OUR CHANGING PLANET

THE FY 1996
U.S. GLOBAL CHANGE RESEARCH PROGRAM

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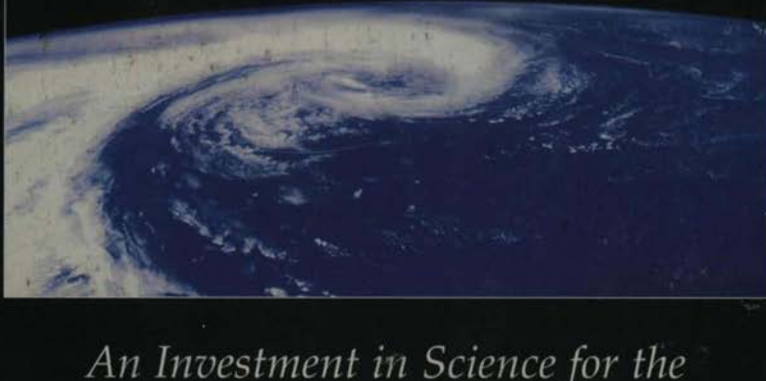

An Investment in Science for the Nation's Future

A Report by the Subcommittee on Global Change Research, Committee on Environment and Natural Resources Research of the National Science and Technology Council

A Supplement to the President's Fiscal Year 1996 Budget

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of the National Science and Technology Council

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EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLICY
WASHINGTON, D.C. 20500

MEMBERS OF CONGRESS:

I am pleased to forward to you a copy of "Our Changing Planet: The FY 1996 U.S. Global Change Research Program." This supplement to the President's Fiscal Year 1996 Budget was prepared by the Subcommittee on Global Change Research (SGCR) of the Committee on Environment and Natural Resources Research (CENR), a committee of the National Science and Technology Council (NSTC). This document complements the report, "Preparing for the Future Through Science and Technology: An Agenda for Environmental and Natural Resources Research," that was prepared by the CENR last winter.

The U.S. Global Change Research Program (USGCRP) has spurred much improved scientific insight into the processes and interactions of the Earth system. As a result, we're making progress in our ability to forecast seasonal to interannual climate changes that can lead to significant events such as floods, droughts, and heat waves. Improved forecasting of these events can save human lives and billions of dollars.

Recent measurements made through the USGCRP confirm that the growth rates of total organic chlorine and bromine in the troposphere are slowing, which suggests that the depleted stratospheric ozone layer will recover over the next several decades in response to measures taken as part of the Montreal Protocol and its amendments. USGCRP research in FY 1996 is expected to improve our understanding of how ozone depletion relates to increased UV radiation. In parallel, health research on the mechanisms by which UV radiation causes skin cancer, immunosuppression, and cataracts will lead to better methods of prevention.

General Circulation Models (GCMs), which were developed to predict climate changes over the next few decades, have improved substantially and can now better account for the observed global warming of the last century of about 0.5°C. Improvements in GCMs enable us to better understand the potential for significant climate change and its impacts over the next century, so that we can develop wise adaptation and mitigation strategies. Equally important is our improved ability to observe changes in global land cover by remote sensing and to assess and prevent undesirable impacts on the global productivity of forests, fisheries, and agriculture through USGCRP supported field programs.

The USGCRP, a program initiated under President Reagan and elevated to a Presidential Initiative under President Bush, has brought our nation huge dividends by greatly increasing our knowledge of Earth system science, thereby giving us a better understanding of the global ecosystem on which we so greatly depend. President Clinton strongly endorses this program and proposes to maintain federal support of the USGCRP at a level of $1.8 billion for FY 1996.

I would like to commend Dr. Robert Corell of the National Science Foundation and Chair of the SGCR, for leading the efforts which have made this program a success. We look forward to another productive year for the support of Earth system science as an investment for the nation's future.

John H. Gibbons
Director

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EXECUTIVE SUMMARY

The U.S. Global Change Research Program (USGCRP) focuses on the scientific study of the Earth system and its components. Global change research provides short- and long-term benefits to the nation in a number of different ways:

- Global change research contributes to fundamental scientific knowledge leading to important insights into the interactions of the Earth system, including the oceans, the continents, snow cover and sea ice, and the atmosphere;
- Global change research improves capabilities for documenting and assessing potential changes in the Earth system and the implications of these changes on climate, surface UV radiation, land cover, the health of terrestrial and marine ecosystems, and the availability of future resources such as water, food, and fiber;
- Global change research assists in the development of improved predictions of extreme events such as floods, droughts, and heat waves, thereby allowing actions to reduce the vulnerability of people and property to natural disasters;
- USGCRP research is organized around a framework of observing and documenting change, understanding processes and consequences, predicting future changes, and assessing options for dealing with change. The large quantities of data generated through these activities require the design and implementation of a sophisticated data- and information-management system. This system is designed to make global change data easily accessible to researchers worldwide. In addition, most USGCRP agencies sponsor public information and education programs, and the USGCRP operates a Global Change Research Information Office to assist with disseminating scientific information; and
- Global change research remains a high priority for the United States. The President's budget for FY 1996 proposes to invest $1.8 billion in global change research, including $749 million for space-based observations of the Earth. This request represents an investment in the future health and security of the nation's citizens.

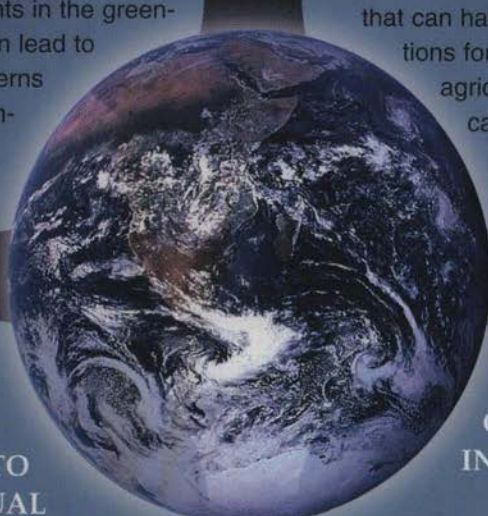
Global Environmental Change

CLIMATE CHANGE OVER THE NEXT FEW DECADES

such as enhancements in the greenhouse effect, that can lead to changes in the patterns of rainfall and temperature.

STRATOSPHERIC OZONE DEPLETION AND INCREASED ULTRAVIOLET (UV) RADIATION

that can have significant implications for human health and agricultural and biological productivity.



SEASONAL TO INTERANNUAL CLIMATE FLUCTUATIONS

and related events (such as droughts, floods, heat waves) that cost the nation tens of billions of dollars a year

CHANGES IN LAND COVER AND IN TERRESTRIAL AND MARINE ECOSYSTEMS

that can affect biodiversity and the productivity of agriculture, forestry, and fisheries around the globe.

1. INTRODUCTION

Global change research brings significant benefits to the nation and the world by providing a well-founded scientific understanding of the Earth system to ensure the availability of future resources essential for human survival, such as water, food, and fiber. The U.S. Global Change Research Program (USGCRP), along with its international partners, provides the foundation for expanding the ability to both predict and respond to extreme events such as floods, droughts, and heat waves. The USGCRP also aims to reduce vulnerabilities to changes in important environmental factors, such as climate, ultraviolet (UV) radiation at the Earth's surface, and land cover. Scientific knowledge is essential for informed decision making on environmental issues and to ensure the social and economic health of future generations. Thus the USGCRP is a critical investment for the future of this nation, its economy, and the health and safety of its citizens.

The USGCRP was created in 1989 and formalized in 1990 by the Global Change Research Act of 1990.* Since that time, global change research has remained a key science initiative. Continuing to improve scientific understanding of the Earth system is a priority of the National Science and Technology Council's Committee on Environment and Natural Resources.

WHAT IS GLOBAL CHANGE?

Global change encompasses the full range of natural and human-induced changes in the Earth's environment. Global change can be defined as changes in the global environment (including alterations in climate, land productivity, oceans or other water resources, atmospheric chemistry, and ecological systems) that may alter the capacity of the Earth to sustain life. Issues related to global change include:

- **SEASONAL TO INTERANNUAL CLIMATE FLUCTUATIONS.**
- **CLIMATE CHANGE OVER THE NEXT FEW DECADES.**
- **STRATOSPHERIC OZONE DEPLETION AND INCREASED UV RADIATION.**
- **CHANGES IN LAND COVER AND IN TERRESTRIAL AND MARINE ECOSYSTEMS.**

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*United States Code 15U.S.C.2921 *et seq.*

Increased scientific knowledge of global change can reduce the vulnerabilities of human and ecological systems to major environmental changes. Scientific research provides the foundation for building a strong society through continued advances in improving human health and longevity, advancing economic growth and prosperity, and ensuring adequate food supplies and the availability and quality of fresh water.

Major economic losses occur annually from events such as drought, floods, and heat waves. The USGCRP supports research on seasonal to interannual climate change that helps to expand society's capabilities to anticipate and respond to such events. Better understanding of changes in temperature and precipitation patterns and their impacts on crops, forests, and human pathogens will enable society to

Major Scientific Challenges

Seasonal to Interannual Climate Fluctuations
Establish a network of research and prediction centers, including an International Research Institute for Seasonal to Interannual Climate Prediction, and develop, maintain and operate an ocean observing system to improve forecasts of the timing and geographic extent of extended weather and climatic events, such as droughts and floods, at least a year in advance.

Climate Change over the Next Few Decades
Distinguish the human influences on climate from natural variability, predict the rates and magnitudes of future climate changes with regional resolution, and understand the vulnerability and adaptability of societal and ecological systems to climate change.

Stratospheric Ozone Depletion and Increased UV Radiation
Model the physical and chemical processes of the stratosphere and upper troposphere that will allow predictions of ozone change and the resulting change in UV radiation at the Earth's surface.

Changes in Land Cover and in Terrestrial and Marine Ecosystems
Expand the range of high quality observations of global land cover and terrestrial and marine ecosystems, and increase understanding of interactions between human activities and natural processes that result in changes in land cover and in terrestrial and marine ecosystems.

be better prepared to cope with potentially costly future changes in climate on times scales of decades to centuries. Similar benefits will be evident with respect to enhanced knowledge about the impacts of increased UV levels associated with ozone depletion, changes in biological diversity, and changes in the productivity of land and water resources.

WHAT IS THE FOCUS OF THE USGCRP?

The USGCRP focuses on the scientific study of the Earth system and its components. Comprehensive investigation of Earth system processes and their interactions is a complex scientific challenge. Human influences and interactions with the environment range from local to global and extend over time periods from days and seasons to as long as decades and centuries. Understanding these diverse scales and interactions requires the participation of an extensive community of scientists from a wide range of scientific disciplines and from all regions of the globe. Therefore, USGCRP activities are coordinated with other related national and international research programs.

USGCRP research is organized around a framework of observing, documenting, understanding, and predicting global change;

Additional Challenges

Maintain a Core Research Program in Earth-System Science
Increase fundamental scientific understanding of the Earth and its inhabitants and search for surprises.

Manage Large Quantities of Global Change Data
Integrate the massive amounts of highly diverse global change data using a dispersed data management system that makes the data easily accessible to researchers worldwide.

Communicate the Results of Global Change Research
Provide effective and objective data and information to decision makers, the public, and other stakeholders on the causes, implications, and likelihood of global changes.

Educate a New Generation of Scientists
Train a new generation of scientists in multi-disciplinary research in Earth-system science, including its physical, chemical, biological, and human dimensions.

assessing the consequences of these changes and the vulnerability of human and ecological systems to their potentially adverse impacts; and developing the tools and capabilities to conduct integrated assessments to synthesize and communicate this body of knowledge.

Observing Global Change

A coordinated program of land, ocean, airborne and satellite-based observing systems that measure and monitor different facets of the Earth system is central to documenting changes in the global environment and gaining a predictive understanding of them. The most comprehensive set of sensors for observing global change is a space-based observing system that is being planned and implemented by the U.S. in cooperation with many international partners (see box page 53). Other space-based systems that are currently operating or being planned include operational weather satellites and satellites that measure ozone and other atmospheric chemicals, global sea level, topography, soil moisture, sea-ice dynamics, and ocean temperatures.

These space-based measurements are complemented and enhanced by many surface and airborne systems. For example, an extensive ocean observing system in the tropical Pacific is providing critical information on ocean-atmosphere interactions. Other in-situ systems measure important Earth system parameters such as greenhouse gases, aerosols, ozone, ultraviolet radiation, and land-atmosphere interactions.

Documenting Global Change

Global change research activities generate and require massive amounts of highly diverse data and information to document change, to improve understanding of global change processes, and to carry out integrated assessments of impacts on society. The scope of global change research is very broad, ranging from studies on ecological systems, biodiversity, ocean and atmospheric interactions, and the human dimensions of change, to the development of tools and methods for scientific assessment. Important data therefore need to be archived, preserved, and made available for individual research activities, and related data from various disciplines and disparate sources need to be identified and combined to maximize interpretation.

Providing access to comprehensive global change data and information in usable formats is vital to investigators worldwide. An interagency Global Change Data and Information System (GCDIS) is being implemented to accomplish this task (see box on page 7 and discussion page 54).

The Science Goal of the USGCRP

To gain a predictive understanding and assess the significance of the interactions among the physical, chemical, geological, biological, and human processes that influence and are influenced by the Earth system.

Understanding Global Change

Research on fundamental processes and mechanisms that control the physical, chemical, biological, and human processes that govern Earth-system behavior provides the foundation needed for predicting future changes and for analyzing potential consequences and impacts. Process research within the USGCRP includes studies of the atmosphere, ocean, cryosphere (snow, ice, glaciers, etc.), lithosphere (land surfaces), marine and terrestrial ecosystems, and the relationships among these components. Understanding the significance of these processes over a wide range of scales in time and space is especially important to predicting future change.

Ongoing programs include studies of clouds and of solar and infrared radiation processes; of the radiative effects of aerosols, especially sulfate particles; and of the interactions of both terrestrial and marine ecological processes with atmospheric composition and climate. The results of this research provide the basis for improved models for predicting future changes in climate and in ozone concentrations, changes in surface UV radiation levels, and changes in the global productivity of fisheries, forests, and agricultural lands.

Predicting Global Change

Global observations and process research studies help scientists develop and improve models that explain and reproduce past global changes and project future changes and their consequences. Accurate predictions of future global change depend on how well models can simulate the dynamics and interactions of the many components of the Earth system, including the oceans, atmosphere, land, and biosphere. Field and observation programs provide the basis for efforts to relate regional-scale and global-scale patterns and variables (especially precipitation, temperature, and surface roughness) and to compare model results with real world conditions.

Improvements in global environmental models are continually being made as modelers extend their efforts to include interactions of the climate system with vegetation, biological productivity, soil processes, trace gas exchange, hydrology, atmospheric circulation and chemistry, radiation budgets, and ocean circulation patterns. For example, recent climate models that incorporate the influence of atmospheric aerosols have been able to predict changes in climate over the last century that are similar to observed changes. These models predict that atmospheric aerosols currently are exerting a nonuniform cooling effect over the globe that is moderating, especially in industrialized regions, the predicted warming from increases in atmospheric greenhouse gas concentrations.

Analyzing Global Change Consequences

Evaluating the consequences of changes in the global environment includes determining and interpreting the economic, health, and environmental impacts of these changes and understanding the potential for adaptation to and mitigation of potential adverse impacts. Ongoing research efforts are focused on improving the understanding of the physiological and ecological responses of plants and animals to global

Interagency Cooperation

The success of the USGCRP is built around the cooperation and coordination of the participating agencies. The integration of planning and program design across agencies had led to more efficient and effective implementation, such as adapting common standards and issuing of joint research announcements. Examples include:

USGCRP Joint Program in Terrestrial Ecology Research

In 1994, the USGCRP identified terrestrial ecology research as a critical gap and requested a special budget increment. In 1995, a joint agency request for proposals was issued through the National Science Foundation. The Terrestrial ECOlogy Initiative (known as TECO) supports research related to: (1) the role of terrestrial ecosystems in the carbon, nitrogen, and related chemical cycles; (2) the consequences of global change on ecosystems; and (3) ecosystem feedbacks on global change. TECO is closely linked to goals of the international IGBP Global Change and Terrestrial Ecosystems Programme.

USGCRP Global Change Data and Information System

USGCRP agencies are working together to construct a Global Change Data and Information System (GCDIS), which will provide an infrastructure for managing the massive amounts of diverse global change data being produced through the Program. Internet links are available to global change databases through the GCDIS home page, which can be accessed through the World Wide Web at: http://www.gcdis.usgcrp.gov.

USGCRP Ultraviolet Radiation Monitoring

Several USGCRP agencies operate UV monitoring networks that address concerns related to the effects of increased UV exposure on agriculture, human health, and fish and wildlife. The networks use different types of instruments to meet various research needs. In 1994, the USGCRP developed a plan for ensuring that the data collected by these networks are intercalibrated and coordinated with international efforts. During 1995, a network calibration facility was established to accomplish this task. Interagency networks will yield a much broader picture of UV radiation measurements at the Earth's surface.

Natural variability of climate can be observed in these three photographs. The top photograph shows a barn in Beedle, South Dakota surrounded by drifting soil and tumbleweed during the "Dust Bowl" in the U.S. in the early 1930's. The middle and bottom photographs, from after the drought, show the gradual, natural reintroduction of sorghum and sudan grasses in the late 1930's.

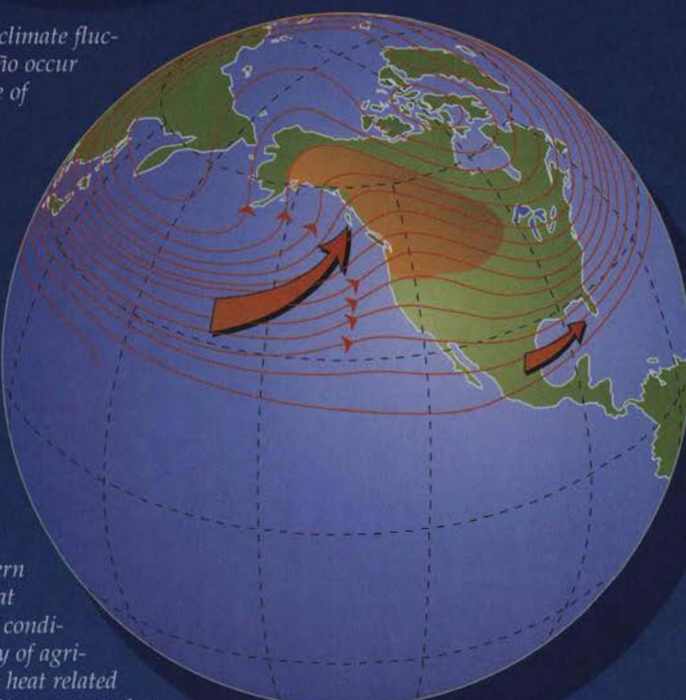
changes in climate, atmospheric gas concentrations, increased UV radiation, changes in land cover, and changes in other environmental factors. These efforts include forest health monitoring; studies of threatened, endangered, and sensitive species; and research into the physiological basis of resistance to environmental stresses such as drought, UV radiation, and the introduction of new pest and predator species. Such programs enable scientists to develop more resistant crop cultivars that are less vulnerable to environmental changes.

Economic research programs are ongoing to analyze the interactions of environmental changes with societal changes, such as changes in consumption patterns, adjustments to technological developments and diffusion, and changing patterns of regional and global trade. Other programs important for evaluating the consequences of global change include those to evaluate substitutes for ozone depleting compounds, efforts to analyze the costs and benefits of a changing mix of energy supply, and projects to study the effectiveness of soil restoration and reforestation.

Developing Integrated Assessments

The USGCRP is continuing to provide strong support for the conduct of scientific assessments on issues of relevance to decision makers. An important aspect of this activity is the development of tools and methodologies for integrating data from the physical, biological, social, and economic sciences. Integrated assessments can help policy makers develop options for responding to global change by providing them with a comprehensive framework for evaluating the effects of different options. This same framework is also useful for identifying priorities for future research to increase scientific knowledge relevant to an issue.

