride, methyl bromide, and hydrochlorofluorocarbons (HCFCs). These compounds have been shown to deplete stratospheric ozone, and therefore are typically referred to as ODSs.

Ozone Layer

The layer of ozone that begins approximately 9 mi. (15 km.) above Earth and thins to an almost negligible amount at about 31 mi. (50 km.), shields the Earth from harmful ultraviolet radiation from the Sun.

Ozone Precursors

Chemical compounds, such as carbon monoxide, methane, nonmethane hydrocarbons, and nitrogen oxides, which in the presence of solar radiation react with other chemical compounds to form ozone, mainly in the troposphere.

P

Particulate Matter (PM)

Very small pieces of solid or liquid matter such as particles of soot, dust, fumes, mists, or aerosols.

Parts per Billion (ppb)

Number of parts of a chemical found in one billion parts of a particular gas, liquid, or solid mixture.

Parts per Million (ppm)

Number of parts of a chemical found in one million parts of a particular gas, liquid, or solid.

Perfluorocarbons (PFCs)

A group of human-made chemicals composed of carbon and fluorine only. These chemicals were introduced as alternatives, along with hydrofluorocarbons, to the ozone-depleting substances.

Photosynthesis

The process by which plants take CO_2 from the air (or bicarbonate in water) to build carbohydrates, releasing O_2 in the process. There are several pathways of photosynthesis with different responses to atmospheric CO_2 concentrations.

Precession

The comparatively slow torquing of the orbital planes of all satellites with respect to the Earth's axis, due to the bulge of the Earth at the equator which distorts the Earth's gravitational field.

R

Radiation

Energy transfer in the form of electromagnetic waves or particles that release energy when absorbed by an object.

Radiative Forcing

Radiative forcing is the change in the net vertical irradiance (expressed in Watts per square meter: Wm-2) at the tropopause due to an internal change or a change in the external forcing of the climate system, such as, for example, a change in the concentration of carbon dioxide or the output of the Sun.

Recycling

Collecting and reprocessing a resource so it can be used again. An example is collecting aluminum cans, melting them down, and using the aluminum to make new cans or other aluminum products.

Reforestation
Planting of forests on lands that have previously contained forests but that have been converted to some other use.

Residence Time
The average time spent in a reservoir by an individual atom or molecule. With respect to greenhouse gases, residence time usually refers to how long a particular molecule remains in the atmosphere.

Respiration
The biological process whereby living organisms convert organic matter to CO_2, releasing energy and consuming O_2.

S

Short Ton
Common measurement for a ton in the United States. A short ton is equal to 2,000 lbs. or 0.907 metric tons.

Sink
Any process, activity, or mechanism which removes a greenhouse gas, an aerosol, or a precursor of a greenhouse gas or aerosol from the atmosphere.

Soil Carbon
A major component of the terrestrial biosphere pool in the carbon cycle. The amount of carbon in the soil is a function of the historical vegetative cover and productivity, which in turn is dependent in part upon climatic variables.

Solar Radiation
Radiation emitted by the Sun. It is also referred to as shortwave radiation. Solar radiation has a distinctive range of wavelengths (spectrum) determined by the temperature of the Sun.

Stratosphere
Region of the atmosphere between the troposphere and mesosphere, having a lower boundary of approximately 5 mi. (8 km.) at the poles to 9 mi. (15 km.) at the equator and an upper boundary of approximately 31 mi. (50 km.). Depending upon latitude and season, the temperature in the lower stratosphere can increase, be isothermal, or even decrease with altitude, but the temperature in the upper stratosphere generally increases with height due to absorption of solar radiation by ozone.

Streamflow
The volume of water that moves over a designated point over a fixed period of time. It is often expressed as cubic feet per second (ft3/sec).

Sulfate Aerosols
Particulate matter that consists of compounds of sulfur formed by the interaction of sulfur dioxide and sulfur trioxide with other compounds in the atmosphere. Sulfate aerosols are injected into the atmosphere from the combustion of fossil fuels and the eruption of volcanoes.

Sulfur Hexafluoride (SF_6)
A colorless gas soluble in alcohol and ether, slightly soluble in water. A very powerful greenhouse gas used primarily in electrical transmission and distribution systems and as a dielectric in electronics.

T

Thermohaline Circulation
Large-scale density-driven circulation in the ocean, caused by differences in temperature and salinity. In the North Atlantic the thermohaline circulation consists of warm surface water flowing northward and cold deep water flowing southward, resulting in a net poleward transport of heat.

Trace Gas
Any one of the less common gases found in the Earth's atmosphere. Nitrogen, oxygen, and argon make up more than 99 percent of the Earth's atmosphere. Other gases, such as carbon dioxide, water vapor, methane, oxides of nitrogen, ozone, and ammonia, are considered trace gases.

Troposphere
The lowest part of the atmosphere from the surface to about 6 mi./10 km. in altitude in mid-latitudes (ranging from 5.5 mi. [9 km.] in high latitudes to 10 mi. [16 km.] in the tropics on average) where clouds and "weather" phenomena occur.

U

Ultraviolet Radiation (UV)

The energy range just beyond the violet end of the visible spectrum. Although ultraviolet radiation constitutes only about 5 percent of the total energy emitted from the sun, it is the major energy source for the stratosphere and mesosphere, playing a dominant role in both energy balance and chemical composition.

United Nations Framework Convention on Climate Change (UNFCCC)

The Convention on Climate Change sets an overall framework for intergovernmental efforts to tackle the challenge posed by climate change. It recognizes that the climate system is a shared resource whose stability can be affected by industrial and other emissions of carbon dioxide and other greenhouse gases.

W

Wastewater

Water that has been used and contains dissolved or suspended waste materials.

Water Vapor

The most abundant greenhouse gas, it is the water present in the atmosphere in gaseous form. Water vapor is a part of the natural greenhouse effect.

Weather

Atmospheric condition at any given time or place. It is measured in terms of such things as wind, temperature, humidity, atmospheric pressure, cloudiness, and precipitation.

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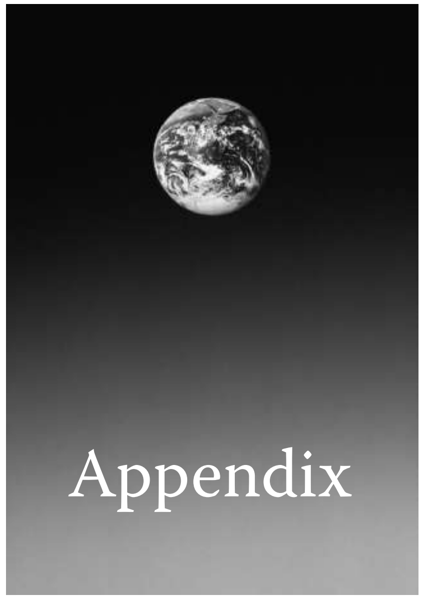
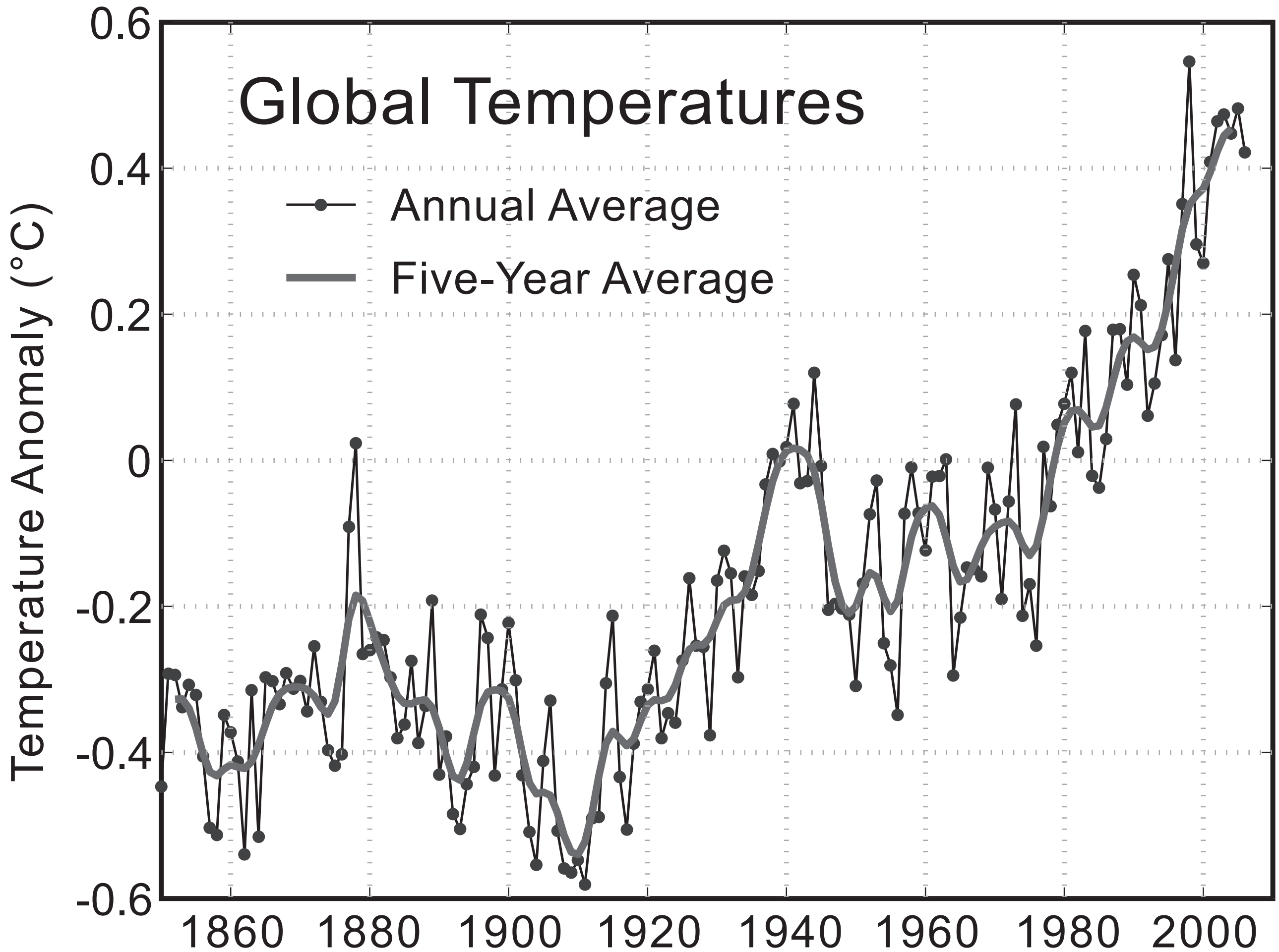


Global Temperatures
Recent Sea Level Rise
Achieved Hurricane Intensity Under Idealized Conditions
Annual Carbon Emissions by Region
Ice Age Temperature Changes
Sixty-Five Million Years of Climate Change
Five Million Years of Climate Change From Sediment Cores
Reconstructed Temperature, 2,000 Years
Holocene Temperature Variations
Phanerozoic Climate Change
Global Fossil Carbon Emissions
Global Warming Predictions
Global Warming Projections
Economic Efficiency of Fossil Fuel Usage
Fossil Fuel Usage per Person
Global Trends in Greenhouse Gases
Milankovitch Cycles