The USGCRP has played a major role in supporting the contributions of U.S. scientists to the international assessment process. International assessments are carried out to develop a broad consensus on scientific findings from information gathered by tens of thousands of scientists throughout the world on issues of global interest. Examples of international assessments are those conducted by the United Nations Environment Programme (UNEP)/World Meteorological Organization (WMO) on ozone depletion and by the Intergovernmental Panel on Climate Change (IPCC) on climate change.



When seasonal to interannual climate fluctuations associated with El Niño occur in the Pacific (at right), a ridge of high pressure (shown as small arrows representing jetstream winds) develops over the west coast of North America, causing higher than normal temperatures in that region (shown in orange). Storms, that under normal conditions (shown above) would pass through Washington and Oregon, are often steered northward toward Alaska (heavy arrow). These conditions also are favorable for the development of storms in the Gulf of Mexico that can bring heavy rains to the southern U.S. Floods, droughts, and heat waves associated with El Niño conditions can affect the productivity of agriculture and fisheries and cause heat related health problems. Research on the processes that link the tropical Pacific Ocean to the global atmosphere has enabled scientists to predict the onset of individual El Niño events and their effects on weather patterns worldwide.

2. SEASONAL TO INTERANNUAL CLIMATE FLUCTUATIONS AND RELATED EVENTS

Science Goals for Research on Seasonal to Interannual Climate Fluctuations and Related Events

- Observe and document the trends and patterns of changes in ocean temperature and circulation, ocean/atmosphere interactions, snow cover, sea ice, vegetation, and other factors that contribute to climate anomalies and related extreme events such as droughts, floods, and heat waves.
- Understand the controlling processes relevant to climate on seasonal to interannual time scales and regional to global scales, and develop predictive climate models that represent these processes.
- Forecast seasonal to interannual climate fluctuations and associated extreme events and simulate the potential economic impacts on agricultural, water resource, and other socio-economic systems.

The climate of the Earth continually experiences natural fluctuations on seasonal to interannual time scales, as evidenced by the El Niño cycle. These naturally occurring fluctuations can lead to extreme climate events such as droughts, heat waves, and floods. Extended periods of drought and heat can increase the susceptibility of urban settlements and forest lands to fire, can disrupt food production and water supplies, and in developing regions, can occasionally lead to massive human migrations. Prolonged and excessive periods of precipitation can cause flooding, delay planting, contaminate water resources, and temporarily disrupt patterns of production and trade.

An improved ability to document and then forecast trends and patterns of change in ocean temperature, snow cover, sea ice, and other factors that contribute to changes in the global climate over seasonal to interannual scales could lead to a reduction of adverse impacts from potentially destructive climate events. Early warnings enable communities to develop strategies to better prepare for these events by, for example, implementing revised planting schedules, switching crops, and modifying water management, all of which have been demonstrated to lead to reduced costs and impacts.

Observations and analyses indicate that in some regions of the globe, seasonal to interannual variations of atmospheric conditions can be predicted up to two years in advance. These predictions are based on observed variations in parameters such as sea surface temperature, soil moisture, and snow and sea-ice cover. Significant changes in seasonal to interannual climate may be a key to the detection of longer-term climate changes.

Some Recent Scientific Accomplishments in Predicting Seasonal to Interannual Climate Fluctuations and Related Events

(see page references for additional details)

- The first year-in-advance predictions of the seasonal variations in sea surface temperatures have been developed based on new knowledge about the processes that link the tropical Pacific Ocean to the global atmosphere. Similar predictions are now being issued regularly by several nations in addition to the U.S., and are being used in agricultural and water resource planning (page 66, 67).
- The U.S. government is now issuing, on a monthly basis, the first-ever year-in-advance forecasts of seasonal mean temperature and precipitation for the United States. The forecasts are based on a blend of statistical and physical coupled ocean-atmosphere models. (page 68).
- USGCRP research results suggest that several recent severe weather events in the U.S. may be related to El Niño-Southern Oscillation (ENSO) conditions in the tropical Pacific Ocean. These include the drought and heat wave in the eastern and central U.S. during the summer of 1988, the floods in the midwest during the spring and summer of 1993, and the frequent

PROPOSED FUTURE RESEARCH ON SEASONAL AND INTERANNUAL CLIMATE

Highlights of USGCRP research in FY 1996 include programs to:

- **Monitor the tropical Pacific to better determine its influence on climate and to improve predictions.** Variations in the tropical Pacific Ocean, particularly variations of sea surface temperature, exert a tremendous influence on the climate of many tropical and mid-latitude countries, including the United States. The USGCRP, in collaboration with its international research partners, has put in place a unique observation array of instruments to constantly monitor the state of the tropical Pacific Ocean and transmit data to research and operational centers in real time.

west coast storms during the early part of 1995. Analyses indicate that conditions in the tropical Pacific Ocean are an important (but not sole) factor influencing the atmospheric circulation patterns over the U.S. (page 69).

- The economic benefits of improved forecasts of ENSO to the agricultural sector of the southeast U.S. have been estimated as being $100 million per year or more. The economic value of improved forecasts to other agricultural regions is also likely to be large. This current assessment suggests that research to support improved ENSO forecasting will bring significant benefits to the nation (page 73).
- Medical research has linked changes in the incidence of diseases carried by mosquitoes and rodents with changes in temperature, rainfall, and the patterns of extreme climatic variations associated with El Niño events. These findings have important implications for human health and welfare (page 70).
- Measurements of carbon dioxide concentrations in the atmosphere and in the surface waters of the equatorial Pacific Ocean indicate that the 1992-93 El Niño event reduced the "normal" (non-El Niño) carbon dioxide release to the atmosphere from this region of the ocean by more than 50 percent. This may be a contributing factor in explaining the slower rates of increase of atmospheric carbon dioxide during that period (page 71).

- **Incorporate field data into models to improve forecasts of climate variability**. Air-sea interaction processes in the western tropical Pacific Ocean are important to the evolution of the El Niño-Southern Oscillation (ENSO) phenomenon. High quality data sets resulting from a recent international field campaign in the western Pacific are being analyzed to improve understanding of the coupling between the ocean and the atmosphere in this climatically important region.

- **Map global precipitation and its relationship to climate change.** Rainfall distributions in the tropics and in several key locations outside the tropics are closely tied to large-scale atmospheric circulation patterns that are forced by the interactions between the atmosphere and the tropical oceans. By merging estimates from a wide range of ground based and satellite measuring systems, the USGCRP, in cooperation with many international partners, has produced the first reli-

What is El Niño?

The term El Niño (Spanish for "the Christ Child") was originally used by fishermen along the coasts of Ecuador and Peru to refer to a warm ocean current that occasionally appears around Christmas-time and lasts for several months. Fish are less abundant during these warm intervals, so fishermen often take a break to repair their equipment and spend time with their families. In some years, however, the water is especially warm and the break in the fishing season persists into May or even June. Over the years, the term "El Niño" has come to be reserved for these exceptionally strong warm intervals that not only disrupt the normal lives of the fishermen but also bring heavy rains and loss of agricultural productivity.

During the past 40 years, nine El Niños have affected the South American coast. Most of them raised water temperatures, not only along the coast, but also around the Galapagos Islands and in a belt stretching 5,000 miles across the equatorial Pacific. The weaker events raised sea temperatures slightly and had only minor impacts on South American fisheries. But the strong ones, like the El Niño of 1982-83, left an imprint, not only upon the local weather and marine life, but also on climatic conditions around the globe. Since 1976, the El Niño has been unusually frequent and long-lived.

able maps of global precipitation. Continued improvements in mapping global precipitation will benefit the global community through improved management of water resources and through better understanding of and ability to predict the climate system.

- **Conduct research to improve prediction skills, particularly over the U.S.** While USGCRP research has made possible the ability to forecast El Niño events up to a year in advance, the forecasts are limited in that they focus on the evolution of the tropical Pacific sea surface

Effects Related to the 1982-83 El Niño

Phenomenon	Victims	Damage
Storms	**U.S. Mountain and Pacific States** 45 dead	$1.1B
Flooding	**U.S. Gulf States** 50 dead	$1.1B
Hurricane	**Hawaii** 1 dead	$230M
Storms	**Northeastern U.S.** 66 dead	—
Flooding	**Cuba** 15 dead	$170M
Drought	**Mexico–Central America** —	$600M
Flooding	**Ecuador–Northern Peru** 600 dead	$650M
Drought	**Southern Peru–Western Bolivia** —	$240M
Flooding	**Southern Brazil–Northern Argentina–Eastern Paraguay** 170 dead, 600,000 evacuated	$3B
Flooding	**Bolivia** 50 dead, 26,000 homeless	$300M
Hurricane	**Tahiti** 1 dead	$50M
Drought, Fires	**Australia** 71 dead, 8,000 homeless	$2.5B
Drought	**Indonesia** 340 dead	$500M
Drought	**Philippines** —	$450M
Wet Weather	**Southern China** 600 dead	$600M
Drought	**Southern India–Sri Lanka** —	$150M
Cold, Snow	**Middle East (Lebanon)** 65 dead	$50M
Drought disease, starvation	**Southern Africa** —	$1B
Drought	**Iberian Peninsula–N. Africa** —	$200M
Flooding	**Western Europe** 25 dead	$200M

Data from NOAA

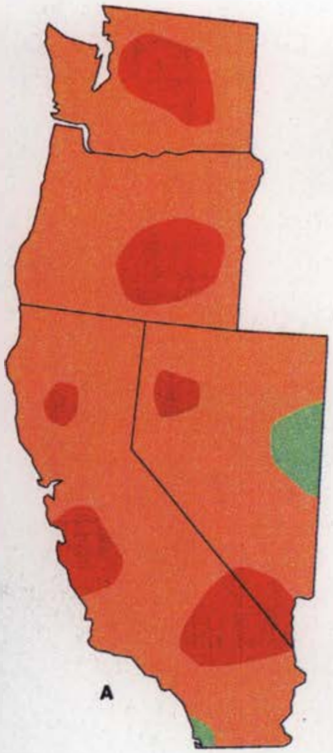
temperature and related climate impacts. Forecast skill is highest in the tropics, near the source of El Niño events and diminishes at higher latitudes (e.g., over North America) where other processes may play a greater role. Further research is planned to extend predictability of climate fluctuations beyond the tropical Pacific to include the effects of the other tropical oceans, higher latitude oceans, and land-surface processes that are believed to contribute significantly to seasonal-to-interannual climate variability, particularly at higher latitudes. The results of such research will improve modeling of precipitation anomalies like those that occurred in the U.S. Midwest in 1993 and this past winter in California.

- **Establish research centers to improve forecast model development.** USGCRP-supported modelers are making their experimental forecast products available to a limited number of tropical countries (e.g., Brazil and Peru). These forecasts are rudimentary and are presently prepared in a research mode, without the routine system for production and distribution that is required for worldwide use. A multinational planning process is underway to establish a network of research centers to enhance the development of regional climate forecast models and methodologies and to sponsor training of scientists from participating countries. One center, the International Research Institute for the Seasonal-to-Interannual Climate Prediction Program, will have the specialized responsibility of producing, assessing, and distributing forecast guidance to interested nations on a regular basis.

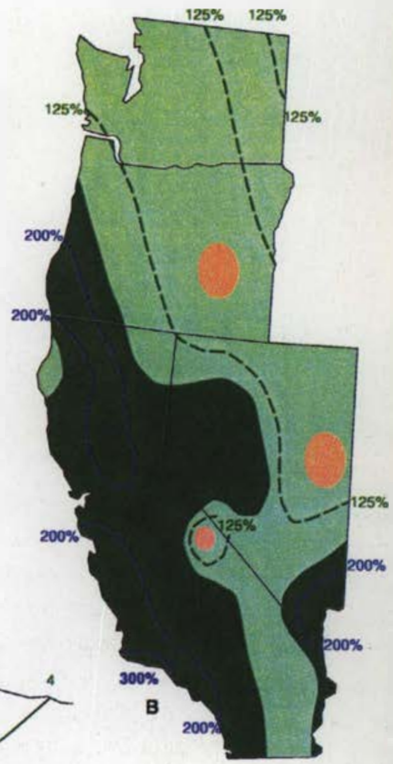
- **Assess human vulnerability to climate variations and identify options for adaptation** based on improved prediction information. An understanding of the social and economic factors that render individuals, communities, and economic sectors more or less vulnerable to seasonal or yearly climatic fluctuations is critical for reducing that vulnerability and improving adjustment. To capitalize on advances in climate analysis and predictive capability, climate information needs to be incorporated into management decisions in climate-sensitive sectors (e.g., hydropower, insurance, transportation, fisheries, and agriculture). Moreover, lessons learned from adapting to natural variability will help society be prepared for the possibility that longer term climate change may manifest itself as changes in the frequency and magnitude of extreme events.

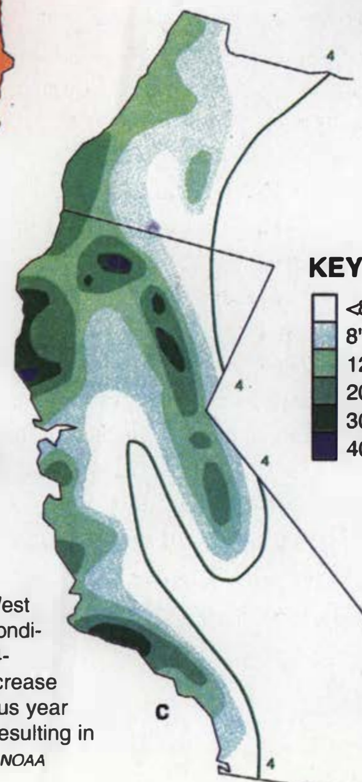
PERCENT OF NORMAL PRECIPITATION

1993/1994 Wet Season
October 1993 - April 1994



1993/1994 Wet Season (To Date)
October 1994 - April 1995





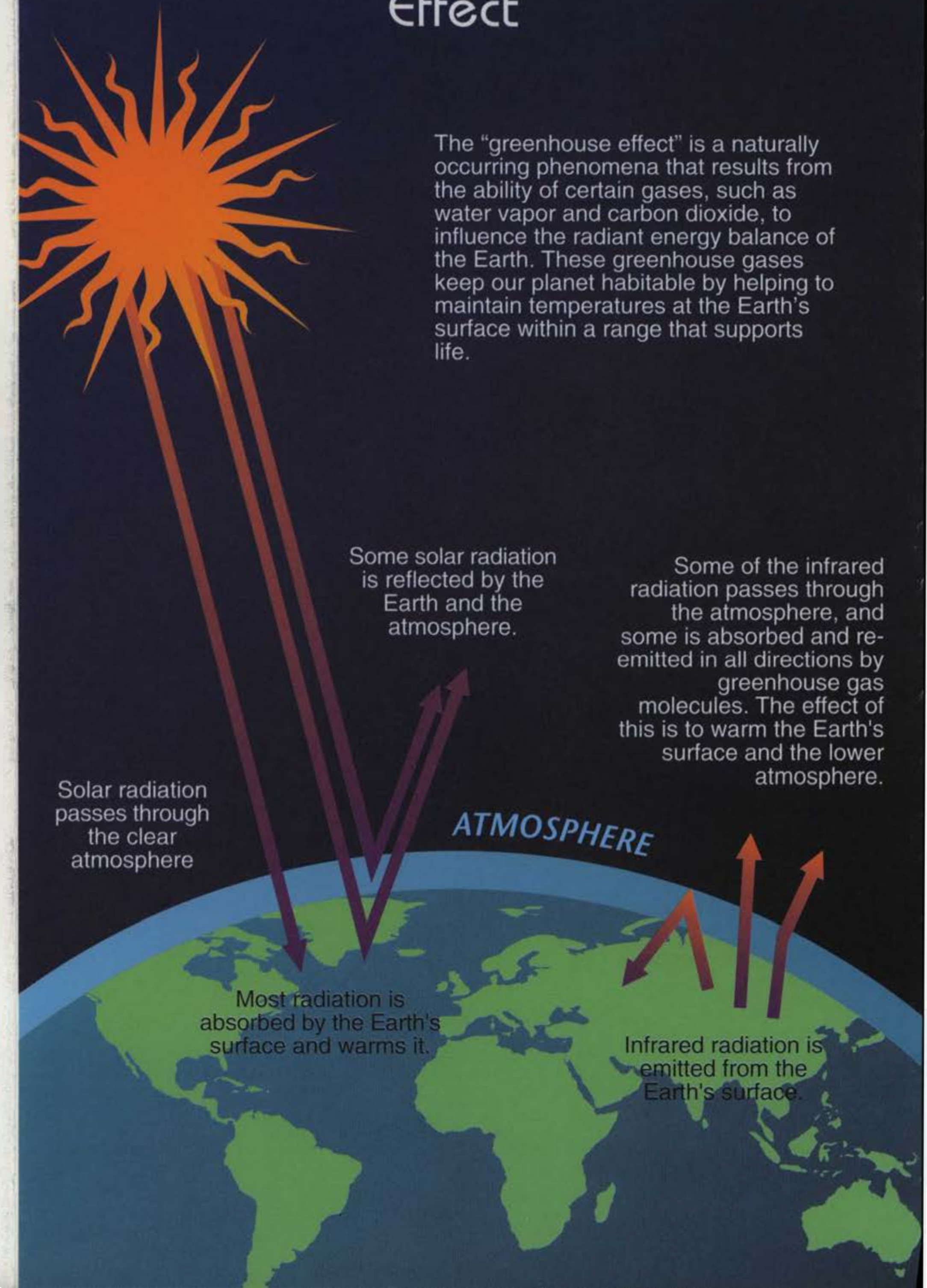
TOTAL PRECIPITATION (inches)

January 1995

Increased frequency of U.S. West Coast storms due to El Niño conditions in the Pacific during 1994-1995 caused a 200 percent increase in precipitation from the previous year over most parts of California, resulting in flooding and mudslides. *Credit: NOAA*

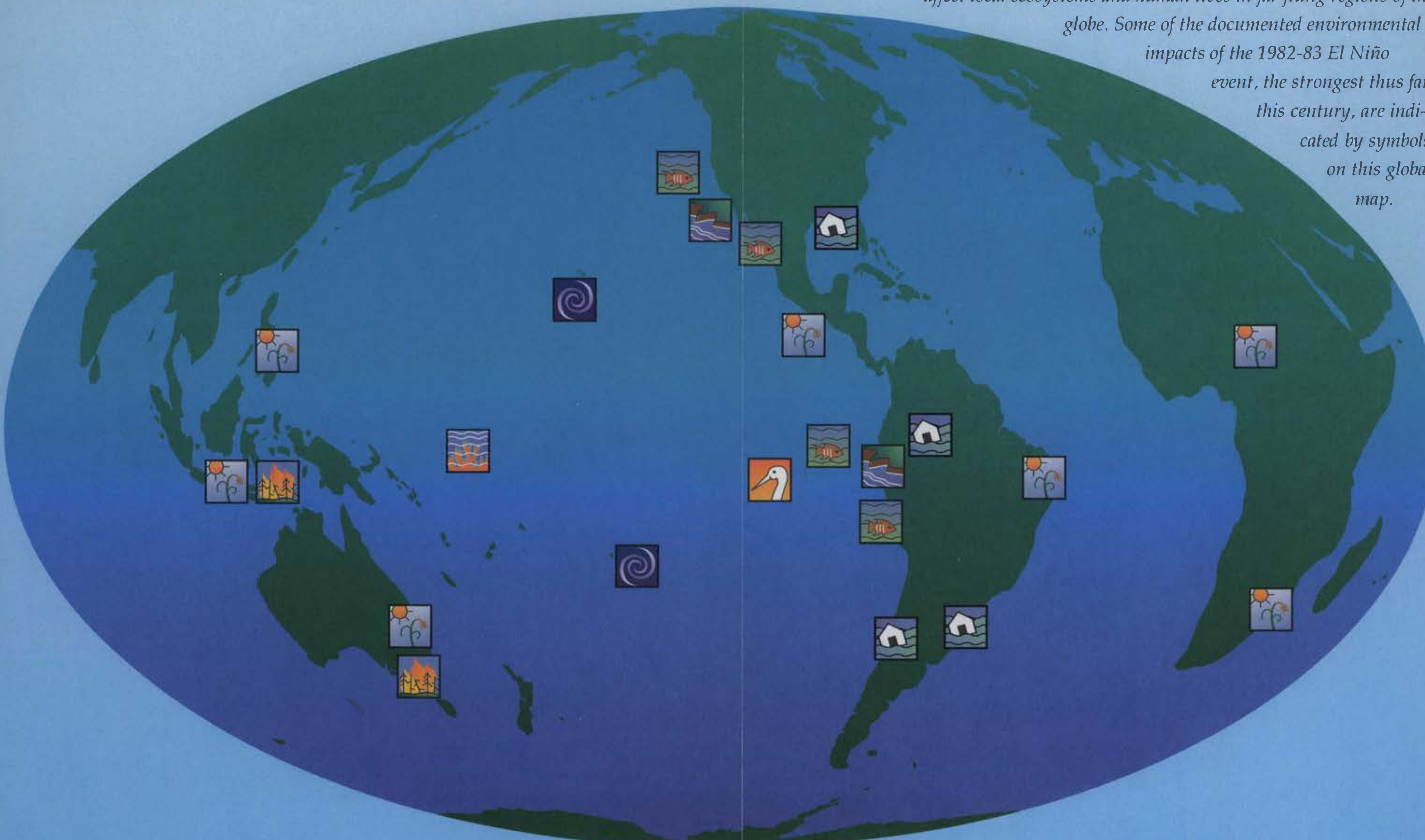
The Greenhouse Effect

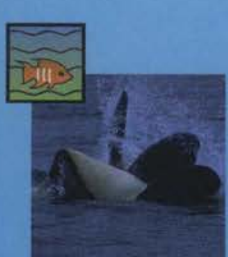
The "greenhouse effect" is a naturally occurring phenomena that results from the ability of certain gases, such as water vapor and carbon dioxide, to influence the radiant energy balance of the Earth. These greenhouse gases keep our planet habitable by helping to maintain temperatures at the Earth's surface within a range that supports life.