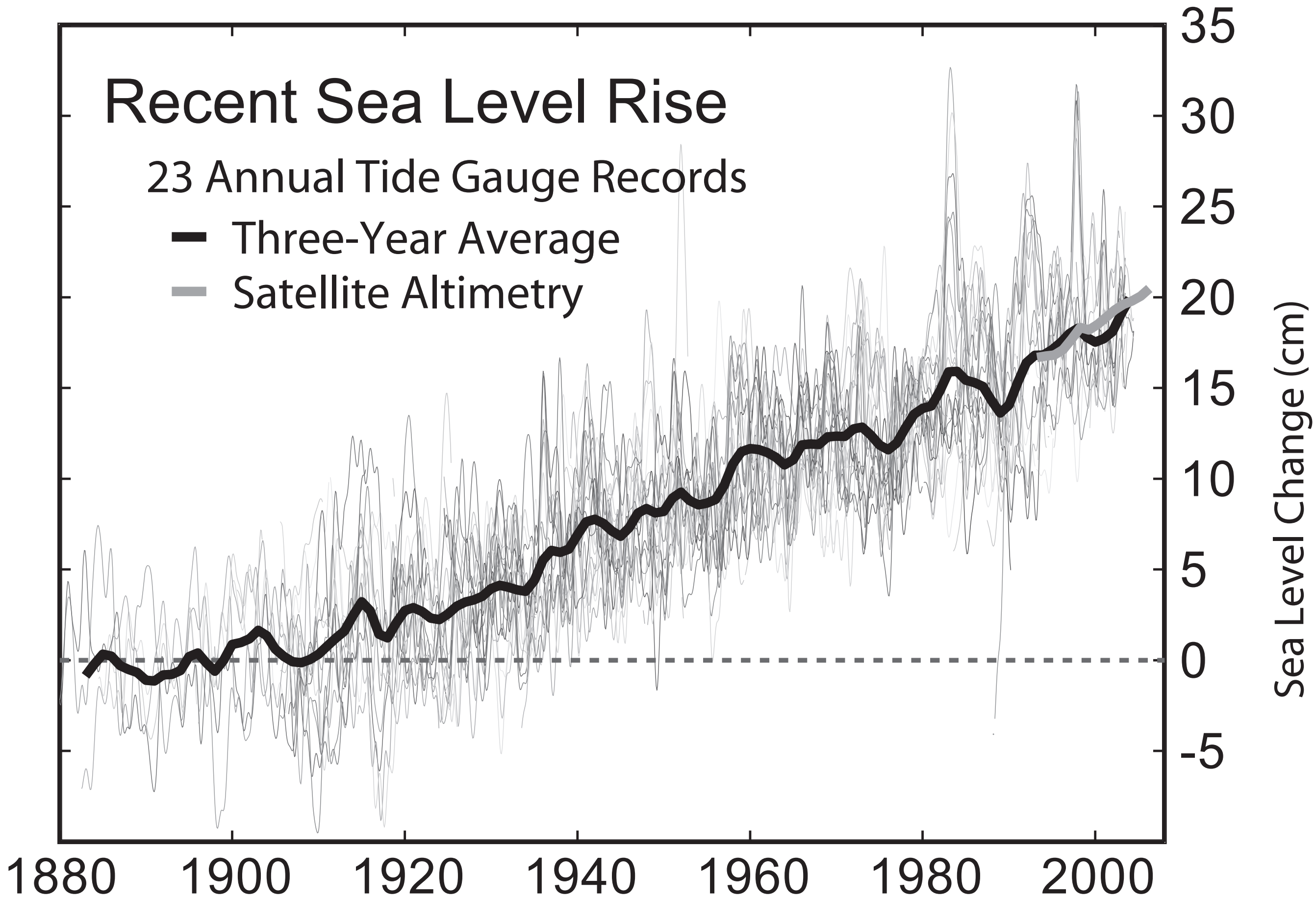
Graphic Plots and Text Prepared by
Robert A. Rohde
University of California, Berkeley



This image shows the instrumental record of global average temperatures as compiled by the Climatic Research Unit of the University of East Anglia and the Hadley Centre of the UK Meteorological Office. Data set HadCRUT3 was used, which follows the methodology outlined by Brohan et al. (2006). Following the common practice of the IPCC, the zero on this figure is the mean temperature from 1961 to1990.

The uncertainty in the analysis techniques leading to these measurements is discussed in Foland et al. (2001) and Brohan et al. (2006). They estimate that global averages since ~1950 are within ~0.05 degrees C of their reported value with 95 percent confidence. In the recent period, these uncertainties are driven primarily by considering the potential impact of regions where no temperature record is available. For averages prior to ~1890, the uncertainty reaches ~0.15 degrees C driven primarily by limited sampling and the effects of changes in sea surface measurement techniques. Uncertainties between 1880 and 1890 are intermediate between these values.

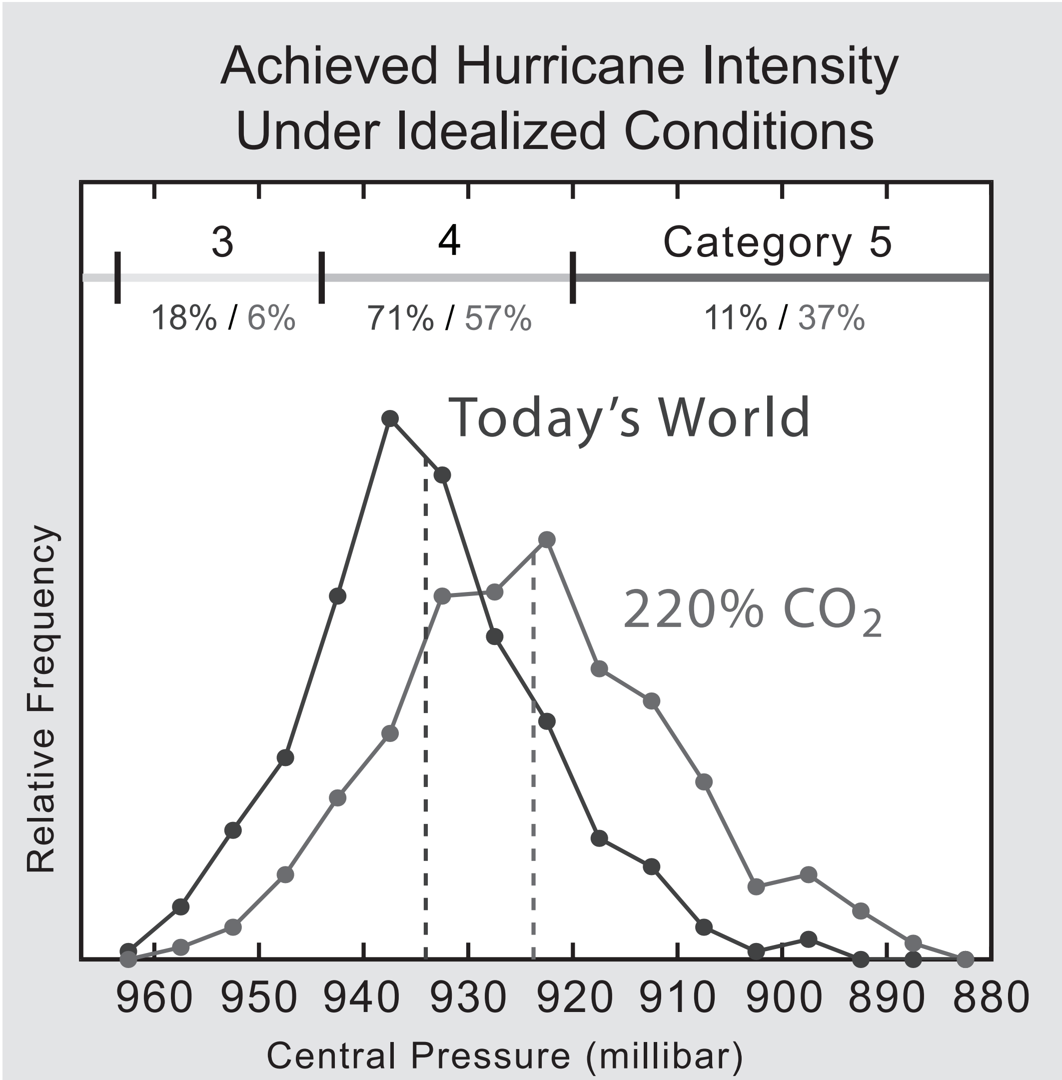
Incorporating these uncertainties, Foland et al. (2001) estimated the global temperature change from 1901 to 2000 as 0.57 ± 0.17 degrees C, which contributed to the 0.6 ± 0.2 degrees C estimate reported by the Intergovernmental Panel on Climate Change (IPCC 2001a, [1]). Both estimates are 95 percent confidence intervals.



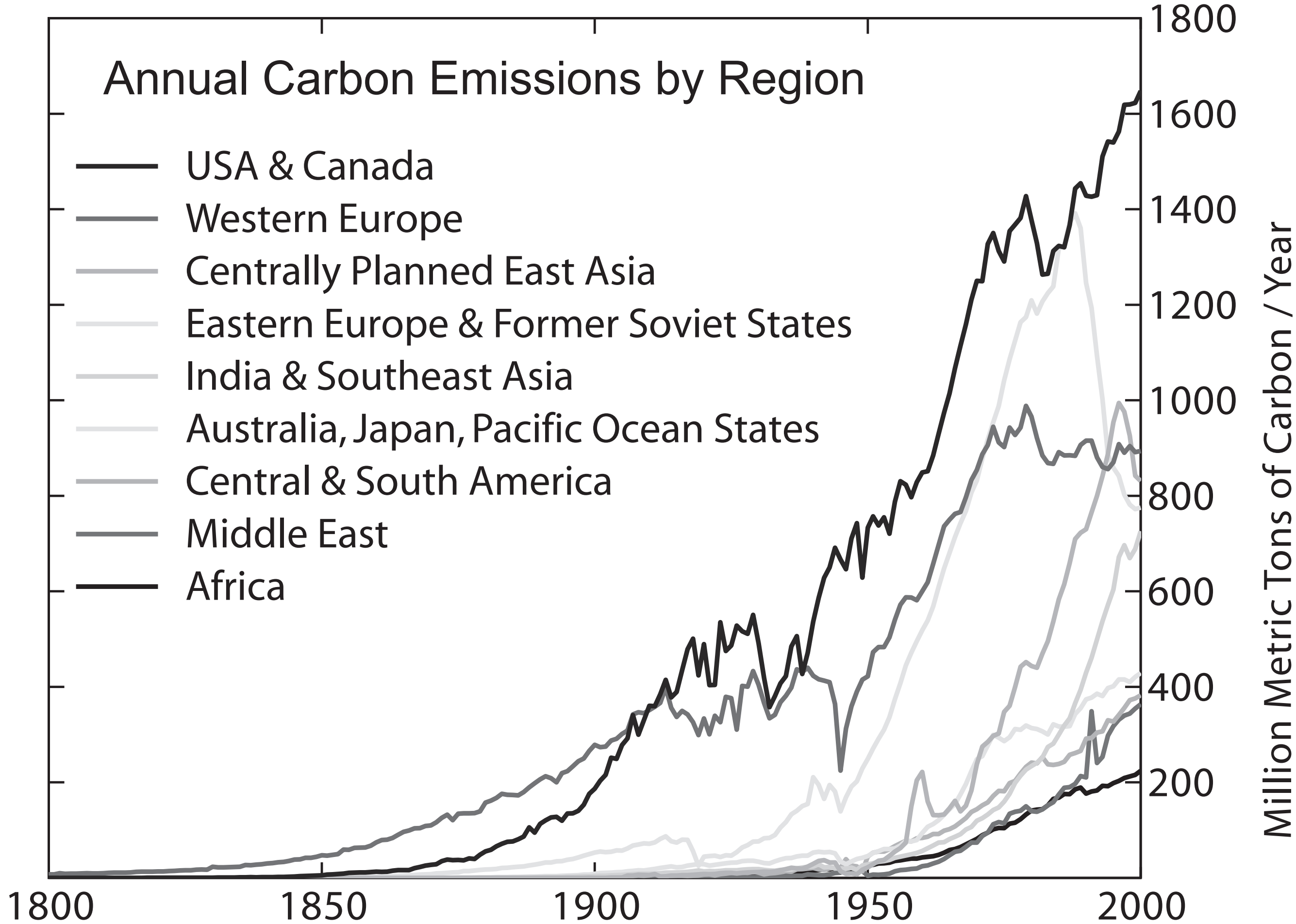
This figure shows the change in annually averaged sea level at 23 geologically stable tide gauge sites with long-term records as selected by Douglas (1997). The thick dark line is a three-year moving average of the instrumental records. This data indicates a sea level rise of ~18.5 cm. from 1900–2000. Because of the limited geographic coverage of these records, it is not obvious whether the apparent decadal fluctuations represent true variations in global sea level or merely variations across regions that are not resolved.

For comparison, the recent annually averaged satellite altimetry data from TOPEX/Poseidon are shown in the thick gray line. These data indicate a somewhat higher rate of increase than tide gauge data, however the source of this discrepancy is not obvious. It may represent systematic error in the satellite record and/or incomplete geographic sampling in the tide gauge record. The month-to-month scatter on the satellite measurements is roughly the thickness of the plotted gray curve.

Much of recent sea level rise has been attributed to global warming.

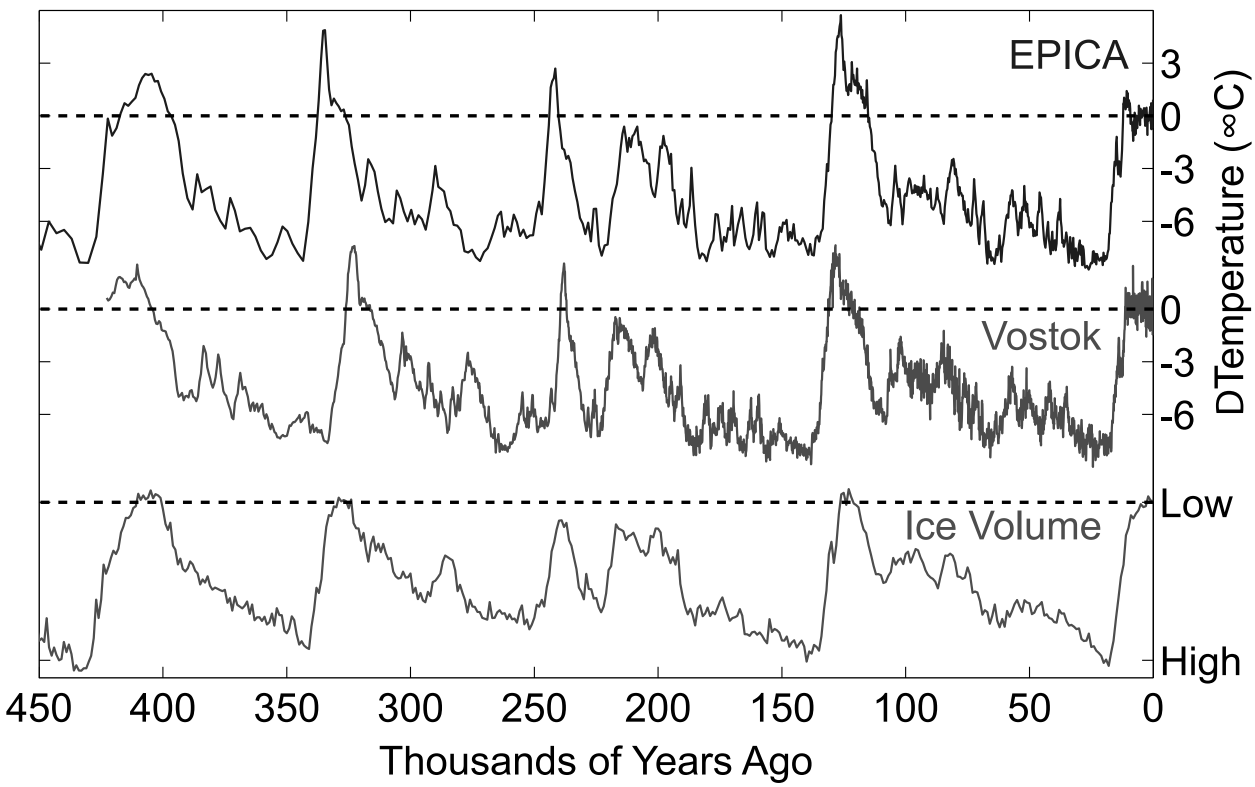


This figure, which reproduces one of the key conclusions of Knutson and Tuleya (2004), shows a prediction for how hurricanes and other tropical cyclones may intensify as a result of global warming. Specifically, Knutson and Tuleya performed an experiment using climate models to estimate the strength achieved by cyclones allowed to intensify over either a modern summer ocean or over an ocean warmed by carbon dioxide concentrations 220 percent higher than present day. A number of different climate models were considered as well as conditions over all the major cyclone-forming ocean basins. Depending on site and model, the ocean warming involved ranged from 0.8 to 2.4 degrees C. Results, which were found to be robust across different models, showed that storms intensified by about one-half category (on the Saffir-Simpson Hurricane Scale) as a result of the warmer oceans. This is accomplished with a ~6 percent increase in wind speed or equivalently a ~20 percent increase in energy (for a storm of fixed size). Most significantly these result suggest that global warming may lead to a gradual increase in the probability of highly destructive category 5 hurricanes. This work does not provide any information about future frequency of tropical storms. Also, since it considers only the development of storms under nearly ideal conditions for promoting their formation, this work is primarily a prediction for how the maximum achievable storm intensity will change. Hence, this does not directly bear on the growth or development of storms under otherwise weak or marginal conditions for storm development (such as high upper-level wind shear). However, it is plausible that warmer oceans will somewhat extend the regions and seasons under which hurricanes may develop.



This figure shows the annual fossil fuel carbon dioxide emissions, in million metric tons of carbon, for a variety of non-overlapping regions covering the Earth. Data source: Carbon Dioxide Information Analysis Center. Regions are sorted from largest emitter (as of 2000) to the smallest:

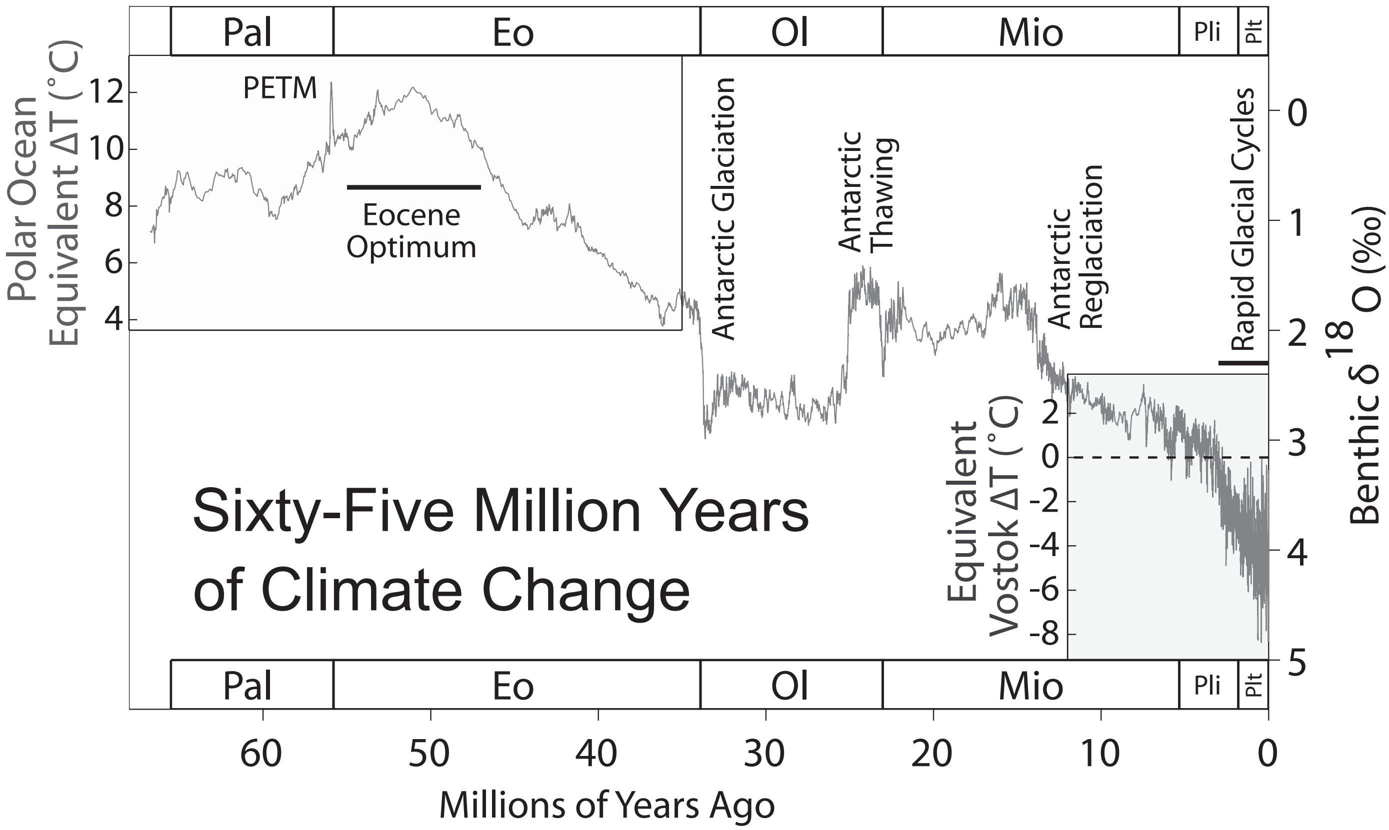
United States and Canada
Western Europe (plus Germany)
Communist East Asia (China, North Korea, Mongolia, etc.)
Eastern Europe, Russia, and Former Soviet States
India and Southeast Asia (plus South Korea)
Australia, Japan and other Pacific Island States
Central and South America (includes Mexico and the Caribbean)
Middle East
Africa



This figure shows the Antarctic temperature changes during the last several glacial/interglacial cycles of the present ice age and a comparison to changes in global ice volume. The present day is on the right.