EL NIÑO

Subtle changes in the interplay of wind and water in the tropical Pacific can affect local ecosystems and human lives in far flung regions of the globe. Some of the documented environmental impacts of the 1982-83 El Niño event, the strongest thus far this century, are indicated by symbols on this global map.





MARINE LIFE

FLOODS

COASTAL EROSION

DROUGHT

CORAL REEFS

BIRD LIFE

FOREST FIRES

TROPICAL STORMS

3. CLIMATE CHANGE OVER THE NEXT FEW DECADES

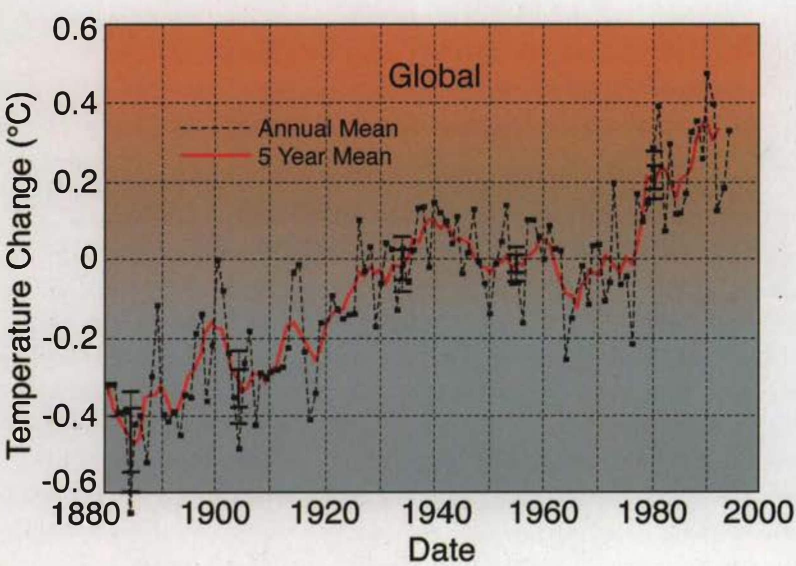
Science Goals for Research on Climate Change over the Next Few Decades

- Observe and document the trends and patterns of change in the Earth's climate system, including the atmosphere, oceans, glaciers, sea ice, and the biosphere.
- Understand Earth system processes relevant to the regulation and radiative forcing of climate, and develop predictive models of regional to global climate change over time scales from a decade to a century.
- Assess the vulnerability of Earth systems, including economic, human health, and ecological systems, to the predicted rates and magnitudes of climate change.
- Support national and international science and technology assessments of the climate system that bring research results from natural and social sciences into a framework for evaluating and communicating the likelihood of significant climate change, and society's potential for mitigating, adapting, or responding to change.

Human society is highly dependent on the Earth's climate. Climate patterns and human adaptations determine the availability of food, fresh water, and other resources for sustaining life. The social and economic characteristics of society have also been shaped largely by adapting to the seasonal and year-to-year (interannual) patterns of temperature and rainfall. While anomalous variations in these shorter time scale patterns can have serious effects on society, the vulnerability of society to longer-term climate change, occurring over periods of decades to centuries, will depend on its ability to understand and respond to this change. Thus, it is imperative that society develop the strongest possible scientific understanding of the causes and dynamics of climate change and greenhouse warming, the potential ecological and socioeconomic impacts of change, and the implications of alternative courses of action to mitigate and adapt to change.

Scientists have determined that climate can be influenced by both natural forces and human activities. For example, habitable temperatures are maintained on Earth by a natural phenomenon known as the "greenhouse effect." Solar radiation is absorbed by the Earth's atmosphere and land and water bodies. The resultant heat is re-emitted as long-wave radiation, some of which escapes to space and some of which is absorbed and trapped by atmospheric gases such as water vapor, carbon dioxide, methane, nitrous oxide, chlorofluorocarbons and ozone. While some of these gases are present naturally, increased concentrations of greenhouse gases as a result of human activity can enhance this natural greenhouse effect, creating additional warming of

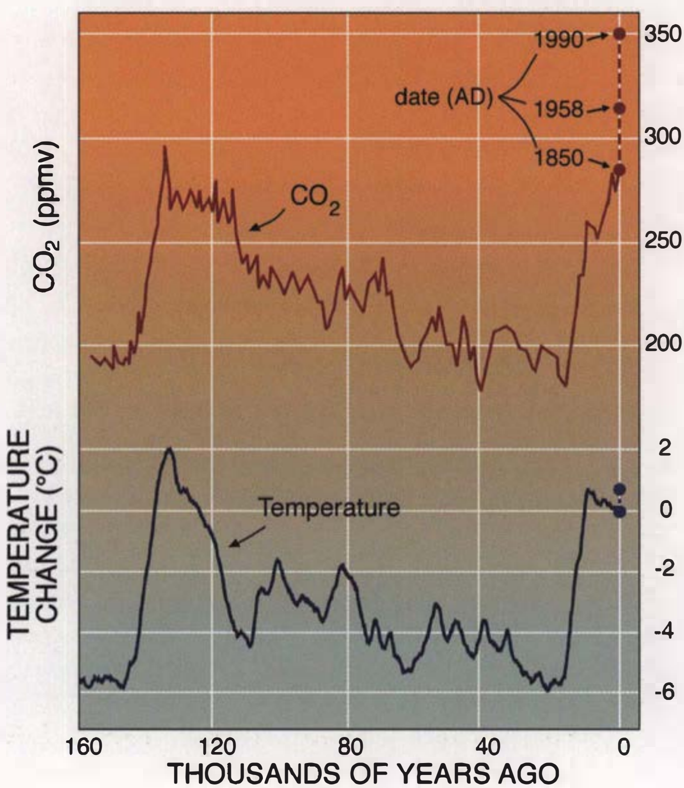
Records of significant changes in temperature in the past provide the context for understanding the potential magnitude and importance of future changes. The figure on the right shows results from an Antarctic ice core analysis of climate changes over the past 160 thousand years. During interglacial periods (about 130 thousand years ago, and beginning 15 thousand years ago), carbon dioxide concentrations increased, possibly due to the effects of increased temperature on the carbon cycle. Increases in carbon dioxide concentrations over the last century are primarily a result of human activities. The curve below shows the observed changes in the mean global temperature over the last hundred years. Credit: J. Hansen, NASA.



the surface and the atmosphere. Human activities such as fossil fuel combustion and land-use change have resulted in a 30% increase in atmospheric carbon dioxide and have contributed to more than a doubling of the methane concentration since preindustrial times.

Human-induced and natural changes in global land cover (such as deforestation and desertification) and emissions of aerosols (from fossil fuel burning and volcanic eruptions) also influence climate. Although much has been learned, there are still significant improvements to be made in estimating how human activities will combine with natural influences to affect the future global climate.

IPCC assessments conducted with the participation of thousands of scientists from more than 150 countries and with significant USGCRP participation, suggest that emissions of greenhouse gases and sulfate aerosols could, by the end of the next century, lead to an increase in global mean temperatures of about 1-4° C, a rise in sea level, and a global change in precipitation patterns. Among other uncertainties, the magnitude and location of projected shifts in global precipita-



Recent Scientific Accomplishments in Observing, Understanding, and Predicting Climate Change over the Next Few Decades

(see page references for additional details)

- Modeling studies predict that atmospheric aerosols, largely emitted from human activities, exert a non-uniform cooling effect over the globe. On average, this effect may be counterbalancing about half of the expected warming induced by increases in atmospheric greenhouse gas concentrations (page 85).

- The decline in snow cover extent in the Northern Hemisphere by about 10 percent over the past 20 years has resulted in a further warming of surface air temperatures, which is consistent with the observed trend of increasing water vapor concentration during this time period. Other evidence of warming includes a decrease in Arctic sea ice, continued melting of alpine glaciers, and a rise of sea level (page 90).

- Information on past changes in the Earth's climate (from ice cores, lake level data, and other indicators) suggests that the melting of very large icebergs associated with glacial retreat can perturb ocean circulation patterns and result in relatively abrupt climate shifts over time periods as short as decades (page 82).

- Oceanographic observations along the central North Atlantic have revealed a distinct warming in the upper 2500 meters over the past 35 years, suggesting either a large-scale warming in the ocean or a shifting of large masses of ocean water (page 91).

- Results of measurements of carbon exchange at a site on the Arctic tundra indicate that the tundra may have shifted from being a net sink for atmospheric carbon dioxide in the 1970's to a net source of CO_2 in the 1990's. Because of the large reservoir of carbon in tundra soils, the release of carbon to the atmosphere from tundra ecosystems could have a major positive feedback effect on the atmospheric CO_2 concentration and on climate change (page 77).

- Combined satellite, aircraft, and surface measurements indicate that significantly more solar radiation may be absorbed by clouds than is currently predicted by general circulation models. The interpretation of these measurements is inconsistent with current understanding and therefore requires further observational confirmation. If confirmed, these new findings will require reanalysis of the Earth's radiation balance and the role of clouds in climate change and could result in significantly improved climate models (page 78).
- Results of analyses of the relationship between the growth of boreal forest trees in northern and central Alaska and climate show that, over the past 100 years, tree growth at first accelerated but then stabilized as climate continued to warm. These results indicate that the response of boreal forest tree growth to climate change may not be simple and linear. (page 95).
- New research indicates that some species could potentially benefit from increased atmospheric concentrations of CO_2. Experiments on the interactive effects of exposing agricultural crop species to different mixtures of atmospheric gases suggest that elevated CO_2 concentrations may, for selected species, mitigate the damaging effects of elevated ozone (O_3) concentrations. However some species, such as aspens, become more sensitive to increased concentrations of O_3 if CO_2 concentrations are elevated. (page 97).
- Potential economic impacts of a global warming scenario on U.S. agriculture were estimated using an approach that accounts for not only the direct impacts of climate change on crop yields but also potential adaptations (e.g., crop substitution) by farmers in response to different climates. Results show a significantly lower overall economic impact of global warming compared to that estimated by using a simple production-function approach that does not account for adaptive, profit-maximizing farmers. The results also suggest that global warming could be beneficial to U.S. agricultural productivity if irrigated water is not limited.(page 101).

tion patterns remain particularly difficult to predict.

Observational data show an increase in global average temperature of about 0.5°C over the last 100 years. The likelihood that this warming is due primarily to natural variability is low. This observed warming trend is continuing despite the influence of the Mt. Pinatubo volcanic eruption, which caused volcanic emissions to reduce incoming solar radiation for nearly two years. The most recent climate model simulations have been able to explain the magnitude and temporal pattern of this observed trend reasonably well. To build greater confidence in predictions of future climate, further improvements are needed in modeling the influence of atmospheric aerosol concentrations, the cycling of atmospheric water in all its phases, cloud-radiation interactions, ocean-atmosphere coupling, and in predicting the expected range of natural climate variability.

Projected climate change over the next few decades, including changes in temperature, precipitation, and sea level, can add to other stresses on natural systems caused by other factors such as population growth, land-use changes, and pollution, posing risks to managed and unmanaged resource systems. Although temperature changes of the magnitude expected from the enhanced greenhouse effect have occurred in the distant past, the evidence suggests that the changes generally took place over centuries or millennia instead of decades. Because rates of natural migration and adaptation of species and communities appear to be much slower than may be forced by the predicted rate of climate change, populations of many species and inhabited ranges could decrease as the climate to which they are adapted effectively shifts northward or to higher elevations.

Overall, various strategies for coping with climate change can be identified for "intensively managed" systems (such as agriculture, water resources, and developed coastlines). For these systems, technological and management options exist to some extent today, although they may be costly to implement. By comparison, fewer options have been identified for natural systems such as wetlands and wilderness areas.

Changes in climate may also have significant impacts on human health. These impacts may include increases in mortality and morbidity as a result of a higher frequency of heat waves and synergistic effects from higher temperatures and air pollutant mixtures (higher temperatures may cause changes in urban air chemistry). There is also evidence that a changing climate will cause a migration into higher latitudes and altitudes of some diseases, such as malaria and dengue, the incidence of which is highly correlated with rainfall and elevated nighttime temperatures.

PROPOSED FUTURE RESEARCH ON CLIMATE CHANGE OVER THE NEXT FEW DECADES

Highlights of USGCRP research in FY 1996 include programs to:

- **Continue to reconstruct past climates of the Earth to improve understanding of the dynamics of climate change** by further analyzing ice core data and other historical records relevant to understanding of the Earth's past climates and climate changes, and comparing simulated climates with the geologic records to evaluate model performance.

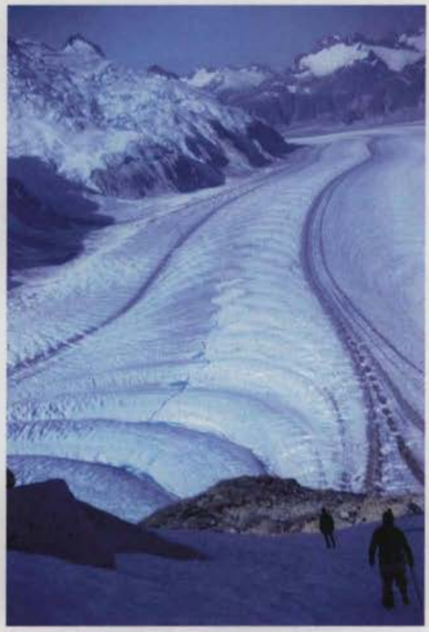
- **Analyze observational evidence of changes in the climate system over the past century** to better distinguish natural variability from the influence of human activities. In addition to space-based and in-situ observations, existing climate data will be reanalyzed for trends and patterns of change and compared with the results of model simulations.

- **Evaluate natural and human-induced factors that lead to climate change,** including the sources, sinks, and lifetimes of greenhouse gases and atmospheric aerosols, and their collective effects on the Earth's radiation balance.

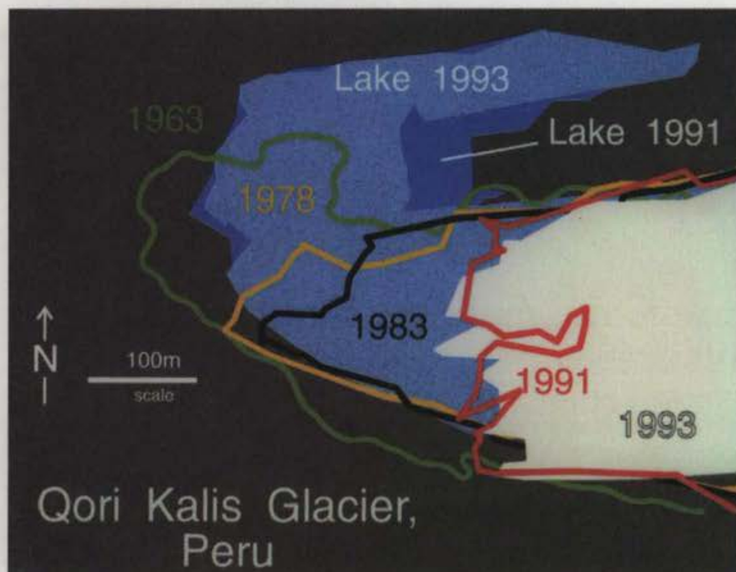
- **Refine predictions of global climate change over the next few decades** by extending model simulations to comprehensively link oceanic, atmospheric, terrestrial, glacial, and sea-ice influences and to include improved representation of important processes, such as cloud-radiation and chemistry interactions.

- **Assess the vulnerability of society to the projected patterns and rates of climate change** at the regional, national, and international levels. Conduct research to assess the vulnerability of Earth systems, including economic, human health, and ecological systems, to the predicted rates and magnitudes of climate change.

- **Develop new integrated assessment tools** to bring together complex information and research results from natural, social, and policy sciences into an evaluation framework.



The volume of the Earth's ice, including the polar ice caps, sea ice, ice sheets, and mountain glaciers, fluctuates with the climate. Predictions that the mean global temperature wll increase over the next century has caused concern over possible changes in sea level. Mountain glaciers can contribute to these changes. The above photo shows the flow lines on the Vaughan Lewis Glacier in southeast Alaska.



Recent observations have documented the worldwide retreat of many mountain glaciers consistent with observed changes in mean global temperature. A regional example of the consequences of this warming is the retreat of the Qori Kalis outlet glacier on the Quelccaya Ice Cap in the Andes of Peru. Between 1983 and 1991, the rate of retreat was three times that from 1963 to 1978. As the glacier retreated (colored lines), the meltwater created a continuously expanding lake (blue areas) at the base of the glacier.

*Potential Impacts on Various Sectors Associated with Climate Change Predictions over the Next Century **

WATER RESOURCES—The quality and quantity of drinking water, water availability for irrigation, industrial use, and electricity generation, and the health of fisheries may be significantly affected by changes in precipitation and increased evaporation. Increased rainfall may cause more frequent flooding. Climate change would likely add stress to major river basins worldwide.

COASTAL RESOURCES—A 50 cm rise in sea level by the year 2100, which is within the center of the range projected by the IPCC, could inundate more than 5,000 square miles of dry land and an additional 4000 square miles of wetlands in the U.S.

HEALTH—Heat-stress mortality could increase due to higher temperatures over longer periods. Changing patterns of precipitation and temperature may produce new breeding sites for pests and pathogens, shifting the range of infectious diseases, such as malaria and dengue fever.

AGRICULTURE—Although droughts may become more frequent in certain areas of the U.S., such as the Great Plains, new technological advances and changes in planting patterns could offset adverse effects on agriculture. However, impacts in developing countries could be significant.