The first two curves show local changes in temperature at two sites in Antarctica as derived from deuterium isotopic measurements (δD) on ice cores (EPICA Community Members 2004, Petit et al. 1999). The final plot shows a reconstruction of global ice volume based on δ18O measurements on benthic foraminifera from a composite of globally distributed sediment cores and is scaled to match the scale of fluctuations in Antarctic temperature (Lisiecki and Raymo 2005). Note that changes in global ice volume and changes in Antarctic temperature are highly correlated, so one is a good estimate of the other, but differences in the sediment record do not necessarily reflect differences in paleotemperature. Horizontal lines indicate modern temperatures and ice volume. Differences in the alignment of various features reflect dating uncertainty and do not indicate different timing at different sites.

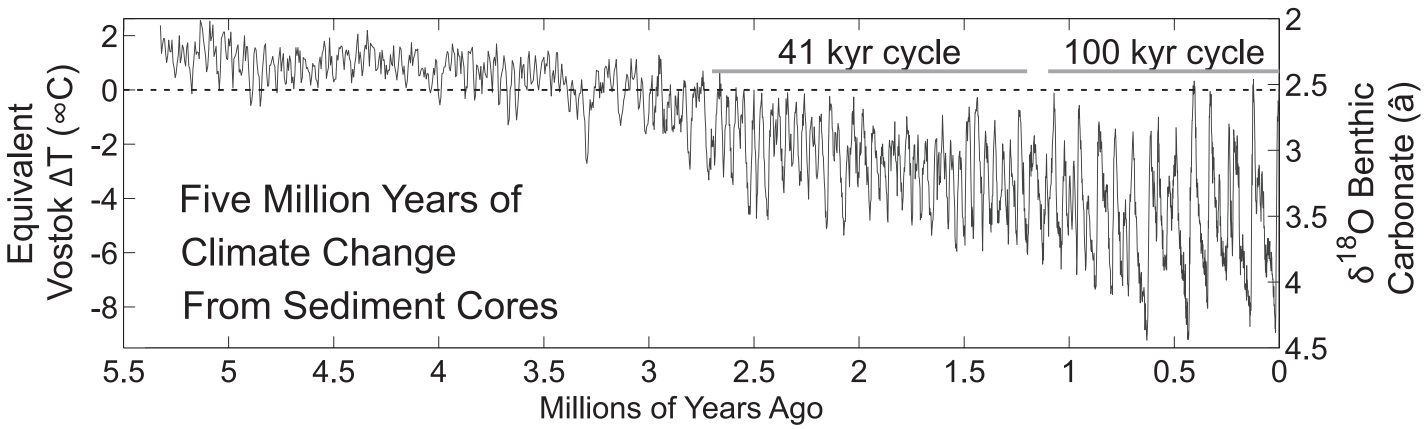
The Antarctic temperature records indicate that the present interglacial is relatively cool compared to previous interglacials, at least at these sites. It is believed that the interglacials themselves are triggered by changes in Earth's orbit known as Milankovitch cycles and that the variations in individual interglacials can be partially explained by differences within this process. For example, Overpeck et al. (2006) argues that the previous interglacial was warmer because of increased solar radiation at high latitudes. The Liesecki and Raymo (2005) sediment reconstruction does not indicate significant differences between modern ice volume and previous interglacials, though some other studies do report slightly lower ice volumes/higher sea levels during the 120 ka and 400 ka interglacials (Karner et al. 2001, Hearty and Kaufman 2000). It should be noted that temperature changes at the typical equatorial site are believed to have been significantly less than the changes observed at high latitude.



This figure shows climate change over the last 65 million years. The data is based on a compilation of oxygen isotope measurements (δ18O) on benthic foraminifera by Zachos et al. (2001), which reflect a combination of local temperature changes in their environment and changes in the isotopic composition of seawater associated with the growth and retreat of continental ice sheets.

Because it is related to both factors, it is not possible to uniquely tie these measurements to temperature without additional constraints. For the most recent data, an approximate relationship to temperature can be made by observing that the oxygen isotope measurements of Lisiecki and Raymo (2005) are tightly correlated to temperature changes at Vostok, Antarctica as established by Petit et al. (1999). Present day is indicated as 0. For the oldest part of the record, when temperatures were much warmer than today, it is possible to estimate temperature changes in the polar oceans (where these measurements were made) based on the observation that no significant ice sheets existed and hence all fluctuation in (δ18O) must result from local temperature changes (as reported by Zachos et al.).

The intermediate portion of the record is dominated by large fluctuations in the mass of the Antarctic ice sheet, which first nucleates approximately 34 million years ago, then partially dissipates around 25 million years ago, before re-expanding toward its present state 13 million years ago. These fluctuations make it impossible to constrain temperature changes without additional controls. Significant growth of ice sheets did not begin in Greenland and North America until approximately 3 million years ago, following the formation of the Isthmus of Panama by continental drift. This ushered in an era of rapidly cycling glacials and interglacials (upper right). Also appearing on this graph are the Eocene Climatic Optimum, an extended period of very warm temperatures, and the Paleocene-Eocene Thermal Maximum (labeled PETM). Due to the coarse sampling and averaging involved in this record, it is likely that the full magnitude of the PETM is underestimated by a factor of 2 to 4 times its apparent height.

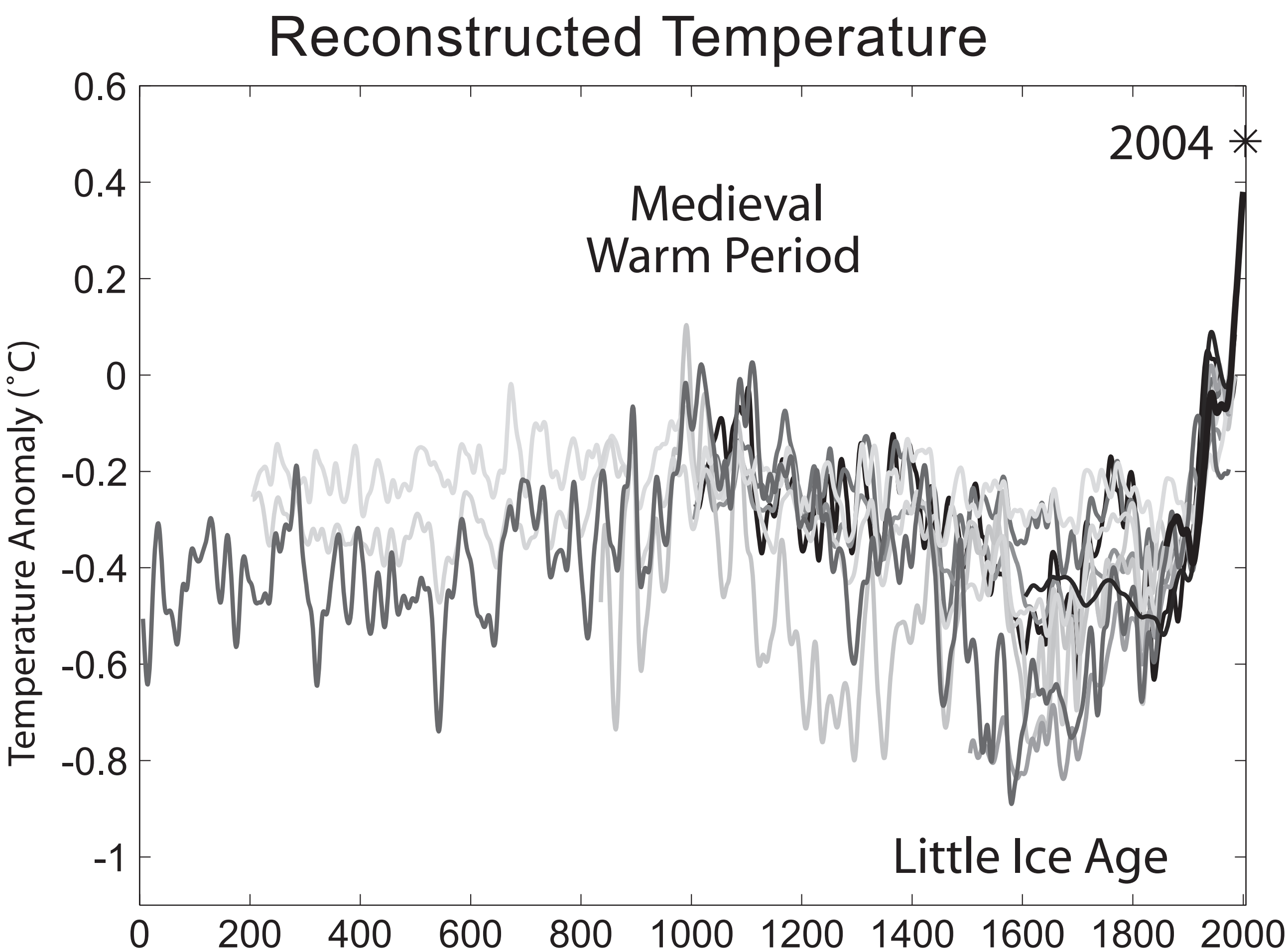


This figure shows the climate record of Lisiecki and Raymo (2005) constructed by combining measurements from 57 globally distributed deep-sea sediment cores. The measured quantity is oxygen isotope fractionation in benthic foraminifera, which serves as a proxy for the total global mass of glacial ice sheets.

Lisiecki and Raymo constructed this record by first applying a computer-aided process of adjusting individual "wiggles" in each sediment core to have the same alignment (i.e.. wiggle matching). Then the resulting stacked record is orbitally tuned by adjusting the positions of peaks and valleys to fall at times consistent with an orbitally driven ice model (see Milankovitch Cycles). Both sets of these adjustments are constrained to be within known uncertainties on sedimentation rates and consistent with independently dated tie points (if any). Constructions of this kind are common, however, they presume that ice sheets are orbitally driven, and hence data such as this can not be used in establishing the existence of such a relationship.

The observed isotope variations are very similar in shape to the temperature variations recorded at Vostok, Antarctica, during the 420 kyr for which that record exists. Hence the right-hand scale of the figure was established by fitting the reported temperature variations at Vostok (Petit et al. 1999) to the observed isotope variations. As a result, this temperature scale should be regarded as approximate and its magnitude is only representative of Vostok changes. In particular, temperature changes at polar sites, such as Vostok, frequently exceed the changes observed in the tropics or in the global average. A horizontal line at 0 degrees C indicates modern temperatures (circa 1950).

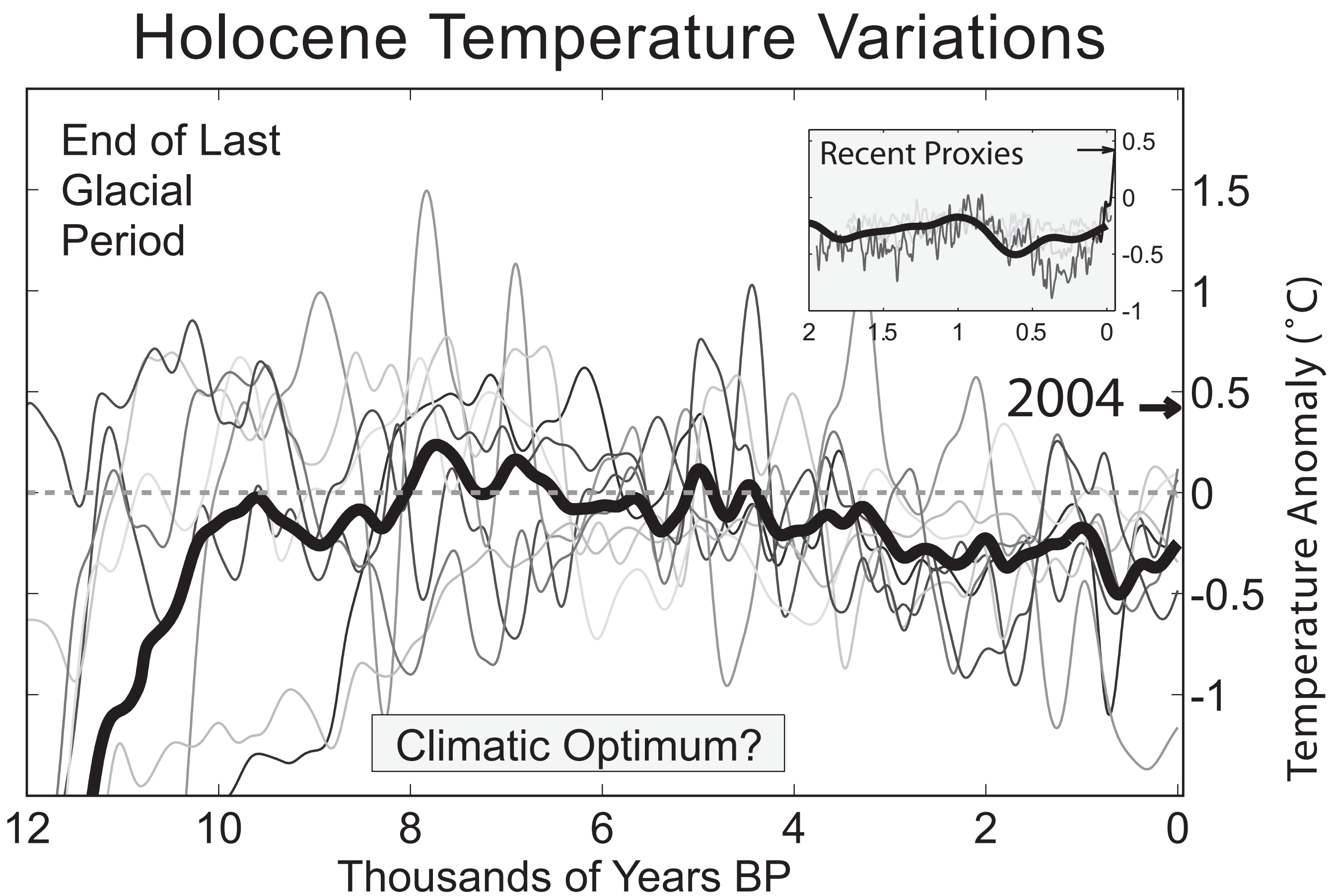
Labels are added to indicate regions where 100 kyr and 41 kyr cyclicity is observed. These periodicities match periodic changes in Earth's orbital eccentricity and obliquity, respectively, and have been previously established by other studies (not relying on orbital tuning).



This image is a comparison of 10 different published reconstructions of mean temperature changes during the last 2,000 years. More recent reconstructions are plotted toward the front and in redder colors, older reconstructions appear towards the back and in bluer colors. An instrumental history of temperature is also shown in black. The medieval warm period and Little Ice Age are labeled at roughly the times when they are historically believed to occur, though it is still disputed whether these were truly global or only regional events. The single, unsmoothed annual value for 2004 is also shown for comparison.

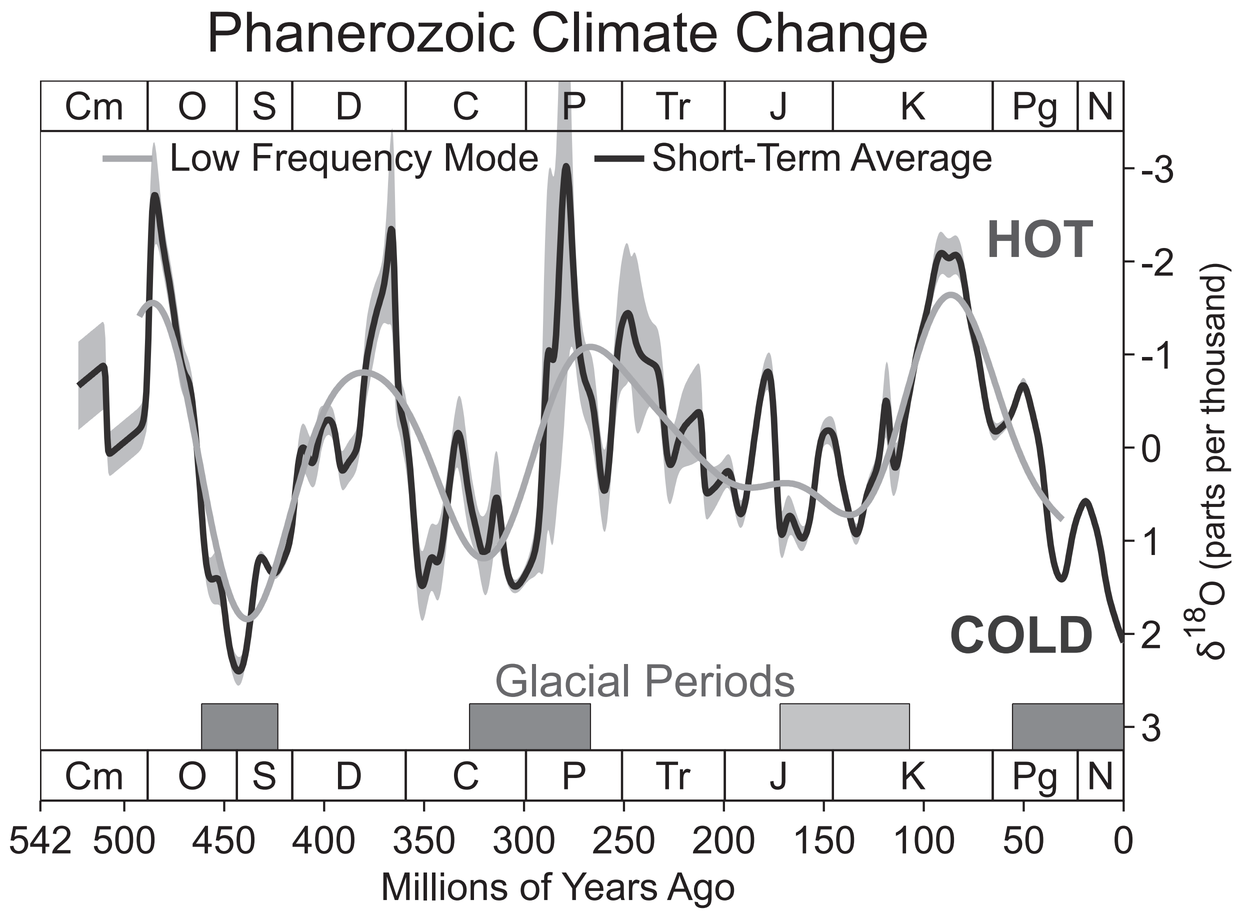
It is unknown which, if any, of these reconstructions is an accurate representation of climate history; however, these curves are a fair representation of the range of results appearing in the published scientific literature. Hence, it is likely that such reconstructions, accurate or not, will play a significant role in the ongoing discussions of global climate change and global warming.

For each reconstruction, the raw data has been decadally smoothed with a $\sigma = 5$ yr Gaussian weighted moving average. Also, each reconstruction was adjusted so that its mean matched the mean of the instrumental record during the period of overlap.



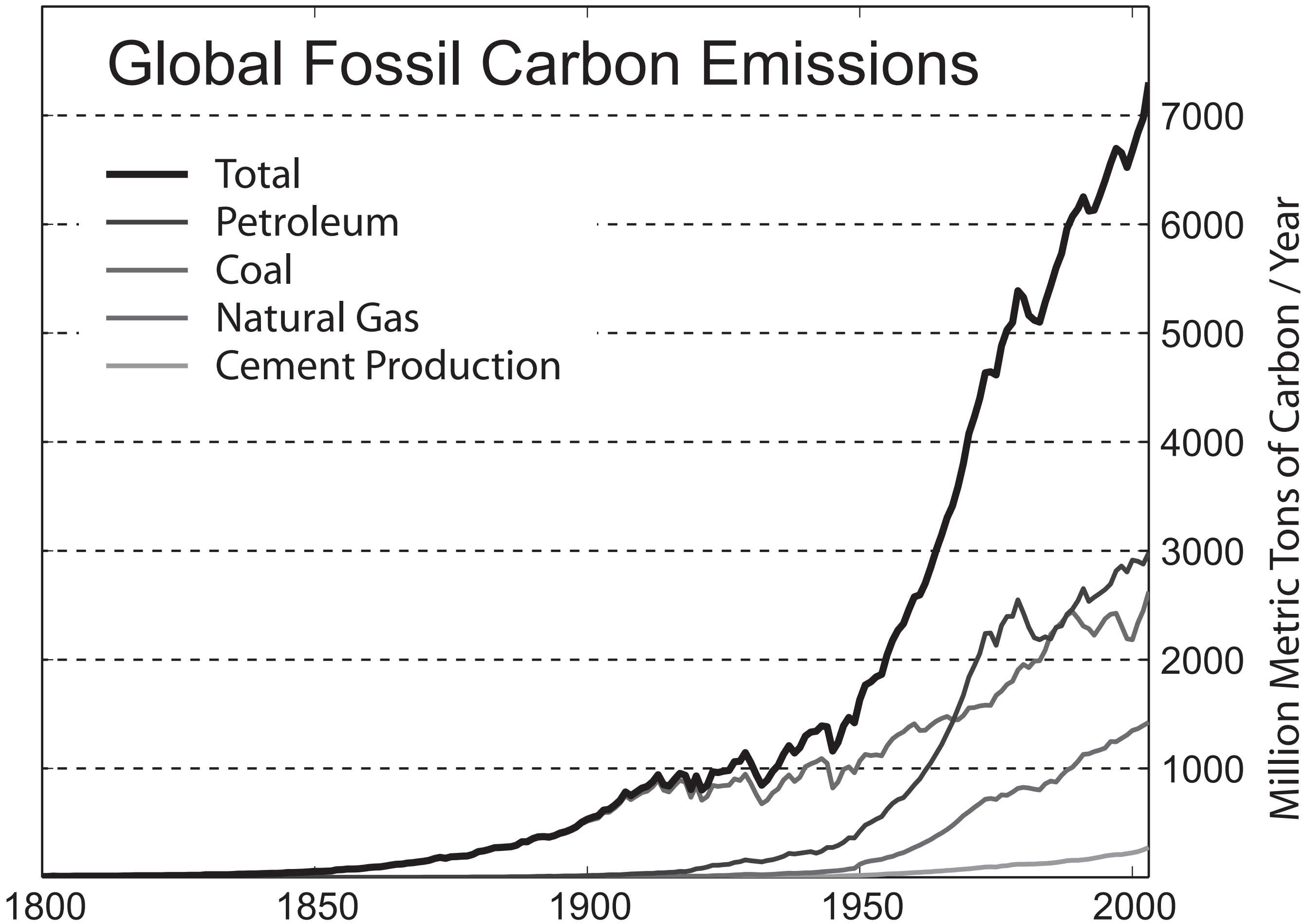
The main figure shows eight records of local temperature variability on multi-centennial scales throughout the course of the Holocene, and an average of these (thick dark line). The records are plotted with respect to the mid-20th-century average temperatures, and the global average temperature in 2004 is indicated. The inset plot compares the most recent two millennia of the average to other high resolution reconstructions of this period. At the far left of the main plot climate emerges from the last glacial period of the current ice age into the relative stability of the current interglacial. There is general scientific agreement that during the Holocene itself temperatures have been quite stable compared to the fluctuations during the preceding glacial period. The average curve above supports this belief. However, there is a slightly warmer period in the middle which might be identified with the proposed Holocene climatic optimum. The magnitude and nature of this warm event is disputed, and it may have been largely limited to summer months and/or high northern latitudes.