FORESTS—Over the next century, the range of North American forest species could shift to the north by as much as 450 kilometers, disrupting or reorganizing existing ecological communities over the next few decades. Higher temperatures and precipitation changes could increase forest susceptibility to fire, disease, and insect damage.

ENERGY AND TRANSPORTATION—Warmer temperatures increase cooling demand but decrease heating requirements. Fewer disruptions of winter transportation may occur, but water transport may be affected by increased flooding or lowered river levels.

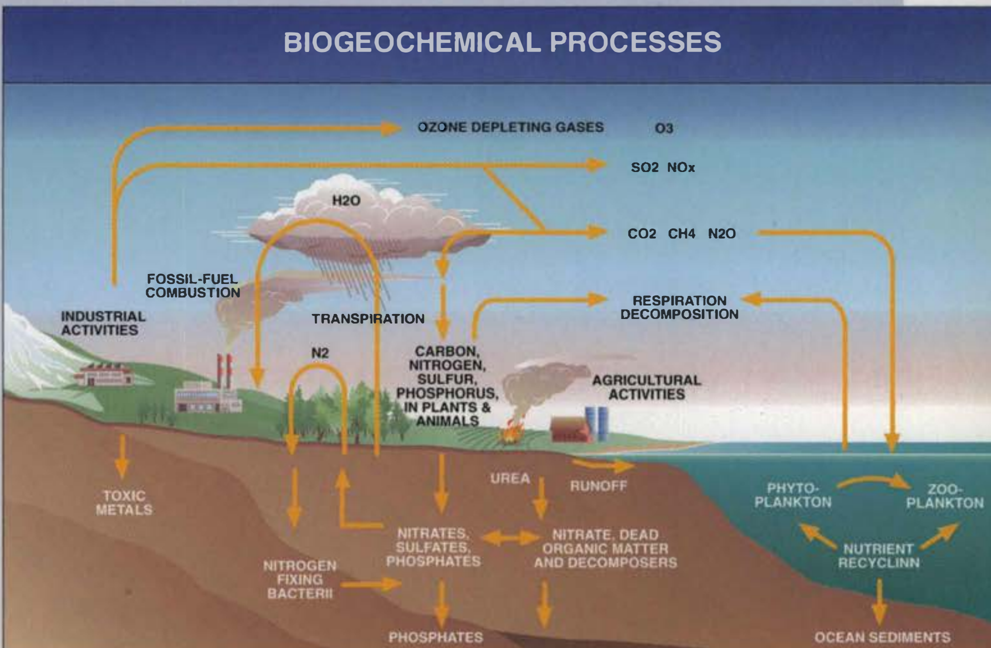
**Climate Action Report*, ISBN 0-16-045214-7, the U.S. submission under the United Nations Framework Convention on Climate Change.

What is the Greenhouse Effect?

The "greenhouse effect" is a naturally occurring phenomenon that results from the ability of certain gases, such as water vapor and carbon dioxide, to change the radiant energy balance of the Earth. These greenhouse gases keep the planet habitable. They absorb the infrared wavelengths of radient energy more efficiently than they absorb the radient energy at solar wavelengths. Thus, greenhouse gases allow solar radient energy to pass through the atmosphere to be absorbed at the Earth's surface, but they trap most of the radient heat emitted from the Earth's surface in the lower atmosphere, not allowing it to escape to space

Greenhouse gases influence the Earth's temperature by allowing solar radiant energy to pass through the atmosphere, where it is absorbed at the surface, and subsequently trapping most of the radiant heat that is re-emitted into the atmosphere. If it were not for this natural greenhouse effect, the Earth's surface would be some 33^{O}C (60 ^{O}F) colder than it is today. The greenhouse analogy arises from the fact that greenhouse gases act like the glass panels of a greenhouse, allowing short wave radiant energy from the Sun to pass through the atmosphere, but preventing some of the longer planetary infrared wavelength radiation from escaping back through the atmosphere.

The current scientific debate associated with "global warming" focuses on the sensitivity of the Earth's climate to an enhanced greenhouse effect and resulting feedbacks caused by increased atmospheric concentrations of greenhouse gases that result from human activities. For example, a warmer Earth would cause increasing evaporation and hence atmospheric water vapor. Because atmospheric water vapor is a strong greenhouse gas, this could lead to further warming. Increased water vapor and changes in atmospheric circulation could also create changes in cloud amounts; however, more clouds would, on average, have a cooling effect. Similar feedbacks occur as a result of ocean, land and sea-ice processes, many of which are highly temperature dependent. A better understanding of the extent to which these feedbacks affect the means and extremes of the Earth's climate will help scientists to better estimate the environmental, economic, and human health risks from an enhanced greenhouse effect.



Complex interactions among different chemicals occur within and between the various parts of the Earth System, including the atmosphere, the lithosphere (land surfaces), the cryosphere (snow, ice, glaciers, etc.), the biosphere (living systems), and the oceans and other freshwater bodies. Quantitative understanding of these interactions and their associated biogeochemical processes is crucial for making reliable predictions of future changes in the global environment. It is also important to characterize the fundamental processes and mechanisms that regulate the water and energy cycles of the Earth over a wide variation of spacial and temporal scales.

The science of human interactions with the environment must be understood in order to predict future global environmental changes. For example, greenhouse gas emissions are associated with human activities in many sectors of society. Each gas is emitted from a variety of sources, has different removal mechanisms (or "sinks"), remains in the atmosphere for varying periods of time, and has a different ability to trap heat and impact the global environment. The total and cumulative effect of all these factors, including projections of the magnitude of future sources and sinks, must be considered in contructing climate prediction models.

What is a Climate Model?

A climate model is a scientific tool that can be used to understand the functioning of the climate system. Climate models consist of sets of mathematical expressions that describe the physical processes associated with climate—e.g., seasonal changes in sunlight, large-scale movements of air masses, evaporation and condensation of water vapor, absorption of heat from the atmosphere into the oceans, and so forth. In most models, the atmosphere is sectioned off into "cells" roughly 500 kilometers (about 300 miles) on a side at the Earth's surface, and the cells are stacked about twenty layers deep. The vertical layers reach 30 kilometers (about 20 miles) or more into the atmosphere. For each cell and period of time (e.g., an hour), the sets of mathematical expressions are solved to predict such variables as temperature, humidity, air pressure, and wind speed. In simulating a century's worth of climate, the process is repeated a million or more times.

At the core of climate models are expressions of physical principles such as the conservation of energy or mass (e.g., of air or water vapor). Such "laws" govern interactions among the atmosphere, oceans, sea ice, land, and vegetation. Because many processes take place at scales smaller than are represented by the grid cells in most models, information from field experiments and observations of how the climate varies from season-to-season and year-to-year are used to develop approximations to the equations. For example, observational data on the occurrence, types, and altitudes of clouds as they relate to temperature and humidity levels are used to predict the form and character of clouds in model simulations. A potential problem with using empirical relationships rather than fundamental physical principles is the possibility that observed relationships may not hold for conditions different than those under which the observations were made.

In the climate models developed to date, atmospheric conditions have been treated more comprehensively than ocean, land, and vegetation conditions. Greater attention now is being given to the development and integration of submodels that more realistically represent non-atmospheric components of the integrated Earth system. The seasonal climate cycle provides a good test of the ability of models to simulate the short-time-scale processes involved. Additional tests of models include simulation of the effect of volcanic eruptions, El Niño events, and climate changes over historical and geological time periods.

Stratospheric Ozone

A High Altitude Protective Layer

Ozone is a relatively unstable molecule made up of three atoms of oxygen. Stratospheric ozone is concentrated in a layer centered about 24 kilometers (15 miles) above the Earth's surface and is crucial for life on Earth, protecting the Earth's surface from the Sun's harmful ultraviolet radiation. Without this shield, humans would be more susceptible to skin cancer, cataracts, and impaired immune systems. Concentrations of this "life protecting" ozone are ***decreasing*** *due to human activities, such as the widescale use of chlorofluorocarbons (CFCs).*

Tropospheric Ozone

Ground-level Ozone - A Component of Smog

At the Earth's surface, in the air humans breathe, ozone is a harmful pollutant that causes damage to lung tissue and plants. Concentrations of this "harmful" ozone are ***increasing*** *due to human activities, such as the use of automobiles and the combustion of fossil fuels, associated with the emission of chemicals that react in the sunlight to form ozone. Ozone is also increasing in the upper part of the troposphere, where it acts as a greenhouse gas and contributes to climate change.*

4. STRATOSPHERIC OZONE DEPLETION AND INCREASED UV RADIATION

Science Goals for Research on Stratospheric Ozone Depletion and Increased UV Radiation

- Observe and document the trends and patterns of change in ozone concentrations in the Earth's stratosphere and upper troposphere and the related trends and patterns of UV radiation at the Earth's surface.
- Model the physical and chemical processes of the stratosphere and upper troposphere that will allow predictions of ozone change and the resulting change in UV radiation at the Earth's surface.
- Assess the implications of changing ozone concentrations and the resulting changes in UV radiation at the Earth's surface to human health and other life forms.
- Assess the efficacy of the development of new replacement compounds for chlorinated and brominated compounds.

Life at the surface of the Earth is protected from the harmful ultraviolet (UV) radiation of the Sun by the stratospheric ozone layer. Over the last several decades, synthetic chemical compounds, such as chlorofluorocarbons (CFCs) and halons, were developed to provide a new generation of refrigerants, insulating foams, fire retardants, and other products. Unfortunately, after extensive use of these compounds, it was discovered that they remain inert in the atmosphere until they reach the stratosphere, where they break down into an active form that destroys ozone. One chlorine atom originating from a CFC molecule can destroy thousands of protective ozone molecules.

Satellite and ground-based observations confirm that losses of ozone are occurring seasonally, particularly in the springtime polar vortex of the Antarctic stratosphere, leading to what is known as the ozone "hole." Also of concern is the more moderate ozone depletion observed in mid-latitudes, where a large portion of the Earth's population resides. In the absence of changes in clouds or pollution, decreases in atmospheric ozone will increase ground-level UV radiation.

Some Recent General Scientific Accomplishments in Understanding Stratospheric Ozone Depletion and Increased UV Radiation

(see page references for additional details)

- The Upper Atmosphere Research Satellite (UARS) has provided an Antarctic-wide data set that characterizes, over broader spatial areas, the polar stratospheric cloud (PSC) processes that were first revealed by airborne measurements. PSC processes shift the balance of atmospheric chlorine toward the more ozone-destroying forms. Because the Arctic is warmer, the formation of polar stratospheric clouds is more localized and transient, and losses of ozone there are less intense. However, future cooling of the stratosphere due to increasing concentrations of certain greenhouse gases could lead to increased polar stratospheric cloud formation, causing greater ozone depletion over the Arctic (page 108).
- Global atmospheric measurements continue to confirm decreases in the growth rates in the concentrations of the ozone depleting chemicals CFC-11, CFC-12, and several halon compounds. The rates of increase in total organic chlorine and bromine in the troposphere have slowed significantly over the past few years. Total stratospheric chlorine/bromine loading is expected to peak in the late 1990s, followed by a slow recovery of the ozone layer over the next several decades (page 105)
- Medical research has found that increased UV radiation can act in two ways to cause the development of cancer. UV radiation can mutate the cancer-suppressing genes in the skin, and can also cause previously damaged skin to produce more mutant cells. Thus, exposure to UV in sunlight can act both as a tumor initiator and tumor enhancer. These findings increase the concern over human exposures to increased UV radiation from ozone layer depletion (page 112).

Analyses of data related to human health, Antarctic marine phytoplankton production, and careful field and laboratory experiments on the impacts of elevated UV exposure, indicate that increased UV radiation at the surface could have substantial negative impacts on human health, fish populations, and many terrestrial and marine ecosystems. In humans and other animals, impacts include immune system suppression, increased incidence of serious sunburn, cataracts and epidermal lesions, reduced vitamin D synthesis, and cancer. In plants, exposure to enhanced UV radiation can inhibit the essential process of photosynthesis. Increased UV radiation can also influence agricultural productivity and cause deterioration of synthetic materials such as plastics.

Due to global recognition of the implications of ozone depletion, emissions of many CFCs and halons are to be phased out over the next few years. Global observations of CFC concentrations in the atmosphere indicate that actions taken in response to the Montreal Protocol and its amendments are having the desired effect. Atmospheric measurements of trichloroethane, a short-lived ozone-depleting substance, indicate that its concentrations are actually declining.

PROPOSED FUTURE RESEARCH ON STRATOSPHERIC OZONE DEPLETION AND INCREASED UV RADIATION

Highlights of USGCRP research in FY 1996 include programs to:

- **Monitor the recovery of the ozone layer.** Total stratospheric chlorine/bromine loading is expected to peak in the late 1990s, and a slow recovery of ozone is then expected to follow. Continued space-based measurements of stratospheric ozone and the reactive chemical species that affect it (oxides of chlorine, bromine, nitrogen, and hydrogen) are needed to ensure public safety and health and verify whether actions taken in response to the Montreal Protocol and its amendments are having the intended effect.

- **Continue to monitor CFC concentrations and other ozone depleting gases in the atmosphere.** Global compliance with international agreements will be needed if the emissions of CFCs, halons, and other ozone depleting gases are to continue to decline as expected. Only by continued long-term space-based monitoring of these gases can international policymakers be assured of compliance with the agreed phase-out schedule.

- **Continue efforts to detect and understand extremes in ozone depletion.** While the average behavior of the ozone layer is expected to recover during the next century, significant depletions could still occur over the next decade. For example, an unusually cold Arctic winter could lead to Arctic ozone depletion. Large amounts of sulfur gases ejected into the stratosphere (e.g., from volcanic eruptions) could cause significant ozone loss through subsequent chemical reactions involving sulfates and human-emitted chlorine and bromine. Such eruptions, if they were to occur over the next few years, could be particularly damaging as the stratospheric chlorine burden reaches its maximum.

Atmospheric Effects of Aviation

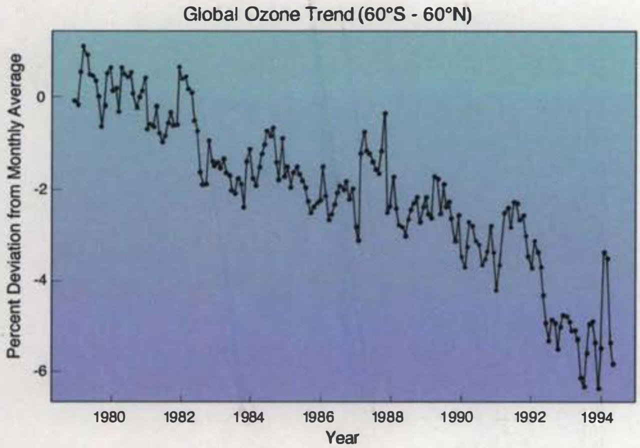
The impact of aircraft operations on air quality in the local airport environment has long been recognized. In order to minimize this impact, a set of emission standards for aircraft during landing and takeoff has been adopted by the international community. Much less attention has been directed to aircraft emissions at cruise altitudes and there are currently no regulations on this facet of aircraft operation. At cruise altitudes, aircraft emit nitrogen oxides (NO_x), which are key participants in ozone photochemistry. Aircraft also emit other chemicals that influence the Earth's radiation budget, namely, water, carbon dioxide, and soot/aerosols. Aircraft exhaust emitted at cruise altitudes persists far longer than that emitted near the ground, making cruise emissions an issue on a global scale. Concern over the potential atmospheric impacts of aircraft have been heightened by aircraft industry projections of a substantial increase in air traffic over the next 20 years. In response to this anticipated increase in demand, larger subsonic aircraft are being designed and the groundwork is being laid for a new generation of supersonic passenger planes.

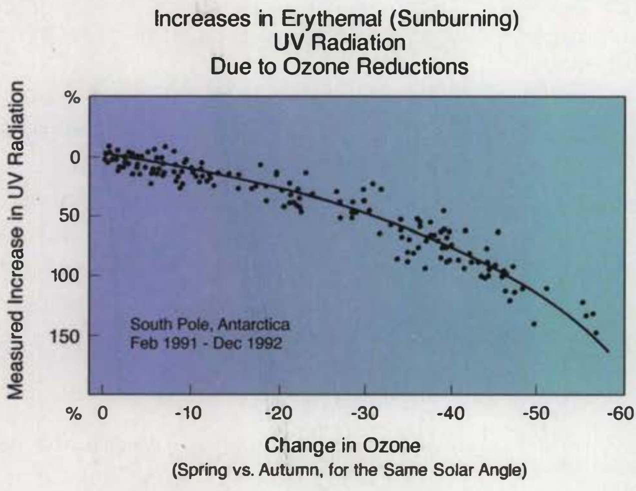
Preliminary estimates indicate that future subsonic and planned supersonic aircraft operations will increase concentrations of nitrogen species in the troposphere and stratosphere by more than 10% and 100%, respectively. The response of ozone to

- **Provide scientific information about the ozone depletion potential and environmental fate of CFC substitutes.** As CFCs and halons are phased out, a wide range of new substitute molecules has emerged. Only by fully understanding the physical and chemical properties of each gas can scientists acquire the information needed to compare the effects of each upon the ozone layer, and the toxicity and fate of each compound in the environment and its potential to contribute to climate change, thus providing an improved scientific basis for choosing among alternatives. This information helps avoid costly errors in the promotion of substitutes.

these perturbations is highly uncertain, but present model simulations indicate ozone concentrations will increase in the troposphere and decrease in the stratosphere. Water vapor and sulfur oxide concentrations are expected to increase significantly, perhaps as much as 40%, in the stratosphere. The current best estimate of climatic impacts is that the positive radiative forcing due to the release of NO_x from aircraft may be of similar magnitude to the effect of CO_2 released from aircraft.

Several major airborne field campaigns, including one directed at sampling the exhaust of a supersonic jet aircraft, have already addressed important aspects of the chemistry associated with aircraft exhaust. However, in order to develop a sound scientific basis for assessing aircraft impacts, a host of issues remain involving the dispersion of exhaust into the atmosphere, possible effects of aircraft contrails on the stability and radiative properties of existing cirrus clouds, and the role of exhaust particulate matter as a catalyst for atmospheric chemical reactions. Information obtained on these issues will allow scientists to make better predictions about the possible environmental impacts of engines that could be used to power high-speed civil transport to be certified in about 2005, and to provide a credible basis for formulation of possible cruise emission standards by the International Civil Aviation Organization.





TOP: These data show the observed long-term change in the globally averaged ozone concentration since 1979, after accounting for the year-to-year effects of solar influences. The downward trend is much greater than that which can be attributed to periodic variation in the Sun's energy output. The decrease in ozone is attributed to increasing chlorine and bromine in the stratosphere, due primarily to emissions of CFCs and other ozone-depleting gases that result from human activities.

BOTTOM: These observations show the correlation between measured increases in UV radiation at the surface with decreases in stratospheric ozone concentrations. These data from Antarctica represent the most complete set illustrating this correlation. Exposure to increased UV radiation can cause skin cancer and eye damage in humans. Continued ozone losses are predicted for the remainder of the decade; however, if nations continue to comply with the Montreal Protocol and its amendments, the ozone layer will recover in the 21st century.

Credit for both figures : World Meteorological Organization/United Nations Environment Programme. Scientific Assessment of Ozone Depletion: 1994

- **Fully establish UV trends.** High-quality measurements of ozone and other factors that affect surface UV radiation (e.g., clouds) are needed in order to understand the physical processes affecting the relationship between ozone depletion and surface UV-trends. Only in this manner can a baseline be established and the variables that affect variance from the baseline be defined. In addition, high-quality UV measurements to define the response to ozone trends in higher impact areas (e.g., managed ecosystems such as forests and croplands) are needed.

- **Better quantify the role of methyl bromide in ozone depletion and identify substitute compounds.** Methyl bromide is a significant ozone-depleting gas with both natural and anthropogenic sources. The sources and sinks of methyl bromide must be better quantified to more accurately determine the current and future ozone depletion potential of this compound. Given the wide range of methyl bromide uses in agriculture, a variety of alternatives to this chemical compound are needed to replace its use as it is phased out.