Because of the limitations of data sampling, each curve in the main plot was smoothed, and consequently, this figure can not resolve temperature fluctuations faster than approximately 300 years. Further, while 2004 appears warmer than any other time in the long-term average, an observation that might be a sign of global warming, it should also be noted that the 2004 measurement is from a single year. It is impossible to know whether similarly large short-term temperature fluctuations may have occurred at other times but are unresolved by the resolution available in this figure. The next 150 years will determine whether the long-term average centered on the present appears anomalous with respect to this plot. Since there is no scientific consensus on how to reconstruct global temperature variations during the Holocene, the average shown here should be understood as only a rough, quasi-global approximation to the temperature history of the Holocene. In particular, higher resolution data and better spatial coverage could significantly alter the apparent long-term behavior.



This figure shows the long-term evolution of oxygen isotope ratios during the Phanerozoic eon as measured in fossils, reported by Veizer et al. (1999), and updated online in 2004 [1]. Such ratios reflect both the local temperature at the site of deposition and global changes associated with the extent of continental glaciation. As such, relative changes in oxygen isotope ratios can be interpreted as rough changes in climate. Quantitative conversion between this data and direct temperature changes is a complicated process subject to many systematic uncertainties, however, it is estimated that each 1 part per thousand change in δ18O represents roughly a 1.5–2 degrees C change in tropical sea surface temperatures (Veizer et al. 2000). Also shown on this figure are blue bars showing periods when geological criteria (Frakes et al. 1992) indicate cold temperatures and glaciation as reported by Veizer et al. (2000). All data presented here have been adjusted to the 2004 ICS geologic timescale. The "short-term average" was constructed by applying a σ = 3 Myr Gaussian weighted moving average to the original 16,692 reported measurements. The gray bar is the associated 95 percent statistical uncertainty in the moving average. The "low frequency mode" is determined by applying a band-pass filter to the short-term averages in order to select fluctuations on timescales of 60 Myr or greater.

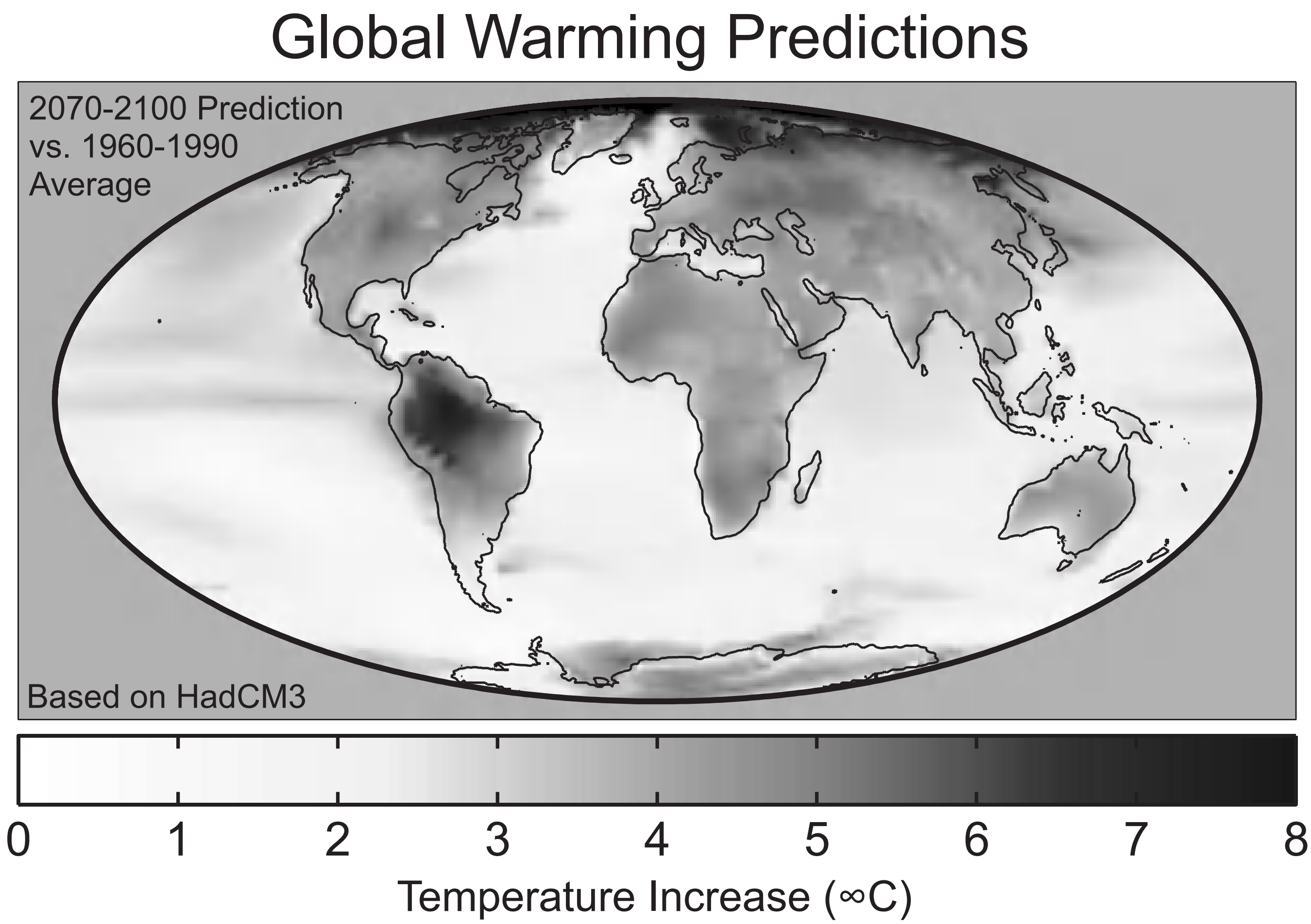
On geologic time scales, the largest shift in oxygen isotope ratios is due to the slow radiogenic evolution of the mantle. It is not possible to draw any conclusion about very long-term (>200 Myr) changes in temperatures from this data alone. However, it is usually believed that temperatures during the present cold period and during the Cretaceous thermal maximum are not greatly different from cold and hot periods during most of the rest the Phanerozoic. Some recent work has disputed this (Royer et al. 2004) suggesting instead that the highs and lows in the early part of the Phanerozoic were both significantly warmer than their recent counterparts. Common symbols for geologic periods are plotted at the top and bottom of the figure for reference.



Global annual fossil fuel carbon dioxide emissions, in million metric tons of carbon, as reported by the Carbon Dioxide Information Analysis Center.

Original data: [full text] Marland, G., T.A. Boden, and R. J. Andres (2003). "Global, Regional, and National CO2 Emissions" in *Trends: A Compendium of Data on Global Change*. Oak Ridge, Tenn., U.S.A.: Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy.

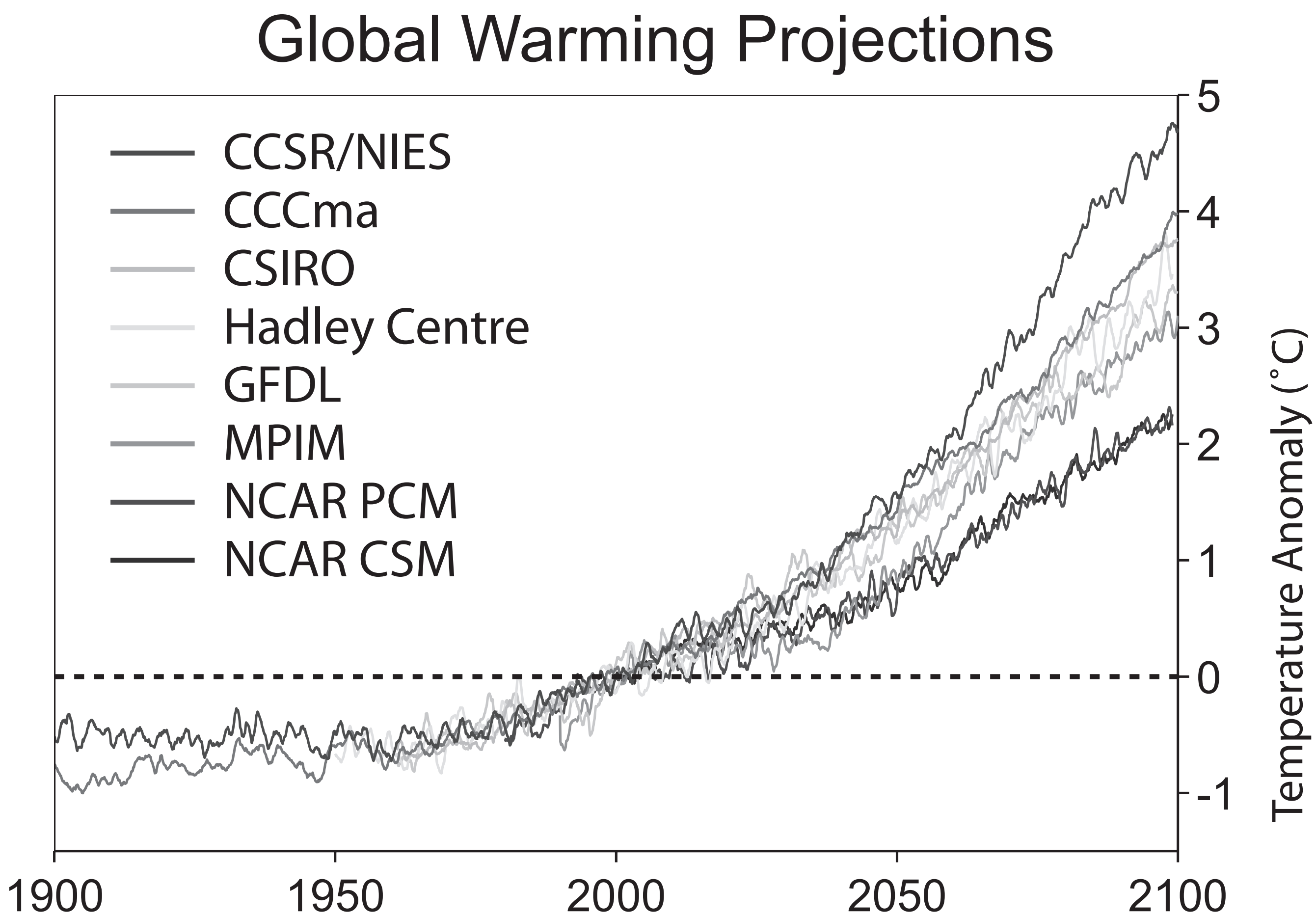
The data is originally presented in terms of solid (e.g., coal), liquid (e.g., petroleum), gas (i.e., natural gas) fuels, and separate terms for cement production and gas flaring (i.e., natural gas lost during oil and gas mining). In the plotted figure, the gas flaring (the smallest of all categories) was added to the total for natural gas. Note that the carbon dioxide releases from cement production result from the thermal decomposition of limestone into lime, and so technically are not a fossil fuel source.



This figure shows the predicted distribution of temperature change due to global warming from the Hadley Centre HadCM3 climate model. These changes are based on the IS92a ("business as usual") projections of carbon dioxide and other greenhouse gas emissions during the next century, and essentially assume normal levels of economic growth and no significant steps are taken to combat global greenhouse gas emissions.

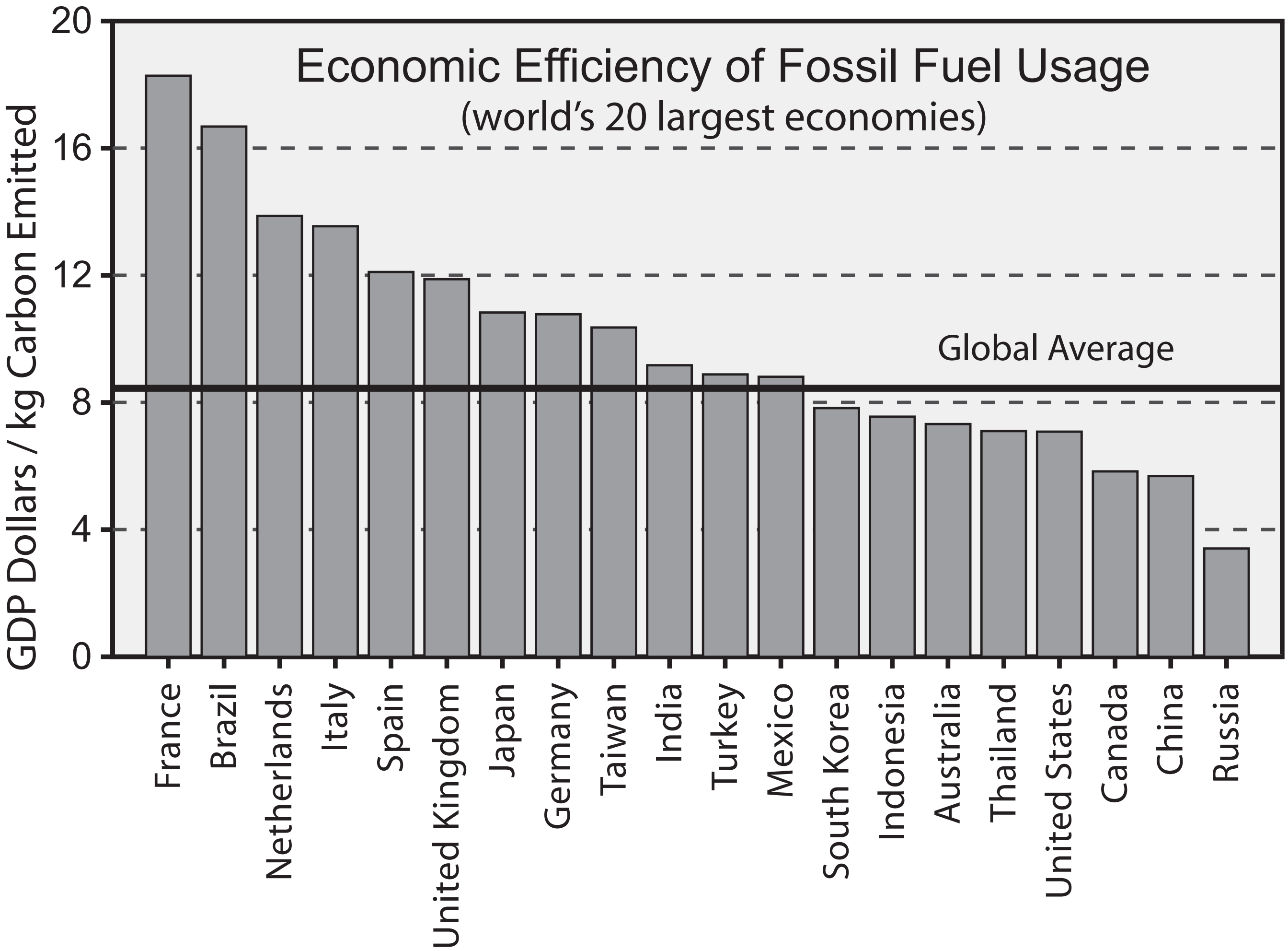
The plotted gray tints show predicted surface temperature changes expressed as the average prediction for 2070–2100 relative to the model's baseline temperatures in 1960–90. The average change is 3.0 degrees C, placing this model on the lower half of the Intergovernmental Panel on Climate Change's 1.4-5.8 degrees C predicted climate change from 1990 to 2100. As can be expected from their lower specific heat, continents are expected to warm more rapidly than oceans with an average of 4.2 degrees C and 2.5 degrees C in this model, respectively. The lowest predicted warming is 0.55 degrees C south of South America and the highest is 9.2 degrees C in the Arctic Ocean (points exceeding 8 degrees C are plotted as black).

This model is fairly homogeneous except for strong warming around the Arctic Ocean related to melting sea ice and strong warming in South America related to predicted changes in the El Niño cycle and Brazillian rainforest. This pattern is not a universal feature of models, as other models can produce large variations in other regions (e.g., Africa and India) and less extreme changes in places like South America.



This figure shows climate model predictions for global warming under the SRES A2 emissions scenario relative to global average temperatures in 2000. The A2 scenario is characterized by a politically and socially diverse world that exhibits sustained economic growth but does not address the inequities between rich and poor nations, and takes no special actions to combat global warming or environmental change issues. This world in 2100 is characterized by large population (15 billion), high total energy use, and moderate levels of fossil fuel dependency (mostly coal). At the time of the IPCC Third Assessment Report, the A2 scenario was the most well-studied of the SRES scenarios.

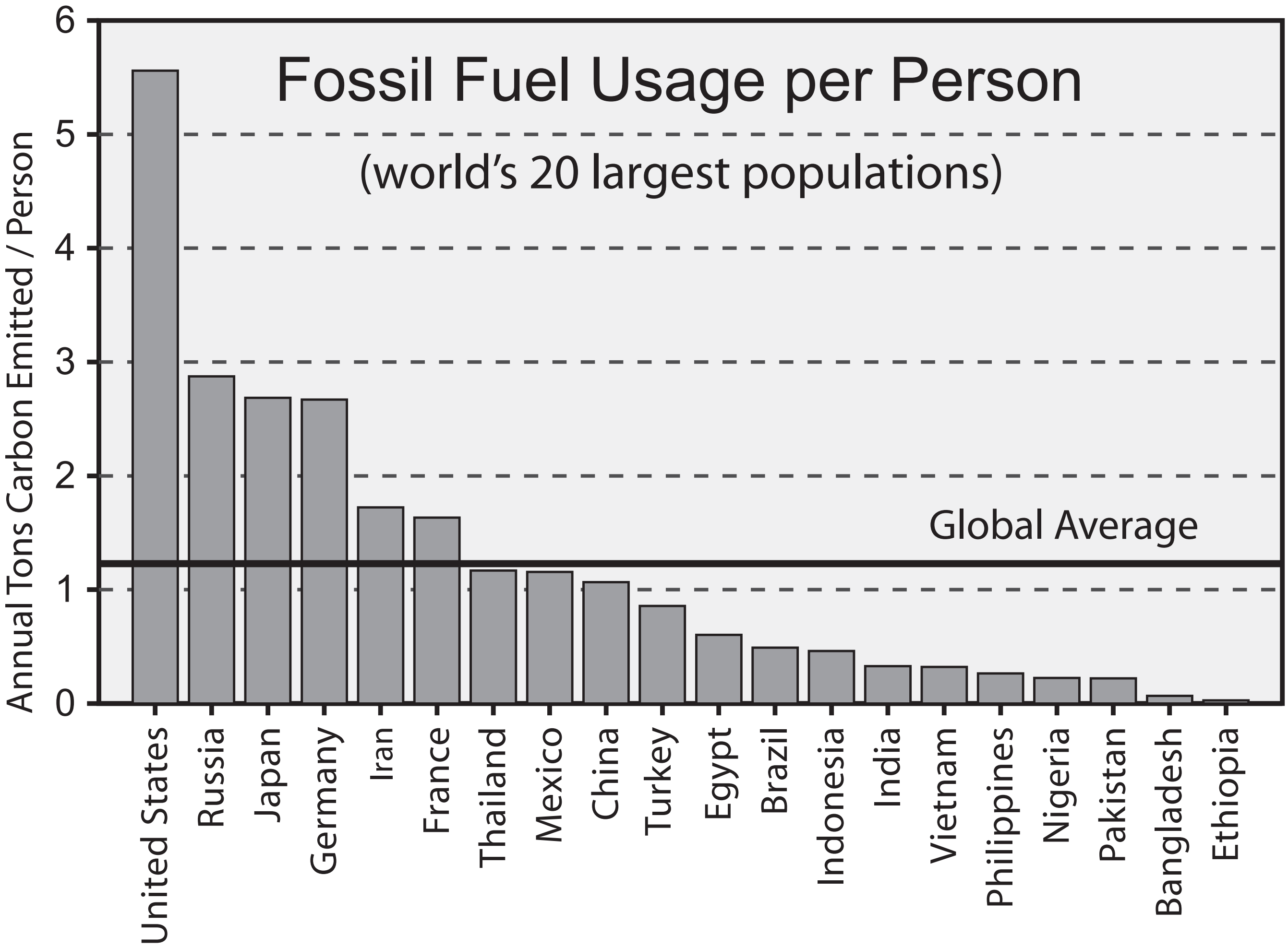
The IPCC predicts global temperature change of 1.4-5.8 degrees C due to global warming from 1990 to 2100 (IPCC 2001a). As evidenced above (a range of 2.5 degrees C in 2100), much of this uncertainty results from disagreement among climate models, though additional uncertainty comes from different emissions scenarios.



This figure shows an estimate of how efficiently the world's 20 largest economies convert fossil fuel usage into wealth as expressed by the ratio of their gross domestic product (calculated by the method of purchasing power parity in U.S. dollars) over the number of kilograms of fossil fuel carbon released into the atmosphere each year. The relatively narrow range of variation between most countries in this figure suggests that the pursuit of wealth in the present world is strongly tied to the availability of fossil fuel energy sources.