- **Better understand processes that affect the chemistry associated with NO_x emissions from aircraft.** Supersonic aircraft emissions can contribute to ozone decreases in the stratosphere (and hence lead to potential UV increases at the surface). Subsonic aircraft emissions can lead to ozone increases in the upper troposphere that may contribute to climate change.

- **Understand the connection between stratospheric ozone and surface climate.** As stratospheric ozone is depleted, the stratosphere cools, tending to cool the surface. The exact relationship depends upon the vertical profile of ozone depletion and perhaps on indirect chemical feedbacks. These relationships must be better quantified if past and future perturbations to the Earth's climate system are to be adequately understood.

Land cover refers to the vegetation and other materials that cover the surface of the Earth. Land-cover changes can occur as a result of natural- or human-induced forces. Natural changes over a long time scale include those produced by glacial or volcanic activity, while changes in land cover can occur over a relatively short time as a result of floods or drought. Human-induced changes in land-cover result from activities such as urbanization, the clearing of forests and fields for agricultural purposes, the harvesting of timber, and the collection of fuelwood. These images from the space shuttle Endeavour show a comparison of the area east of Candle Lake in Prince Albert, Canada, during the spring (left) and the fall (right) seasons. The area is near the southern limit of the boreal forest and is composed primarily of coniferous trees. In the spring, the top of the forest canopy is still frozen (red and green for spruce and aspen; purple for jack pine), as are many of the lakes (bright blue). The melting snow and thawing landscape result in increased evaporation of moisture and emission of carbon dioxide into the atmosphere. In the fall, there is frequent rain and cloud cover, the lakes are melted, and the pine canopy is thawed (shown in red). The small blue area near the intersection of the two roads is the result of logging which occurred after the spring image was acquired.

5. CHANGES IN LAND COVER AND IN TERRESTRIAL AND MARINE ECOSYSTEMS

Science Goals for Research on Changes in Land Cover and in Terrestrial and Marine Ecosystems

- Observe and document the trends and geographic and temporal patterns of change in global land cover.
- Understand the processes, both natural and human-induced, that lead to changes in land cover, land use, and ecosystem health, including those resulting in deforestation, desertification, and loss of global resources, such as biological diversity and reductions in productivity of farms and fisheries.
- Predict the likelihood of significant changes in the extent, vitality, and diversity of global resource systems in relation to local, regional, and global economic development.
- Understand the processes that regulate ocean uptake of atmospheric carbon dioxide.
- Predict changes in the structure of phytoplankton (microscopic plants) communities—which form the base of the food chain in the ocean—and understand their links with higher species (e.g., fish, invertebrates, marine mammals).

Human-induced changes in land cover have occurred throughout human history. Large tracts of land have been cleared for agriculture, forestry, the collection of fuelwood, and for urban and industrial growth. Ecosystems have been transformed both in response to land-cover change and as the result of the inadvertent and intentional introduction of plants and animals from outside their normal habitats, thereby introducing new pests, diseases, and competitive species. The damming, diversion, and rechanneling of rivers, the development of intensive agricultural irrigation systems, and the dramatic increases in the consumption of water for urban and industrial purposes have altered the natural water cycles of many regions, the impacts of which were often felt in remote locales because of the far-reaching character of hydrologic systems.

Worldwide land-cover and ecosystem changes have become especially pronounced in recent decades. As the rates of change in many places have accelerated, so also have the magnitude of those changes and their impacts. More than ever, a comprehensive view of land-cover and ecosystem change is needed. Fortunately, new techniques for acquiring and managing information about these elements have been developed. The science and new technologies for measuring and understanding the dynamics and consequences of land-use and land-cover change have improved dramatically in the last decade. Studies in both tropical and temperate regions using Landsat data have demonstrated that rates of deforestation can be documented, and regrowth and reclearing of secondary growth also can be measured. Satellite data can be combined with ground-based and airborne measurements to determine the influence of land-cover change on biological diversity, hydrologic processes, and the potential for future resource production and utilization of an area. Research results and methods for measuring large-area land-cover and land-use change are now being used by commercial interests to develop sustainable plans for the production of livestock and forest products and to manage public lands for multiple uses.

The increasing volume of data on land cover and related variables greatly facilitates analyses of the dynamics of land-cover change. USGCRP-sponsored research has examined the patterns and rates of land-cover change in a wide range of different areas, exploring different ways for classifying land cover and related land-use practices. These efforts have led to delineation of a set of land-cover regions for the globe. Regional case studies have begun in many of these regions using a common protocol developed by scientists involved in the Land-Use and Land-Cover Change (LUCC) project, a core project of both the International Geosphere-Biosphere Programme and the international Human Dimensions of Global Environmental Change Programme (HDP). Through the use of comparable approaches in the conduct of these regional case studies, analyses of the dynamics of land-cover change in each of the regions form the basis for more general advances in understanding the complex interactions among human and natural processes. In the next decade, major new advances in the capabilities for remote sensing of land-cover and land-use dynamics are expected, resulting in an even greater increase in data available for documenting the dynamics of land-cover change.

In addition to gaining a better understanding of changes associated with the land, changes affecting or affected by the oceans (which cover 70% of the Earth's surface) are also critical to understanding the dynamics of the total Earth system. Warmed by the Sun and driven by winds, this vast mass of flowing water regulates the planet's seasonal and interannual climate fluctuations. The oceans are home to diverse communities of plants and animals, which take in and release dissolved carbon, nitrogen, oxygen, and other elements. Marine organisms participate in the global cycles of such elements, affecting their concentrations in the oceans, atmosphere, and land. Studies of ocean biology and circulation are crucial to understanding these biochemical cycles and their role in the maintenance of life.

The oceans now are under increasing pressure from human activities. Industrial waste, synthetic fertilizers, and other pollutants are carried by rivers into the ocean, where they can injure life and cause radical changes in the composition of marine ecosystems. The species composition of algal blooms is shifting, and "red tides" of toxic algae are more common along the coasts of the world. Coral reefs, which support a wide variety of organisms in the tropical seas, have been particularly

Some Recent Scientific Accomplishments in Observing and Understanding Changes in Land Cover and in Terrestrial and Marine Ecosystems

(see page references for additional details)

- Long term experiments at specific locations suggest that soil carbon losses from intensive farming systems can be reversed through changes in farming technology, such as reduced tillage systems and the use of cover crops and manure amendments to increase soil carbon levels and enhance soil fertility (page 120).
- New analyses using satellite data from the Amazon rain forest suggest that as much as 30% of the deforested land is in some stage of secondary succession. These regrowing systems are potentially important sinks for atmospheric carbon dioxide (page 120)
- Satellite observations of fires in the southern African savannas are providing new information on the rate and spatial distribution of biomass burning in this region. This research suggests that earlier biomass burning estimates are too high (page 122).

hard hit. Fish and shellfish have suffered as well, with heavy impacts on marine industries. Through significant new remote sensing capabilities and the use of other satellites, aircraft, and ground-based instruments on ships, buoys, and moorings, USGCRP-sponsored research is studying the responses of marine life to various kinds of natural and human-induced global environmental change.

Humans are placing increasing demands on terrestrial and marine ecosystems. The challenge is to understand the potential consequences of natural and human-induced transformations and the effects of industrial activity on the structure and function of terrestrial and marine and coastal ecosystems. Such understanding is essential to maintaining the goods and services essential for human life provided by ecological systems and for developing mitigation options. It is also essential that the potential benefits derived from human-induced land transformations and industrial processes be balanced against the potential costs associated with the reduction or loss of ecological goods and services which result from such activities.

PROPOSED FUTURE RESEARCH ON CHANGES IN LAND COVER AND IN TERRESTRIAL AND MARINE ECOSYSTEMS

Highlights of USGCRP research in FY 1996 include programs to:

- **Classify and inventory North American land cover.** Federal agencies are cooperating to analyze Landsat satellite data (with resolutions of less than 100 meters) and to classify and inventory the land cover of North America and the entire equatorial tropics from 1970 to the present. This effort will document changes that affect the functioning of ecological systems and provides the global change research community and policy makers with valuable and accurate estimates of changes such as deforestation. A program is being developed to study land-cover change in portions of Mexico in cooperation with the Mexican government. This research is aimed at identifying land-cover changes on decadal time scales, especially those related to the conversion from agricultural to urban land uses and from forest to agricultural land use. This research will enhance knowledge related to productivity changes.

- **Participate in the international Land-Use and Land-Cover Change Programme.** A comprehensive science plan has been developed for studying global land cover and land use to determine how these have varied over the past and to evaluate the current land-cover status. The program, which will aim for global coverage of land cover at 1 km spatial resolution, will examine the major human causes of land-use change in different geographical and historical contexts and project changes that may occur over the next few decades. Projecting the future responses of terrestrial ecosystems to land-cover change requires understanding the relationships between past changes in land cover and in the structure and function of ecosystems.

- **Study how ecosystems react to change and influence global phenomena.** The interagency program on Terrestrial Ecology and Global Change (TECO) will continue in 1996. New studies under the program will: (1) focus on improving the understanding of how species, ecological characteristics and processes, and ecosystems are related to land-cover change, and (2) enhance capabilities to predict consequences of multiple influences (e.g., when the physical environment and ecological parameters change simultaneously).

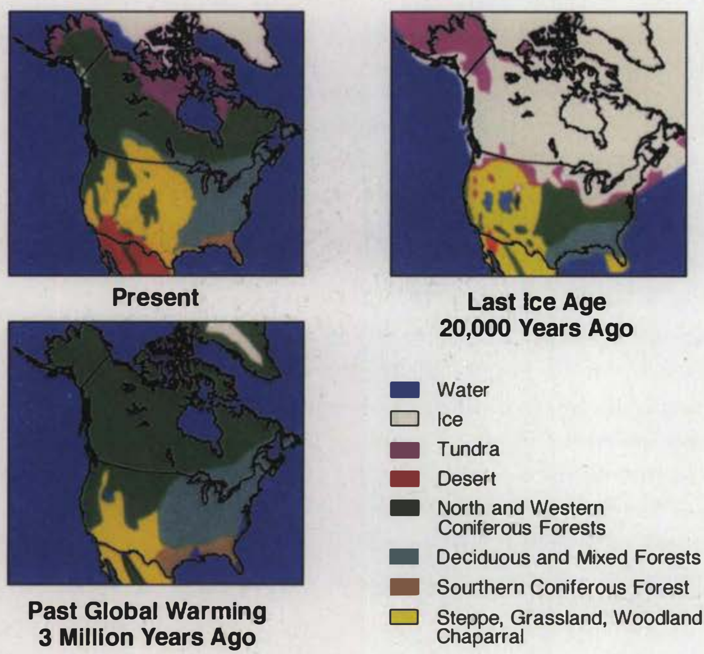
- **Work with international partners throughout North and South America to understand the dynamics of land use and land- cover change.** A comprehensive new project, building on research already underway, includes the development of a model of the deforestation process at work in the Amazon using demographic data linked to satellite observations.

- **Study the response of marine life to global environmental change.** A science plan has been developed to study the effects of natural and human-induced environmental changes on marine life. Research focuses on (1) the inputs of nutrients from land, the atmosphere, or the ocean interior via upwelling, (2) temperature changes that alter physiological states, (3) radiation (e.g., UV) changes that affect primary productivity or damage cells, and (4) changes in circulation patterns and other oceanic processes that affect ecosystem structure and function.

- **Develop a system for tracking changes in carbon flux resulting from land-use change.** A new research program has been initiated to quantify terrestrial carbon fluxes from changes in land use and land management. Information at both national and regional levels is being collected on the successional status of ecosystems, carbon densities, and carbon cycling, and their relationships to changes in land use. This information is needed to address scientific issues related to carbon sources and sinks, and to provide a scientific basis for developing response options to a CO_2 enhanced greenhouse effect.

◆ **Apply new satellite ocean color data to coastal problems.** A coastal program will focus on: (1) distinguishing and tracking harmful algal blooms; (2) tracking coastal and estuarine sediments to determine the fate of suspended sediments and land runoff into coastal oceans; (3) tracking coastal dynamic processes (ocean circulation pattern) to determine dispersal patterns of pollutants and red tides; and (4) application to coastal fisheries and ecosystem management.

Natural Change in North America



Land-Cover Change—The Earth's land cover has gone through significant changes during the last few million years. Studies of past land cover and climates provide key insights into natural variation of the Earth's environment and provide data for testing general circulation model simulations of different conditions. During the glacial time, average global climate was about 5°C cooler than today; during the last extended warm interval, 3 million years ago, the climate was 2 to 3°C warmer on average. Credit: USGS

What is Land Cover and What Causes It to Change?

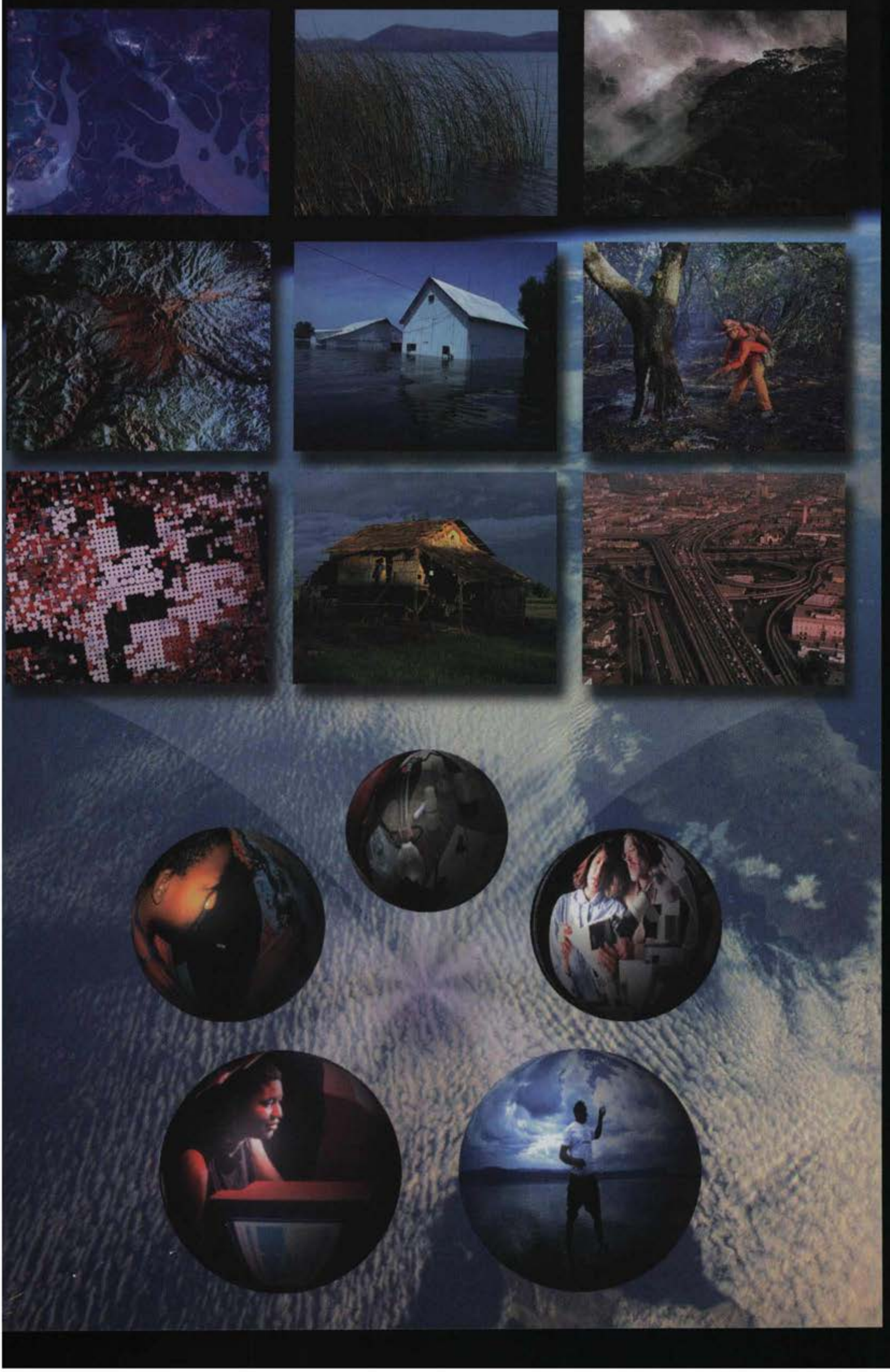
Land cover refers to vegetation and other materials that cover the surface of the Earth. In many parts of the world, land cover is natural, occurring in the form of grasslands, forests, wetlands, and other undisturbed landscapes. Elsewhere, land cover is predominantly controlled by human activities. Croplands, managed pastures, and plantation forests predominate in many rural areas, while roadways, residences, and other structures cover the land surface of cities.

Land cover can change because of natural forces. The change in climate that followed the retreat of glaciers at the end of the last Ice Age led to successive transformation of forests in much of the U.S. and Canada. More recently, changes in drainage systems, including increases and decreases in the levels of water tables, have produced often dramatic changes in vegetation. Even short-term events like floods and droughts can alter vegetation patterns.

Land-cover change most frequently results from changes in the ways that humans use the land. One example is seen in the expansion of cities, where forests and fields have been replaced by houses, factories, shopping centers, parks, and their attendant roads and parking lots. Another form of human-induced land-cover change is seen in the deforestation of tropical rainforests, where trees have been removed for a variety of reasons, including the extraction of timber, the establishment of pastures and crops, and the generation of energy. In other parts of the world, a major cause of deforestation has been the increased collection of fuelwood to be used by rapidly growing populations for heating and cooking.

Just as human land uses may have profound impacts on land cover, human activities often lead to significant changes in marine ecosystems and in the productivity of fisheries, forests, soils, and other natural resources. Land uses influence the flow of water, nutrients, and sediments in coastal areas, thereby directly linking human populations with the nature and quality of marine ecosystems.

GLOBAL CHANGE RESEARCH



6. CROSSCUTTING ASPECTS OF GLOBAL CHANGE RESEARCH

GLOBAL OBSERVATION SYSTEMS

It is essential that long-term, comprehensive regional and global observations are collected, archived, and analyzed in order to advance scientific understanding of the entire Earth system and to develop a deeper comprehension of its components and the interactions among them. The USGCRP has a coordinated program of many land-, ocean-, airborne-, and satellite-based systems that measure and monitor different facets of the Earth system in an integrated observational strategy .

A comprehensive global observing system enhances the ability to understand and predict the effects of many parts of the Earth system. These include:

- ► Hydrologic and dynamic processes, which control the Earth's temperature and the formation, maintenance, and dissipation of clouds and their interactions with solar radiation.
- ► Biogeochemical processes, which contribute to the formation, transport, and fate of trace gases and aerosols and their global distributions.
- ► Climatological processes, which govern the interactions of land and ocean surfaces with the atmosphere through the transport of water, heat, mass, and momentum.
- ► Geophysical processes, which have shaped and continue to modify the Earth's surface through volcanism and the melting of glaciers and ice sheets.

The USGCRP is participating in developing an international observation program to support measurements and research on atmospheric clouds, aerosols, water vapor, radiation budgets, and ozone, as well as on critical ocean and land parameters important to global change. The most comprehensive observation system in the USGCRP is the space-based Earth Observing System (EOS), which is being planned and implemented by U.S. scientists in cooperation with other nations. When implemented, following a series of launches scheduled between 1998 and 2014, EOS will consist of a series of polar-

Critical Measurements to be Made by EOS

- ▶ Clouds, radiation, and aerosols
- ▶ Ocean circulation and sea level
- ▶ Surface temperatures of land and ocean
- ▶ Precipitation and humidity
- ▶ Snow cover, ice-sheet elevation, and sea ice
- ▶ Land-surface elevation
- ▶ Vegetation and ocean phytoplankton
- ▶ Global biological productivity
- ▶ Chemistry of the atmosphere
- ▶ Solar radiation

orbiting and low-inclination satellites providing global observations of the land surface, biosphere, solid Earth, atmosphere, and oceans for a minimum of 15 years. EOS will greatly enhance the ability to understand and predict the dynamics of many parts of the Earth system. Other space-based sensors include weather satellites, satellites that measure ozone and other atmospheric chemicals, satellites that record global sea level with unprecedented accuracy, and radar systems that can observe the Earth's surface through cloud cover in order to record topography, soil moisture, sea-ice dynamics, and ocean temperatures.

Space-based observations are complemented by surface-based systems that measure key Earth-system parameters such as greenhouse gases, aerosols, ozone, ultraviolet radiation, and critical variables of ocean-atmosphere-land system interactions. The U.S. collaborates with many nations to operate an extensive array of ocean monitoring instruments. An interagency UV monitoring network has been developed to provide intercalibrated UV data nationwide (see page 7). Atmospheric concentrations of greenhouse gases and ozone-depleting substances are monitored through an informal worldwide network of in situ and flask-sampling sites. The U.S. also is developing a plan to establish a network of sites for long term observations and research on terrestrial and marine ecological systems. Existing USGCRP ecological observation systems are being considered for inclusion in this network.

EOS and Associated International Satellites and Mission Objectives

SATELLITES (Launch Status)	MISSION OBJECTIVES
EOS AM Series (1998) Earth Observing System Morning Crossing (Descending)	Clouds, aerosols, and radiation balance; characterization of terrestrial ecosystems; land use, soils, terrestrial energy/moisture, tropospheric chemical composition; contribution of volcanoes to climate, and ocean primary productivity (includes Canadian and Japanese instruments)
Landsat -7 (1998) Land Remote-Sensing Satellite	High -spatial-resolution visible and infrared radiance/reflectance to monitor land surface
EOS Color (1998) EOS Ocean Color Mission	Ocean primary productivity (under review)
ENVISAT Series (ESA - 1998) Environmental Satellite	Environmental studies in atmospheric chemistry and marine biology.
ADEOS II (Japan - 1999) Advanced Earth Observing Satellite II	Visible-to -thermal infrared radiance and reflectance, microwave imaging, scatterometry, ozone, aerosols, atmospheric temperature, winds, water vapor, sea surface temperature, energy budget, clouds, snow and ice, ocean current, ocean color/biology (includes French and U.S. instruments).
EOS Radar ALT Series (joint with France) (1999) EOS Ocean Altimetry Mission	Ocean circulation
EOS PM Series (2000) Earth Observing System Afternoon Crossing (Ascending)	Clouds, precipitation, and radiative balance; characterization of terrestrial processes; air-sea fluxes of energy and moisture; and sea-ice extent (includes European instruments)
ATMOS Series (Japan and NASA - Proposed for 2000) Tropical Rainfall Measurement Mission	Precipitation and related variables and Earth radiation budget in the tropics and higher latitudes; also trace gases
METOP Series (EUMETSAT/ESA-2000) Meteorological Operational Satellite	Operational meteorology and climate monitoring, with the future objective of operational climatology
ALOS (Japan-2001) Advanced Land Observation Satellite	Land surface, cartography, and disaster monitoring
EOS CHEM Series (2002) EOS Chemistry Mission	Atmospheric chemical composition; troposphere-stratosphere exchange of energy and chemicals; chemistry-climate interactions; air-sea exchange of chemicals and energy (includes an ozone-measuring Japanese instrument)
EOS Laser ALT Series (2003) EOS Ice-Sheet Altimetry Mission	Ice sheet mass, balance and cloud top and land-surface topography

THE GLOBAL CHANGE DATA AND INFORMATION SYSTEM

Global change research activities generate and require massive amounts of highly diverse data and information to document, understand, model, and assess global change. A major focus for data and information management efforts within the USGCRP is the development of the Global Change Data and Information system (GCDIS). The development of GCDIS is being coordinated with related activities within the U.S. Government, including those of the Federal Geographic Data Committee and the emerging National Information Infrastructure, in particular with the Government Information Locator Service. GCDIS will provide the infrastructure of the global change data and information management program. The GCDIS is a priority-driven system composed of individual agency systems made interoperable by the use of common standards and approaches, technology sharing, and data policy coordination. The GCDIS functions include setting priorities for individual data and information sets, identifying and/or developing those sets, and incorporating them and the necessary related service into GCDIS. The USGCRP recently published the U.S. Global Change Data and Information System Implementation Plan.

The U.S. continues to maintain a policy for all of full and open access to global change data collected as part of the USGCRP

GCDIS will also include a number of long-term, retrospective data sets that are critical for evaluating climate variability and for use in detecting global changes. These data sets include global data from historical marine meteorological observations, upper air observations, global and regional variations of temperature and precipitation, oceanographic observations, and baseline studies on atmospheric trace constituents, including aerosols and ozone. Retrospective data sets from Landsat, for example, have been invaluable for studying global land-cover change.

The Earth Observing System Data and Information System (EOSDIS), a component of GCDIS, is being built in an evolutionary manner to support launch of EOS platforms. EOSDIS is beginning to provide data sets through its Distributed Active Archive Centers (DAACs). Improve-ments scheduled for 1996 will provide faster, more comprehensive user services and links to other global change data sets. EOSDIS is also providing access to existing long-term satellite data sets (Pathfinder data). Data from other major research programs, such as the Atmospheric Radiation Measurement (ARM) program, are being incorporated as a component of GCDIS.

RESEARCH ON THE HUMAN DIMENSIONS OF GLOBAL CHANGE AND TOOLS FOR CONDUCTING INTEGRATED ASSESSMENTS

As knowledge about the dynamics of global change increases, greater emphasis in the USGCRP has been placed on research on fundamental social and behavioral processes related to environmental change. U.S. research on the human dimensions of global change is coordinated with related efforts in other nations through the framework of the international Human Dimensions of Global Environmental Change

Priorities for the Human Dimensions of Global Change Research Include

- Impacts of population growth, migration, and social and institutional change on the environment and on international environmental negotiations.
- Processes through which individuals and groups anticipate and adapt to global change.
- Impacts of changing environmental conditions on human health, including increased exposure to ultraviolet radiation and the altered epidemiology of communicable diseases.
- Economic issues, including the impacts of environmental change on international trade and the development of global models for different economic sectors.
- Governmental and legal dimensions of global change, including institutional decision-making processes.
- Economic and social processes related to the development and diffusion of industrial, energy, and environmental technologies.

Programme (HDP). Within the U.S., fundamental research is conducted on the economic, demographic, social, institutional, geographic, and human health-related aspects of global change. Attention is given to the processes through which human activities affect natural systems and the ways that humans respond to changing natural conditions. Among the most important forms of human-environmental interaction are transformations of the land surface, the product of the interaction between human land uses and natural processes that also alter land cover.

In addition to providing important understanding about the complex ways that human and natural systems interact with each other, USGCRP research has developed new tools and approaches to assist decision makers in thinking about global change. Several programs have supported the development and use of methods and models for integrated assessment of global change. Integrated assessments are a new approach for examining the complex interactions among the Earth's physical, biological, and human systems. Integrated assessments involve the effective linkage of quantitative models and other representations of different systems in ways that permit evaluation of the impacts of changes in one system on other systems. In addition to providing valuable information about the dynamics of change, integrated assessments can provide national and international decision makers in government and the private sector with a framework for identifying and evaluating the likely consequences of different alternatives. Among the topics on which research has focused are the development of rigorous modeling approaches that link physical, biological, and socioeconomic systems; meta-analyses of models and data; and the treatment of uncertainty and risk in integrated systems.

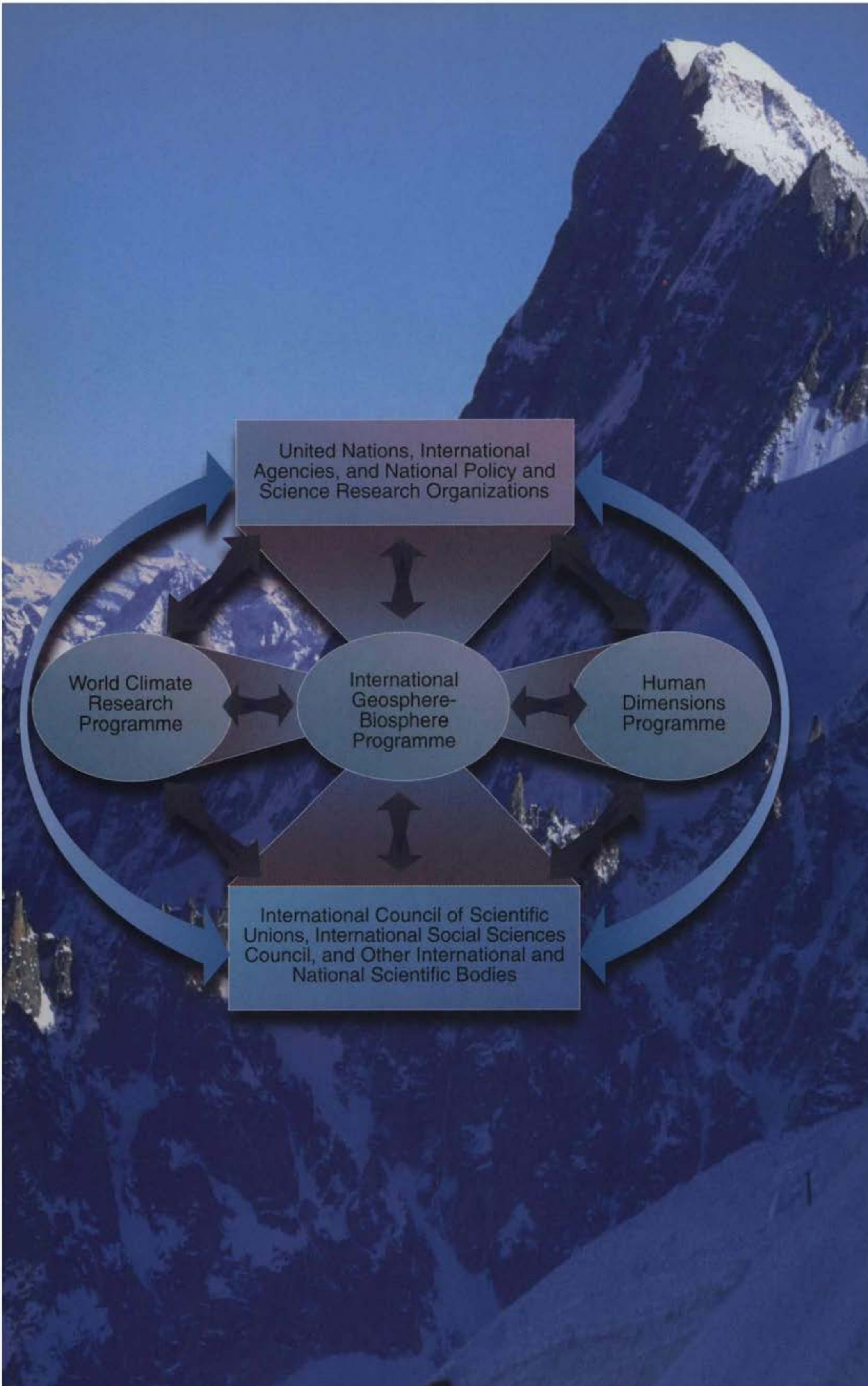
Human dimensions research also has focused on the processes, methodological tools, and formal models fundamental to the creation, implementation, and evaluation of environmental policies and other kinds of decisions. Among the methodological issues on which research has focused are the availability and reliability of data on human systems; the use of expert judgments in decision making; economic valuation of environmental resources; measures of sustainability; indicators of environmental quality; and the extraction of generalized relationships from case studies. Research projects also have examined the processes through which problems are identified and responses are outlined, implemented, and evaluated. Among the studies falling in this category are investigations of technological innovation and diffusion and the processes of international environmental negotiations.

GLOBAL CHANGE EDUCATION AND COMMUNICATION

An important goal of the USGCRP is to enhance knowledge about the state of the Earth system and the changes which are expected to occur. To achieve this goal, the USGCRP assists in training future scientists through supporting undergraduate, graduate and post-doctoral research, as well as through the development of teacher-training and curricular materials for K-12 educators. The USGCRP also sponsors public education efforts to provide people with scientific information about global environmental issues. Traditional education methods have been expanded to focus on multimedia communication and recognition of the complex interdisciplinary nature of global change science.

The most important functions of interagency cooperation in global change education and communication are the encouragement of activities to educate and inform the public of progress in scientific research that increases human knowledge of society and its Earth-system interactions. Specific elements of the strategy used to achieve this objective are to continue involvement of teachers and the general public in both formal and informal education activities through regionally focused programs; to emphasize an interactive approach to education through hands-on computational and experimental activities; and to continue supporting fellowships in undergraduate and graduate education to prepare the next generation of scientists. The education program also encourages the use of high-speed communications technologies to communicate new knowledge, and it promotes the dissemination of federal data and information on global change.

In addition, the USGCRP has established the Global Change Research Information Office (GCRIO) "to disseminate to foreign governments, businesses, and institutions, as well as citizens of foreign countries, scientific research information available in the United States which would be useful in preventing, mitigating, or adapting to the effects of global change," as called for in the 1990 Global Change Research Act. GCRIO also provides extensive information services to citizens and institutions within the United States.


United Nations, International Agencies, and National Policy and Science Research Organizations
World Climate Research Programme
International Geosphere-Biosphere Programme
Human Dimensions Programme
International Council of Scientific Unions, International Social Sciences Council, and Other International and National Scientific Bodies

7. INTERNATIONAL COOPERATION

Understanding the fundamental nature of global change research requires world-wide cooperation. For this reason, and in order to make the best use of available resources, the USGCRP cooperates extensively with other nations in a broad range of formal and informal global change research efforts.

INTERNATIONAL RESEARCH PROGRAM

International scientific institutions have organized three cooperative global change research programs: (1) the World Climate Research Programme (WCRP), which is part of the World Climate Programme; (2) the International Geosphere-Biosphere Programme (IGBP); and, (3) the Human Dimensions of Global Environmental Change Programme (HDP). These and other international programs are coordinated at several levels, including scientist-to-scientist, agency-to-agency, and government-to-government, through a broad range of multilateral and bilateral organizations and arrangements. The International Council of Scientific Unions (ICSU) provides strong leadership for scientific planning for many of the key international programs. The U.S. shares in funding ICSU's coordination of these activities, and U.S. scientists and agencies participate in and interact regularly with ICSU and related committees. U.S. agencies also work with their counterparts through informal international coordination groups, such as the International Group of Funding Agencies for Global Change Research (IGFA). IGFA recently completed a survey of international funding for global change research, which confirmed the leadership role of the U.S. in supporting this research.

INTERNATIONAL ASSESSMENTS

International assessments document the current state of scientific understanding on global environmental issues through the involvement of thousands of scientists from more than 150 countries in reviews and analyses of recently published scientific literature. Recent assessments include the Intergovernmental Panel on Climate Change (IPCC) science assessments and the World Meteorological Organization

(WMO)/United Nations Environment Programme (UNEP) Assessment of Stratospheric Ozone Depletion and Associated Environmental Impacts, Technology Development, and Economic Considerations.

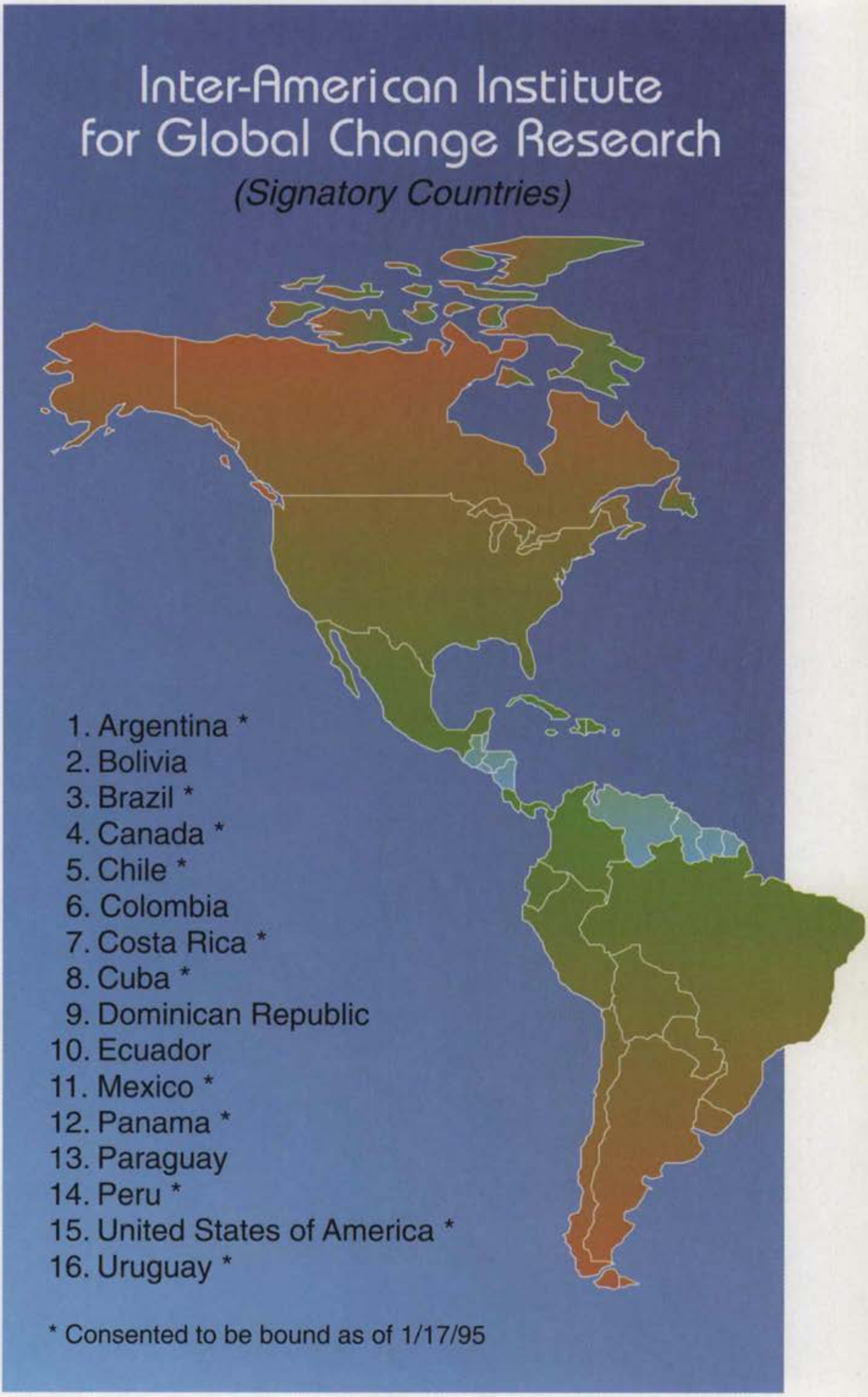
In mid-1994, the IPCC released a Second Supplementary Report to the 1990 IPCC Scientific Assessment, focusing on radiative forcing of the climate system. The IPCC expects to complete a second comprehensive assessment of climate change in late 1995. This assessment has been undertaken by three working groups. Working Group I, co-chaired by the United Kingdom and Brazil, is charged with assessing the state of science with respect to the climate system, including possible changes as a result of human activity. Working Group II, co-chaired by the United States and Zimbabwe, assesses potential impacts of, adaptation to, and mitigation measures for global change. Working Group III, co-chaired by Canada and South Korea, addresses cross-cutting issues, including the economic implications of climate change and of selected emissions scenarios. Many U.S. scientists have served as lead and contributing authors for chapters prepared by the three working groups.

The USGCRP has established a small secretariat for IPCC-related activities. This secretariat staffs U.S. participation in IPCC activities and, in particular, supports the U.S. co-chairman of Working Group II. The USGCRP also assists in supporting U.S. authors and organizes the U.S. government review process for the 1995 IPCC assessments. This review process involves agencies, scientists, industry, business, and other interested stakeholders and groups, all of whom are invited to review and comment on the work of the IPCC and its working groups.