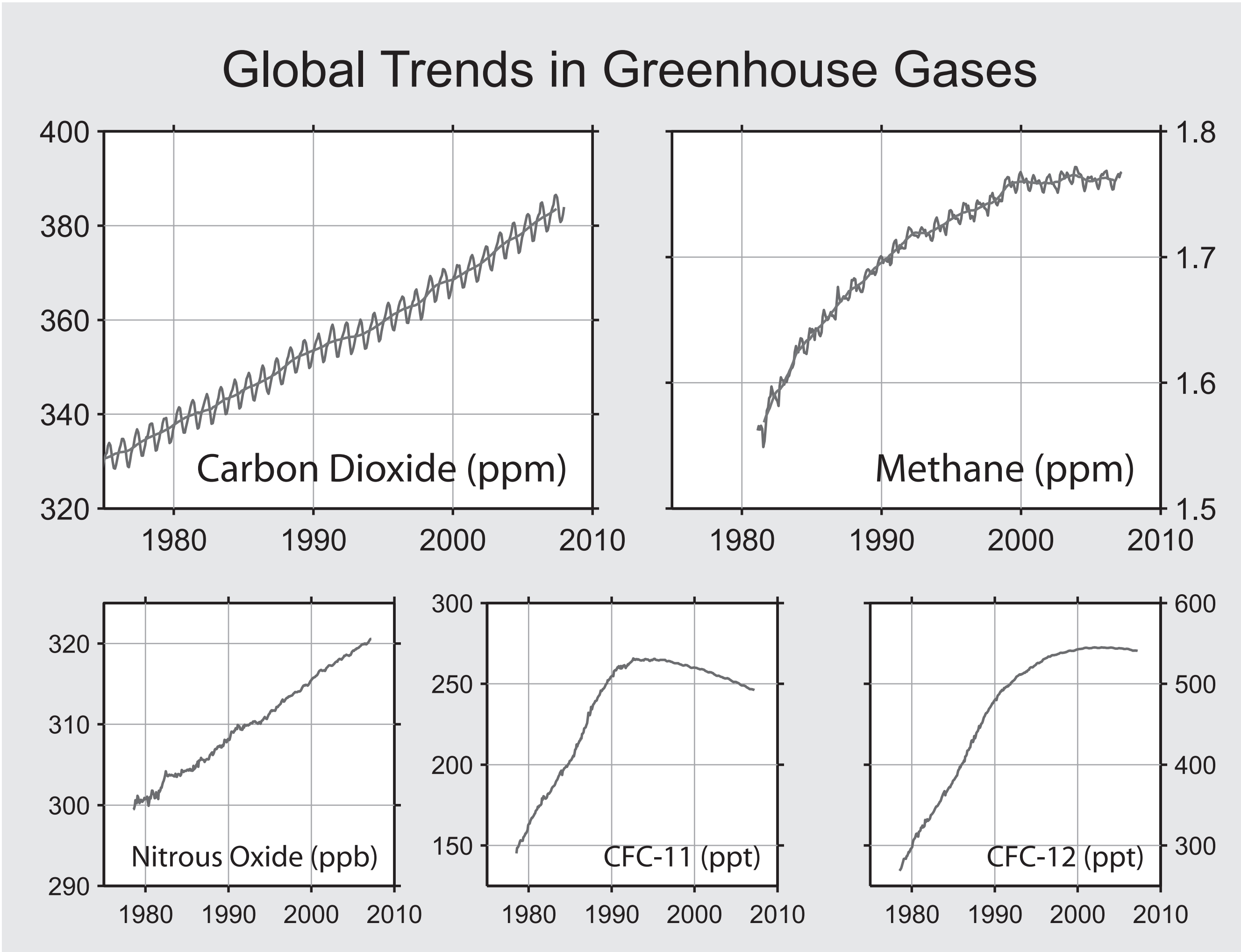
As countries may be reluctant to combat fossil fuel emissions in ways that cause economic decline, this figure serves to suggest the degree to which different large economies can decrease emissions through short-term improvements in efficiency and alternative fuel programs.

The two countries that produce the highest GDP per kilogram carbon, Brazil and France, are heavily reliant on alternative energy sources, hydroelectric and nuclear power, respectively.



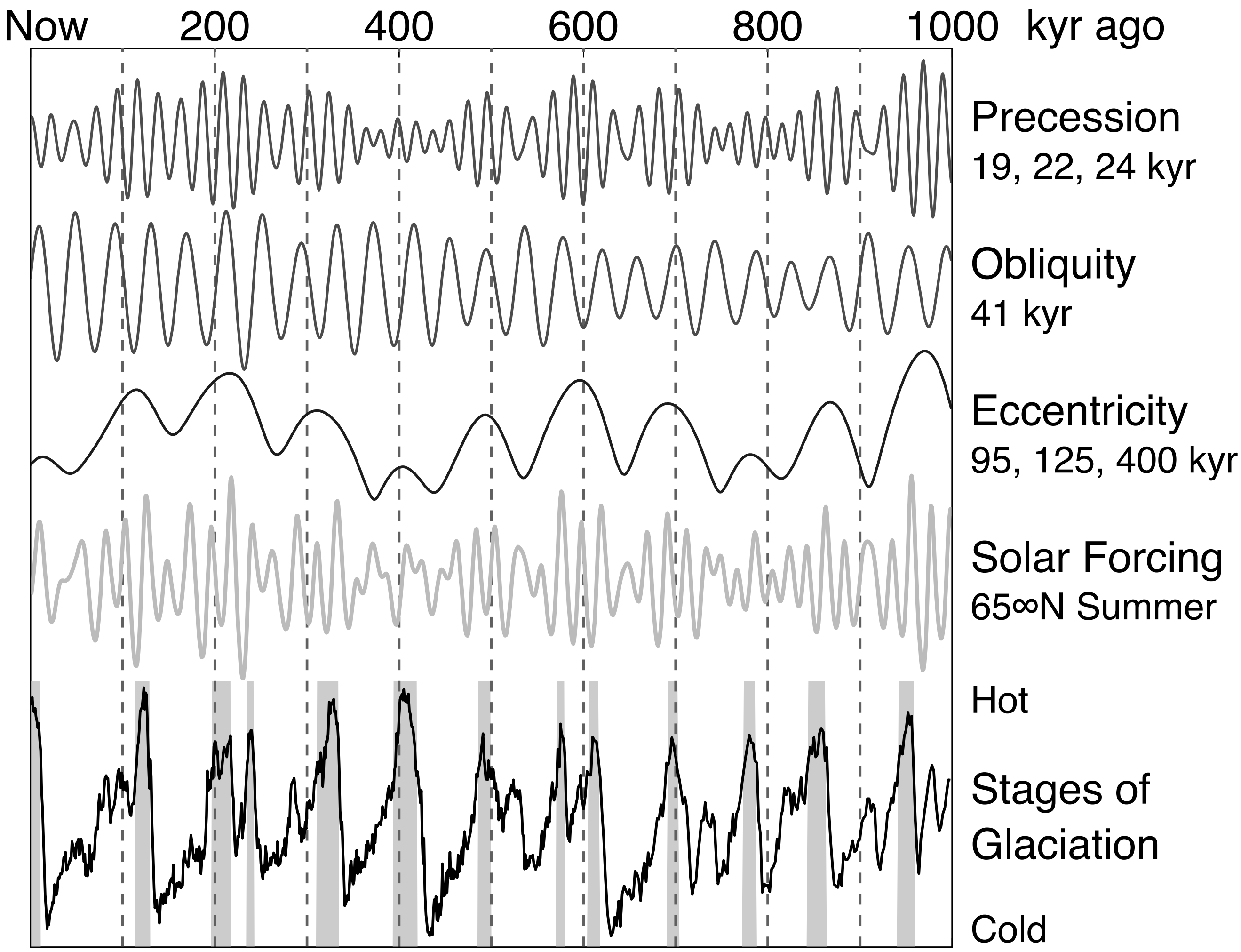
This figure shows the disparity in fossil fuel consumption per capita for the countries with the twenty largest populations. The large range of variation is indicative of the separation between the rich, industrialized nations and the poor/developing nations. The global average is also shown.

As most countries desire wealth and aim to develop that wealth through the development of industry, this figure suggests the degree to which poor nations may strive to increase their emissions in the course of trying to match the industrial capacity of the developed world. Managing such increases and dealing with the apparent social inequality of the present system will be one of the challenges involved in confronting global warming.



Global trends in major greenhouse gas concentrations. The rise of greenhouse gases, and their resulting impact on the greenhouse effect, are believed to be responsible for most of the increase in global average temperatures during the last 50 years. This change, known as global warming, has provoked calls to limit the emissions of these greenhouse gases (e.g., Kyoto Protocol). Notably, the chlorofluorocarbons CFC-11 and CFC-12 shown above have undergone substantial improvement since the Montreal Protocol severely limited their release due to the damage they were causing to the ozone layer.

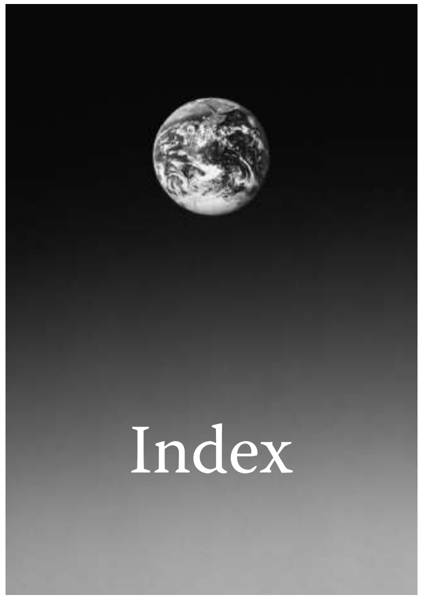
At present, approximately 99 percent of the 100-year global warming potential for all new emissions can be ascribed to just the three gases: carbon dioxide, methane, and nitrous oxide.



Milankovitch Cycles

The Earth's orbit around the sun is slightly elliptical. Over time the gravitational pull of the moon and other planets causes the Earth's orbit to change following a predictable pattern of natural rhythms, known as Milankovitch cycles. Over a ~100,000 year cycle the Earth migrates from an orbit with near-zero eccentricity (a perfect circle) to one with approximately 6 percent eccentricity (a slight ellipse). In addition, the tilt of the Earth axis, known as its obliquity, varies from 21.5 to 24.5 degrees with a 41,000 year rhythm. And lastly, the orientation of the Earth's axis rotates with a ~20,000-year cycle relative to the orientation of the Earth's orbit. This cycle, known as "precession", affects the intensity of the seasons.

The figure shows the pattern of changes in each of the three modes of orbital variability: eccentricity, obliquity, and precession. These changes in the Earth's orbit lead to a complex series of changes in the amount of sunlight that a given location on Earth can expect to receive during a given season. An example is shown for summer sunlight near the Arctic circle. Sunlight at this location is believed to influence the growth and decay of ice sheets during ice ages. The last line shows measured changes in climate during the last million years with warm interglacials highlighted in gray bands. As can be seen, such interglacials appear to preferentially occur near maxima in eccentricity and slightly following times of maximum summer sunlight.



Note: Page numbers in **boldface** refer to volume numbers and major topics. Article titles are in **boldface**.

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