INTERNATIONAL INSTITUTES

The USGCRP supports U.S. participation in the development of regional institutes that facilitate the conduct of collaborative global change research within regions and supports the augmentation of scientific and technological capacity in other parts of the world. Several emerging regional networks have been developed throughout the world, including ones in the Asia-Pacific region (APN), in Europe-Africa (ENRICH), and in the Americas.

Sixteen countries, including the U.S., have signed an agreement to establish the Inter-American Institute (IAI) for Global Change Research. Following the entry into force of the agreement in 1994, the IAI Conference of the Parties selected a Scientific Advisory Committee, an Executive Council, a site for the IAI Directorate (National Space Research Institute of Brazil), and an IAI Director. Regional cooperation


Inter-American Institute
for Global Change Research
(Signatory Countries)
1. Argentina *
2. Bolivia
3. Brazil *
4. Canada *
5. Chile *
6. Colombia
7. Costa Rica *
8. Cuba *
9. Dominican Republic
10. Ecuador
11. Mexico *
12. Panama *
13. Paraguay
14. Peru *
15. United States of America *
16. Uruguay *
* Consented to be bound as of 1/17/95

fostered by the IAI is expected to promote optimal use of available resources for global change research and to augment the scientific capacity of the region. Scientific data and information provided by IAI researchers will be managed as a common resource for the region and should provide baseline information for use in regional planning.

The international commitment to build capacities for global change research in the developing world is further reflected in the SysTem for Analysis, Research and Training (START), a joint effort of the HDP, IGBP, and WCRP. The START regional research networks promote focused research and training on regional issues of global importance, integrate and synthesize research results, and provide input to decision makers at national and regional levels.

INTERNATIONAL COORDINATION OF GLOBAL CHANGE OBSERVATIONS

Global Climate Observing System (GCOS)—In order to coordinate global change observation programs undertaken by the U.S. and other nations, the World Meteorological Organization (WMO) has led efforts to organize a Global Climate Observing System (GCOS). The overall GCOS Plan and several related plans focusing on data and information management and on space-based observations are currently near completion. Because GCOS relies on national programs, both for planning and implementation, mechanisms to increase the flow of information about GCOS to participating countries have been initiated. The GCOS data and information system will be a comprehensive, distributed system that specifies procedures for collection, quality control, comparison of observations from different sources, dissemination, and utilization of all relevant data. Plans for observations concerned with the atmosphere, ocean, and land also are being coordinated with the WMO World Weather Watch and the Global Atmospheric Watch, the Global Ocean Observing System (GOOS), and the Global Terrestrial Observing System (GTOS). Discussions are underway to develop plans for more complete integration of these different observing systems.

Committee on Earth Observation Satellites (CEOS)—The Committee on Earth Observation Satellites (CEOS), an informal international organization, is undertaking an analysis of all satellites, sensors, and data products in operation or planned over the next ten to fifteen years and the requirements of the major international scientific and intergovernmental user organizations. This study will establish priorities and provide an opportunity for CEOS members to voluntarily fill gaps and reduce overlaps. CEOS has prepared a future strategy document that calls for all CEOS participants to establish fully functioning interoperable user services and data systems with common functionalities over the next five years. CEOS also has adopted principles that promote increased access to and availability of satellite data for global change research.

HIGHLIGHTS OF RECENT USGCRP RESEARCH RESULTS

The following section describes recent research results that represent scientific advances in addressing each of the four issues that are the current focus of the USGCRP. Thousands of scientists, researchers, and students, both nationally and internationally, contribute to the research results of the USGCRP. It often takes many small contributions before a major advance can be made in increasing human understanding of the Earth system and all its interactions. While it is impossible to list all of the projects and individual publications that have led to advancing this field of knowledge, this section highlights some of the recent results and accomplishments of USGCRP-supported research to provide a sense of the scope and depth of the increased understanding of the Earth system that is gained through this program. The research highlights in this chapter are organized by the current primary global change issue and science question addressed. For further information on any of these items, the reader may consult the one or two primary references given. Unfortunately, due to space limitations, all relevant references could not be included here.

A. SEASONAL-TO-INTERANNUAL CLIMATE CHANGE

1. What progress has been made in predicting significant changes in seasonal to interannual variability?
2. What are some of the events and their consequences associated with predicting significant changes in seasonal to interannual variability?

1. What Progress Has Been Made in Predicting Significant Changes in Seasonal to Interannual Variability?

I. TOGA PROGRAM COMPLETED: ENHANCED FUNDAMENTAL KNOWLEDGE OF THE OCEAN CONTRIBUTING TO FORECASTING ABILITY, INCLUDING ANOMALIES IN TEMPERATURE AND PRECIPITATION IN THE U.S.

The Tropical Ocean-Global Atmosphere (TOGA) program, one of the first projects under the USGCRP, was successfully completed in 1995. A ten-year international research effort, TOGA produced fundamental new knowledge of the processes that couple the tropical Pacific Ocean to the global atmosphere and ultimately led to a successful prediction capability of the El Niño phenomenon. The program developed and implemented a tropical Pacific Observing System to monitor the state of the tropical Pacific Ocean, providing real-time records of the evolution of El Niño events. The centerpiece of this observing system is the Tropical Atmosphere Ocean (TAO) array, which is comprised of 68 moored buoys spanning the tropical Pacific measuring sea surface temperature, surface winds, and upper ocean thermal structure. TOGA also conducted an unprecedented international field campaign (TOGA COARE) in 1992-93 to quantify air-sea interaction processes in the tropical western Pacific Ocean. The data set resulting from the experiment is being analyzed to improve the understanding of the coupling between the ocean and the atmosphere and the representation of such coupling in models. TOGA developed a number of coupled ocean-atmosphere models, one of which successfully forecasted the El Niños of 1986-87 and 1991-92 more than a year in advance. Another model successfully predicted the continuance of El Niño conditions in 1992-93. Finally, individual TOGA researchers began distributing experimental forecast products to a number of tropical countries (e.g., Brazil and Peru), where they have been successfully used by government officials and farmers to sustain agricultural productivity.

Reference: Proceedings of the International TOGA Conference, WMO/ WCRP Report, Melbourne, Australia, April 2-7, 1995, Vol. 1 and 2, in press, 1995.

USGCRP SCIENTISTS EXTEND THE PREDICTIVE SKILL OF EL NIÑO FORECASTS

A team of oceanographers and meteorologists have recently extended the useful lead-time predictive skill of El Niño forecasts. A coupled ocean-atmosphere data assimilation procedure yields substantially improved retrospective forecasts of El Niño for the 1970s and 1980s compared with previous forecasting procedures. The improvement is attributed to the explicit consideration of low frequency characteristics of air-sea interaction in the initialization of the model forecast. The results suggest that El Niño is more predictable than previously estimated. The assimilation of surface wind observations as part of the initialization process also eliminates the "spring barrier" to ENSO prediction, implying that it may not be intrinsic to the real climate system.

Reference: An Improved Procedure for El Niño Forecasting, Chen, D., et al., Science, submitted, 1995.

NEW MODELING METHOD DEVELOPED TO PROVIDE GLOBAL FORECASTS

A new two-tiered approach has been developed and tested for global climate forecasting. The method first uses a coupled ocean-atmosphere model to predict tropical Pacific sea-surface temperatures There are then used to force a high-resolution atmospheric model that provides climate forecasts out to two seasons. Prediction of seven large climatic events of the 1970s to 1990s by this technique are in general agreement with observations over many regions of the globe. The demonstrated forecast skill suggests that the approach can provide highly useful predictions of climatic anomalies associated with ENSO events during the northern winter of at least six months. The success of the method relies on the prediction and occurrence of significant warm or cold events that occur every two to four years; it is these events that tend to have the largest societal impact.

References: (1) A Two-Tiered Approach to Long Range Climate Forecasting, Bengtsson, L., et al., Science, Vol. 261, pp. 1026-1029, 1993; (2) Forecasting Global ENSO-Related Climate Anomalies, Barnett, T. P., et al., Tellus, Vol. 46A, pp. 381-397, 1994; (3) Experimental Predictions of Climatic Variability for Lead Time of Twelve Months, Hunt, B. G., et al., International Journal of Climate, Vol. 14, pp. 507-526, 1994.

FIRST MULTI-SEASONAL CLIMATE FORECASTS ISSUED FOR U.S.

With funding from the USGCRP, the Federal Government in January 1995 began issuing on a monthly basis the first-ever long-lead forecasts of seasonal mean temperature and precipitation for the United States. The forecasts are made for periods beginning one-half month after the forecast time, progressing by monthly increments to one year into the future. This capability is based on advances made through USGCRP research efforts leading to improved observing systems for the ocean and atmosphere, improved physical understanding of tropical ocean-atmosphere interactions, and significant gains in skill of climate models. This new product, which replaces the previous zero-lead one-season forecast issued during the past decade, extends the forecast period substantially out to one year and bases the forecasts on a blend of statistical and physical coupled ocean-atmosphere circulation models. One of the newest products of the USGCRP, the forecasts demonstrate the effectiveness in identifying and transferring "cutting edge" technologies from theory to applications as well as the importance of partnership and cooperation between the academic and government research communities.

References: (1) Long-Lead Seasonal Forecasts-Where Do We Stand?, Barnston, Anthony G., et al., Bulletin of the American Meteorological Society, Vol. 75, pp. 2097-2113, 1994; (2) The Long-Lead Multi-Season Climate Outlook, Climate Prediction Center, Vol. 1, No. 1, 1995.

2. What are Some of the Events and their Consequences Associated with Predicting Significant Changes in Seasonal to Interannual Variability?

MIDWEST FLOODS IN 1993 AND 1995 AND WEST COAST STORMS IN 1995 RELATED TO EL NIÑO

Analyses of the drought and heat wave in the eastern and central U.S. during the summer of 1988 and of the 1993 and 1995 floods over North America reveal that mature El Niño conditions in the tropical Pacific contributed to the broad-scale circulation and related jet stream pattern over the North Pacific and across North America in the months leading up to these events. In the well studied 1993 case, a broader jet stream and storm track were displaced significantly south of normal. The flow pattern during June was characterized by strong west-to-east flow from the western Pacific to the eastern United States and provided a duct for intense cyclone activity to propagate directly into the Midwest. An analysis of the moisture budgets has revealed a strong river of moisture flowing across the Gulf of Mexico into the eastern U.S. The lower-than-normal latitude of the storm track allowed cyclonic disturbances to tap into the Gulf moisture source and transport moisture into the upper Mississippi River basin where it precipitated. Increases in local soil moisture and evaporation appeared to enhance the precipitation and helped perpetuate and prolong the conditions. Consequently, these effects should be viewed as feedbacks which amplify and prolong the response while, from the standpoint of the atmosphere, the anomalous tropical Pacific sea surface temperatures are a notable (but not sole) external forcing of the patterns. Preliminary analyses of the California and Midwest flooding in 1995 also indicate on influence of El Niño on the forcing of atmospheric circulation patterns that set-up the cyclone tracks which bring the heavy rains.

References: (1) Atmospheric Circulation Associated with the Midwest Floods of 1993, Bell, G. D., and J. E. Janowiak, Bull. Amer. Meteor. Soc. 76, pp. 681-695, 1995; (2) Trenberth, K. E., and C. J. Guillemot, 1995, Physical Processes Involved in the 1988 Drought and 1993 Floods in North America, 1995, Journal of Climate, submitted; (3) ENSO Winter Impacts, California Flooding, Mild to the East, Climate Analysis Center, NOAA Special Climate Summary-95/1, 1995; (4) Flooding in the Central United States, Climate Analysis Center, NOAA Special Climate Summary-95/2, 1995; (5) Issues in

Establishing the Causes of the 1988 Drought over North America, Trenberth, K. E., and G. W. Branstator, Journal of Climate, Vol. 5, pp. 159-172, 1992; (6) The Global Climate of June-August 1988: A Swing to the Positive Phase of the Southern Oscillation, Drought in the United States, Ropelewski, C. F., Journal of Climate, Vol. 1, pp. 1153-1174, 1988.

MONITORING EL NIÑO HAS IMPORTANT IMPLICATIONS FOR SURVEILLANCE OF EMERGING DISEASES

There has recently been a global reemergence of infectious diseases associated with changing temperatures and precipitation patterns. In 1993, a virulent rodent-borne hantavirus appeared in the arid U.S. Southwest. Following 6 years of drought, the heavy rains appear to have dramatically increased population of natural hosts for the virus, which increased the chances that the virus would be passed on to humans. A novel cholera variant also appeared in Asia that year, during which there was an unusual abundance of coastal algal blooms that harbor and amplify the cholera virus. Evidence suggests that the emergence of these diseases, and others such as malaria are associated with heavy rains, result from anomalous weather patterns, such as those which occur during El Niño events.

Reference: (1) Emerging Diseases and Ecosystem Instability: New Threats to Public Health, P. R. Epstein, MD, American Journal of Public Health Vol. 85, No.2, pp. 168-172, 1995. (2) Marine Ecosystems, Epstein, P. R., Ford, T. E., and R. R. Colwell, The Lancet, Vol. 342, pp. 1216-1219, 1993.

INCREASED CORAL BLEACHING APPEARS TO BE A RESPONSE TO OCEAN WARMING

Coral reef ecosystems are among the most susceptible to rising temperatures, sea levels, soil erosion, and to excess nutrients from sewage and fertilizers. Monitoring their condition thus provides a very sensitive measure of environmental change. Major bleaching events were reported for all major reef provinces between 1983 and 1991. Coral-reef bleaching results from the expulsion of symbiotic zooxanthellae algae from coral reefs. These algae provide reef corals with most of their carbon, their limestone-depositing ability, and their color. When zooxanthellae vacate coral reefs, the reefs die. Investigations indicate that these events occurred following periods when positive temperature anomalies (hot spots) of more than 1° C took place during the months of the year with the warmest ocean temperatures. These hot spots have been identified and can be tracked in real time using satellite data. While the algae can return as the temperature anomaly subsides, many reefs died when the anomalous warming persisted. El Niño warming events can partially explain the recent global pattern of bleachings; further, the susceptibility of reefs to sea-surface warming raises concerns about the effects of continued greenhouse gas-induced warming.

Reference: Coral Bleaching and Ocean Hot Spots, Goreau, T. J., and R. L. Hayes. Ambio, Vol. 23, pp. 176-180, 1994.

EL NIÑO EVENTS FOUND TO SIGNIFICANTLY REDUCE CARBON DIOXIDE FLUX OUT OF THE EQUATORIAL PACIFIC OCEAN

Measurements of carbon dioxide concentrations in the atmosphere and in the surface waters of the equatorial Pacific Ocean during the spring and autumn of 1992 indicate that the 1992-1993 El Niño event reduced the "normal" (non-El Niño) carbon dioxide release to the atmosphere from this region by more than 50 percent. This may be a contributing factor in explaining the slower rates of increase of atmospheric carbon dioxide during the period of time in question.

References: (1) CO_2 Distributions in the Equatorial Pacific during the 1991-92 ENSO Event, Feely, R. F., et al., Deep-Sea Research, in press, 1995; (2) Seasonal and Lateral Variations in Carbon Chemistry of Surface Water in the Eastern Equatorial Pacific During 1992, Wanninkhof, R., et al., Deep-Sea Research, in press, 1995; (3) Surface Water CO_2 Values in the Eastern Equatorial Pacific during the 1992-93 El Niño, Wanninkhof, R., et al., Journal of Geophysical Research, submitted, 1995.

EFFECTS OF EL NIÑO FOUND TO BE VERY LONG-LIVED

El Niño events have generally had significant local effects lasting up to two years. However, it has been believed that the long-range effects of El Niños are restricted to changes transmitted through the atmosphere, for example causing precipitation anomalies in distant locations. New evidence from observations and modeling studies suggests that planetary scale ocean waves generated by reflection of equatorial shallow-water waves from the American coasts during the 1982-83 El Niño have crossed the North Pacific, and a decade later caused northward re-routing of the Kuroshio current that normally transports large amounts of heat from the southern coast of Japan eastward into the mid-latitude Pacific. This phenomenon has led to increases in sea surface temperature at high latitudes in the northwestern Pacific of the same amplitude and with the same spatial extent as those observed in the tropics during significant El Niño events. The influence of these changes on the North American climate during the past decade is being evaluated.

Reference: Decade-Scale Trans-Pacific Propagation and Warming Effect of El Niño Anomaly, Jacobs, G. A., et al., Nature, Vol. 370, pp. 360-363, 1994.

VARIABILITY IN ATMOSPHERIC CIRCULATION PATTERNS FOUND TO AFFECT COASTAL ESTUARIES

Estuaries, their freshwater source or watershed, and the oceanic processes which affect them are dynamically linked together by the atmosphere. Preliminary research shows that much of the year-to-year variability, and part of the long-term trend in the salinity of the San Francisco Bay, for example, are the result of natural fluctuations in the large-scale patterns of atmospheric circulation over the eastern North Pacific Ocean, rather than from upstream freshwater diversions. Improved understanding of climate variability, including forecast information, will thus have significant implications for estuarine management and freshwater availability.

Reference: The Role of Climate in Estuarine Variability, Peterson, D., et al., American Scientist, Vol. 83, pp. 58-67, 1995.

ENSO EVENTS AND CROP YIELDS OF VARIOUS COUNTRIES WORLDWIDE HAVE BEEN FOUND TO BE HIGHLY CORRELATED

USGCRP research has investigated the relationship between El Niño and crop yield statistics in countries throughout the world and found that thirty-nine economically important crops in thirty-three countries exhibited significant correlation to eastern equatorial Pacific sea surface temperatures. Because coupled dynamical models can predict the ENSO signal with a lead time of up to twelve months, these strong ENSO-crop yield correlations illuminate the possibility of using ENSO predictions for agricultural planting and crop selection decisions in many countries around the world.

References: (1) Statistical Survey of Relationships between ENSO and Global Crop Productivity, Kane, A. I., C. Rosenzweig, and M. A. Cane, Nature, submitted, 1995; (2) Forecasting Zimbabwean Maize Yield using Eastern Equatorial Pacific Sea Surface Temperature, Cane, M. A., G. Eshel, and R. W. Buckland, Kane, A. I., C. Rosenzweig, and M. A. Cane, Nature, Vol. 370, pp. 204-205, 1994.

ECONOMIC STUDIES INDICATE SIGNIFICANT VALUE OF EL NIÑO FORECASTS

When experimental forecasts of El Niño are fully implemented in an operational context, similar to present day weather predictions, immediate benefit is expected in agriculture, forestry, fishery, hydroelectric, and insurance sectors of the U.S. economy. This has already proven true in practice for countries such as Peru, Brazil, and Australia. Economic research indicates that El Niño has a deleterious impact of up to 15 percent on the agriculture sector of the southeastern tier of the United States. The value to the southeastern U.S. economy of El Niño forecasts is estimated to be more than $100 million per year.

Reference: The Value of Improved Long-Range Weather Information: Southeastern U.S. ENSO Forecasts as They Influence U.S. Agriculture, R. M. Adams et al., Contemporary Economic Policy, in press, 1995.

B. CLIMATE CHANGE OVER OVER THE NEXT FEW DECADES

1. What new evidence is there about processes that result in changes in greenhouse gases and aerosol concentrations in the atmosphere?
2. What has been learned about the influence of clouds and other feedbacks on climate?
3. What has been learned about the influences of ecosystem changes on climate?
4. What has been learned about future climate changes from research on past climate changes over the history of the Earth?
5. What improvements have been made in predicting future changes in climate?
6. What new evidence is there that the climate is changing in response to societal activities?
7. What has been learned about the potential consequences of climate change?
8. What new information is there regarding the potential for society to adapt to and mitigate climate change?

1. What New Evidence is There about Processes that Result in Changes in Greenhouse Gases and Aerosol Concentrations in the Atmosphere?

VARIATIONS IN THE ANNUAL RATE OF INCREASE OF ATMOSPHERIC CO_2

Highly unusual variations in the global carbon balance have been occurring over the past five years. In the 1960s and early 1970s, the CO_2 concentration increased at a rate of about 1.0 part per million by volume (ppmv) per year, varying from even lowest rates to increases of more than 1.5 ppmv/yr. For much of the 1980s the concentration of CO_2 in the atmosphere increased at about twice the earlier annual rate of rise, averaging about 1.5 ppmv/yr. [Note that annual fossil fuel emission of 5.5 GtC/yr and biomass emissions of about 1.5 GtC/yr are equivalent to increments of about 2.5 and 0.7 ppmv/yr, or about 3.2 ppmv/yr total. 1 GtC = 1 billion tonnes of carbon] From 1989 to 1993, the growth rate dropped significantly, averaging only about 1.0 ppmv/yr, reaching as low as 0.5 ppmv/year. Such a sustained decrease had not previously been observed in the 35-year record. The downturn does not appear to have been caused by any significant reduction of human-induced CO_2 emissions, because global CO_2 emissions from fossil fuel have actually increased slightly over this period. It is hypothesized that either an enhanced natural sink in the terrestrial biosphere (or possibly in the oceans) or a reduced natural source is likely responsible for the slowdown in the rate of CO_2 increase. Analyses of the carbon-climate record and indications that the CO_2 growth rate has returned to higher levels during late 1994 and early 1995 suggest that this unusual downturn in carbon dioxide growth rates may be primarily a climate-related phenomenon resulting from recent variations in the global climate, especially in air temperature and possibly precipitation. Research is underway to understand the effects of climate and other factors on the dynamics of the carbon cycle.

Reference: Interannual Extremes in the Rate of Rise of Atmospheric Carbon Dioxide Since 1980, Keeling, C. D., Nature, Vol. 375, pp. 666-670, 1995.

WORLDWIDE DECREASE IN CARBON MONOXIDE CONCENTRATION SUGGESTS IMPORTANT CHANGES IN TROPOSPHERIC OXIDATION PROCESSES

Carbon monoxide (CO) plays an important role in the oxidizing capacity of the Earth's atmosphere and may therefore indirectly affect the concentration of many man-made and natural trace gases. By changing their concentrations, the CO can, in turn, affect climate, atmospheric chemistry, and the ozone layer. CO is produced in the atmosphere by the oxidation of methane and other hydrocarbons and is released into the atmosphere from automobiles, agricultural waste, and the burning of grasslands and other areas. Recent estimates show that human activities such as those are presently responsible for more than half of the annual global emissions of CO. During the 1980s CO emissions were increasing at roughly 1.2% per year. However, over the period 1988 to 1992, the global CO concentration started to decline, with the rate of decline increasing sharply to about -2.6% per year. Possible explanations for the CO decrease are increases in the atmospheric hydroxyl (OH) concentration, decreased CO emissions from biomass burning, or decreased CO production from a decrease in the oxidation of non-methane hydrocarbons. Whatever the cause, the total amount of CO in the atmosphere is now less it was a decade ago. A continuing trend of decreasing CO may signify important changes in atmospheric oxidation processes, which could affect the rates at which methane and CFC replacements are removed from the atmosphere.

References: (1) Global Decrease in Atmospheric Carbon Monoxide Concentration, Khalil, M. A., and R. A. Rasmussen, Nature, Vol. 370, pp. 639-641, 1994; (2) Recent Changes in Atmospheric Carbon Monoxide, Novelli, P. et al., Science, Vol. 263, pp. 1587-1590, 1994.

NEW CAPABILITIES TO MEASURE THE OXYGEN TO NITROGEN RATIO WILL HELP DETERMINE SOURCES OF CO_2

A recent development in research on the global carbon cycle is the ability to measure the atmospheric oxygen/nitrogen ratio with high precision. With this technique, new information on the movement of carbon can be derived by examining variations over the seasonal cycle, the interhemispheric gradient, and the long-term trend of the oxygen/nitrogen ratio of the atmosphere. The long-term trend in the oxygen/nitrogen ratio, for example, can be used to subdivide the overall CO_2 sink into its oceanic and terrestrial components. Also, the long-term trend in O_2 loss, and the interhemispheric gradient can be used to place limits on CO_2 emission estimates resulting from changes in land cover, land use, and land management. This technique will contribute significantly to improved understanding (and, therefore, reduced uncertainty) in determining the sources of atmospheric CO_2 and the role of the oceans and oceanic processes in limiting the increase in the atmospheric CO_2 concentration.

Reference: What Atmospheric Oxygen Measurements Can Tell Us About the Global Carbon Cycle, Keeling, R. F. et al., Global Biogeochemical Cycles, Vol. 7, pp. 37-67, 1993.

ARCTIC ECOSYSTEMS MAY BE A SOURCE OF CO_2

New evidence indicates that Arctic ecosystems may be acting as a net source of CO_2 to the atmosphere and potentially accelerating global climate change. Measurements made at an Arctic tundra ecosystem in Barrow, Alaska in the early 1970s found that it was a net sink for CO_2. However, this ecosystem site was remeasured and found to be a source of CO_2 to the atmosphere in the early 1990s. Indications that the Arctic tundra is releasing CO_2 to the atmosphere are increasing. Despite absorption of carbon in the wettest habitats, many of the geographic regions that have been investigated, including in the Alaskan, Icelandic, and Russian Arctic, have been found to be net sources of CO_2 to the atmosphere. Other evidence indicates that losses of CO_2 during snow covered periods may even exceed losses during the snow free-period, that the loss of carbon is increased for up to 30 years following fire in tussock tundra, and that Arctic ecosystems adjust relatively quickly adjust to elevated atmospheric CO_2, so that there is likely not a CO_2 "fertilizer" effect from the increasing atmospheric concentrations. In that the tundra region contains as much as 180 GtC as soil organic matter (equivalent to about 30 years worth of fossil fuel emissions at current emission rates), its release to the atmosphere even in part could have a major positive feedback on the CO_2 concentration and on climate change.

References: (1) Recent Changes of Arctic Tundra Ecosystems from a Net Carbon Dioxide Sink to a Source, Oechel, W. C. et al., Nature, Vol. 361, pp. 520-523, 1994; (2) Transient Nature of CO_2 Fertilization in the Arctic Tundra, 1995, Oechel, W. C. et al., Nature, Vol. 371, pp. 500-503.

AVAILABILITY OF IRON CAN LIMIT ATMOSPHERIC CO_2 REMOVAL BY THE TROPICAL PACIFIC OCEAN

An open ocean experiment demonstrated that phytoplankton photosynthesis in certain regions of the equatorial Pacific Ocean is impaired by the lack of iron in sea water, resulting in a significant reduction in the efficiency with which light is converted to stored chemical energy. Consequently, the growth of phytoplankton in the equatorial Pacific is physiologically limited by iron rather than processes such as grazing. These results add credence to theories which suggest that large inputs of dust from the continents to high nitrate, low chlorophyll regions of the open sea could have contributed to greater oceanic uptake of atmospheric CO_2 during glacial (global cooling) epochs. These results also suggest that future increases in desertification could bring about increased iron fluxes to certain regions of the open ocean, which could, in turn, stimulate marine phytoplankton growth and increase the rate at which the ocean will absorb CO_2.

Reference: (1) Iron Limitation of Phytoplankton Photosynthesis in the Equatorial Pacific Ocean, Kolber, Z., R. T. Barber, K. H. Coale, S. E. Fitzwater, R. M. Greene, K. S. Johnson, S. Lindley, and P. G. Falkowski, Nature, Vol. 371, pp. 145-149, 1994; (2) Dynamical Limitations on the Antarctic Iron Fertilization Strategy, Peng, T.H., and W.S. Broecker, Nature, 349: 227-229, 1991.

2. What has been Learned About the Influence of Clouds and Other Feedbacks on Climate?

NEW DISCREPANCY NOTED BETWEEN PREDICTED AND OBSERVED ABSORPTION OF SOLAR RADIATION BY CLOUDS

The prediction and assessment of the effects of changes in atmospheric composition on the Earth's radiation balance currently rely on theoretical models of atmospheric radiation to predict how much of the incoming short wave solar energy is absorbed by clouds. Initial results of combined satellite, aircraft, and surface measurements of solar radiation at geographically diverse locations suggest that 25-40 watts per square meter more of this radiation is absorbed in cloudy sky regions than is currently predicted by available radiation models. This anomalous or enhanced absorption is thought to be due to clouds; however, there is no known physical mechanism that can explain the absorption, and there are concerns about the representativeness of the measurements. If confirmed, this unexplained discrepancy between predicted and observed absorption of solar radiation reflects a potentially important gap in understanding of the Earth's radiation balance. If the discrepancy is due to atmospheric absorption, changes will be needed in the radiation algorithms used in the atmospheric models. It is not yet clear the extent to which such changes would affect the global response to increasing greenhouse gases. However, the changes would likely result in a redistribution of energy from the surface to the atmosphere, which might resolve some long-standing problems of how present GCM results compare to observations. As part of the Atmospheric Radiation

Program (ARM), an experiment involving the use of unmanned aerospace vehicles and ground based measurements is planned for 1995 to determine the validity and extent of the anomalous absorption. This experiment should also contribute mechanistic information needed to modify existing theoretical models so that they more accurately simulate the absorption of solar radiation.

References: (1) Absorption of Solar Radiation by Clouds: Observations Versus Models, Cess, R. D., M. H. Zhang, P. Minnis, L. Corsetti, E. G. Dutton, B. W. Forgan, D. P. Garber, W. L. Gates, J. J. Hack, E. F. Harrison, X. Jing, J. T. Kiehl, C. N. Long, J.-J. Morcrette, G. L. Potter, V. Ramanathan, B. Subasilar, C. H. Whitlock, D. F. Young, and Y. Zhou, Science, Vol. 267, pp. 496-498, 1995; (2) Warm Pool Heat Budget and Shortwave Cloud Forcing: A Missing Physics?, V. Ramanathan et al., Science, Vol. 267, pp. 499-503, 1995; (3) Direct Observations of Excess Solar Absorption by Clouds, Pilewskie, P., and F. P. J. Valero, Science, Vol. 267, pp. 1626-1629, 1995.

HIGH CLOUDS FOUND TO BE IMPORTANT TO THE STABILIZATION OF SEA SURFACE TEMPERATURES

Observations collected during the Central Equatorial Pacific Experiment (CEPEX) and from TOGA COARE have provided new insights into the processes that regulate the sea surface temperatures of the large "warm pool" of the tropical Pacific Ocean. These results suggest that optically thick, high-level clouds that form as a result of deep convection play an important role in stabilizing sea surface temperatures and limiting them to a maximum climatological value of about 31°C, as observed in both paleo and contemporary records. It appears that sea surface evaporation, which was previously thought to be the critical stabilizing factor, does play a role, but one that diminishes as the sea surface temperatures increase beyond a threshold value.

Reference: Warm Pool Heat Budget and Shortwave Cloud Forcing: A Missing Physics?, Ramanathan, V., B. Subasilar, G. J. Zhang, W. Conant, R. D. Cess, J. T. Kiehl, H. Grassl, and L. Shi, Science, Vol. 267, pp. 499-502, 1995.

3. What has been Learned about the Influences of Ecosystem Changes on Climate?

PRIMARY PRODUCTIVITY IN THE EQUATORIAL PACIFIC MAY BE DRIVEN BY AMMONIUM RATHER THAN NITRATE, WITH IMPLICATIONS FOR CO_2 UPTAKE BY THE OCEANS

The Equatorial Pacific Process Study (EqPac) of the Joint Global Ocean Flux Studies (JGOFS) program has provided substantial new insights into the dynamics of primary production associated with the upwelling in the equatorial Pacific. The equatorial Pacific is the single largest oceanic source for carbon dioxide release to the atmosphere, and up to 50% of world ocean primary production occurs there. Both primary productivity and chlorophyll were found to be lower than expected for this high-nutrient area, and two hypotheses have been put forward to explain this anomaly—one related to grazing by the zooplankton and the other related to the input of the micronutrient iron. In the spring, EqPac researchers found that 80% to 90% of the phytoplankton growth was consumed by grazing; during cold tongue conditions grazing remained unchanged, but primary production was boosted, leading to increased sedimentation of carbon to the deep ocean. The rapid turnover indicates a food web driven by ammonium rather than nitrate. The spatial distribution of dissolved iron suggests that this micronutrient enters the food web both from upwelling and via atmospheric deposition, suggesting that current popular notions about iron limitation in this region should be re-examined.

References: Physical and Biological Controls on Carbon Cycling in the Equatorial Pacific, Murray, J. W., R. T. Barber, M., R. Roman, M., P. Bacon, and R. A. Feely, Science, Vol. 266, pp. 58-65, 1994.

FORESTS SPECIES RESPOND DIFFERENTLY TO ELEVATED CO_2 AND O_3

Multiple stress experiments have shown that white pine, trembling aspen and yellow poplar grown in open top chambers demonstrate very different responses to elevated ozone levels, alone or in combination with exposure to carbon dioxide. In experiments with trembling aspen exposed to ozone, the addition of elevated carbon dioxide produced a strong negative interaction, illustrating the difficulty of generalizing about the likely response of ecosystems based on single factor experiments with a limited number of species.

References: (1) Photosynthetic Productivity of Aspen Clones Varying in Sensitivity to Tropospheric Ozone, Coleman, M. D., R. E. Dickson, J. Isebrands, and D. F. Karnosky, Tree Physiology, in press, 1995; (2) Carbon Allocation and Partitioning in Aspen Clones Varying in Sensitivity to Tropospheric Ozone, Coleman, M. D., R. E. Dickson, J. Isebrands, and D. F. Karnosky, Tree Physiology, in press, 1995; (3) Photosynthetic Responses of Aspen Clones to Simultaneous Exposures of Ozone and CO_2, Kull, O., A. Sober, M. Coleman, R. Dickson, J. Isebrands, Z. Gagnon, and D. Karnosky, Canadian Journal of Forest Research, submitted, 1995.

4. What has been Learned about Future Climate Changes from Research on Past Climate Changes over the History of the Earth?

BACKGROUND INFORMATION: *Long-term records from around the globe indicate that during glacial periods (extending back from more than 10,000 years ago) the Earth's climate was significantly different than it is today, with rapid fluctuations in character. The period of warmth over the past 10,000 years appears to be unique over the past 100,000 years (or more). A wide variety of records of past climate history are providing an information base that can help improve understanding of the variability of the Earth's natural climate. Instrumental climate records exist for only a few centuries. This makes the use of reconstruction techniques essential for providing the context for recognizing human-induced changes in climate, and disentangling these from natural variability.*

A WARMER CLIMATE THREE MILLION YEARS AGO MAY HAVE RESULTED IN A SEA LEVEL 30 METERS HIGHER THAN TODAY'S

Reconstruction of marine and terrestrial records throughout the Northern Hemisphere during the middle Pliocene (about 3 to 4 million years ago) suggest that sea level was at least 25 meters higher than it is today. This is the last time period in the Earth's history when global temperatures were as warm as those predicted by climate models for the time when there has been a doubling of the CO_2 concentration. Analytical and modeling studies of this period have been used to provide insights into the potential consequences of future climate change. One study indicated that 3 million years ago the northern forests extended to the margin of the Arctic Ocean, sea level was approximately 30 meters higher than today because of a reduction in ice volume in the polar regions, and the globally averaged temperature was 3.5°C warmer than it is today.

Reference: Modeling of Middle Pliocene Climate with the NCAR GENESIS General Circulation Model, Sloan, L. C., T. J. Crowley, and D. Pollard, Global and Planetary Change, Vol. 9, pp. 169-195, 1994.

SEDIMENT RECORD FROM CENTRAL ASIA REVEALS THAT THE CLIMATIC RESPONSE AS THE OCEANS AND ICE SHEETS FOR OVER 250,000 YEARS

The center of the Asian continent, far from oceans and ice sheets, plays a critical role in determining the global climate. The region generates important weather patterns in both winter and summer seasons, including the monsoons of Asia. Recent studies of the sediment record from Lake Baikal, including magnetic, radiochemical, and biogenic components, have clarified the response of this highly seasonal environment to solar forcing. Rather than a direct linear response to changes in solar radiation, the paleoclimate indicators from Lake Baikal show the same intricate pattern of climatic variation as the oceans and ice sheets. In particular, the indicators correlate extremely well with global ice volumes over the last 250,000 years, as indicated by the marine oxygen-isotope records.

Reference: A Rock Magnetic Record from Lake Baikal, Siberia: Evidence for Late Quaternary Climate Change, Peck, J. A., J. W. King, S. M. Colman, and V. A. Kravchinsky, Earth and Planetary Science Letters, Vol. 122, pp. 221-238, 1994.

MASSIVE ICEBERG DISCHARGES LINKED TO PAST GLOBAL CLIMATE CHANGE

Evidence has been found for episodic outflows of icebergs from continental ice sheets during the last ice age. These outflows flooded the North Atlantic, creating a significant freshening of the salt water as they melted. The six or so great iceberg discharges in the North Atlantic region were apparently not isolated events, but associated with other simultaneous environmental changes. These included surges in mountain glaciers in the Chilean Andes and in the Alps of New Zealand and changes in paleovegetation from Florida to British Columbia, in plankton records from the Sulu Sea, in ice core records from Greenland and Antarctica, and in lake levels in Africa. There is some evidence that these events may be linked to the precession of the seasons caused by changes in the Earth's orbit around the Sun. These massive iceberg discharges and associated releases of freshwater into polar oceans can rapidly disrupt the normal pattern of the thermohaline circulation that warms the North Atlantic, thereby causing rapid cooling of this region that can last for many centuries, disrupting the global climate.

Reference: Massive Iceberg Discharges as Triggers for Global Climate Change, Broecker, W. S., Nature, Vol. 372, pp. 421-424, 1994.

PAST CLIMATE CHANGES AT THE NORTH POLE TIED TO CLIMATE CHANGES AT THE SOUTH POLE OVER THE SAME PERIOD

Ice cores have been obtained from the Greenland and Antarctic Ice Sheets that have layers of snow spanning the period of the last ice age from 20,000 to 105,000 years ago. Past changes in the climate appear to have been more rapid and more numerous in Greenland than in Antarctica. By counting changes in a number of variables recorded in the layers of snow, 22 warming events of short duration have been identified in the Greenland ice cores and 9 warming events of short duration in the Antarctic ice cores. In the Greenland ice core records, the short warming events are characterized by very rapid warming and rapid cooling transitions at the beginning and end of the events. In Antarctica, related short warming events are characterized by slow warming at the onset of the warming period, and slow cooling at the end of the brief warming period. The preliminary results of this work suggest that warming events occurred in Antarctica whenever warming events in Greenland lasted longer than 2,000 years. The evidence suggests that partial melting of continental ice sheets (e.g., on North America) and changes in ocean circulation were, at least in part, responsible for the climatic teleconnection between the north and south polar regions. There is evidence that North Atlantic Deep Water (NADW) production slowed or ceased during much of the Earth's last glacial period, stopping the transport of heat northward by the Gulf Stream to warm northern Europe. Resumption of NADW production during this cold period has been suggested as the immediate cause of rapid warming during the 22 warming events recorded in the Greenland ice cores.

Reference: Climate Correlations between Greenland and Antarctica during the Past 100,000 Years, Bender, M., T. Sowers, M. Dickson, J. Orchardo, P. Grootes, P. A. Mayewski, and D. A. Meese, Nature, Vol. 372, p. 663-666, 1994.

GREENLAND ICE CORES SUGGEST THAT LARGE ABRUPT SHIFTS IN OXYGEN ISOTOPE RATIOS OCCURRED DURING MELTING OF THE ICE SHEETS

The termination phase of the last ice age was characterized by a series of abrupt returns to glacial climate, the best-known of which was the Younger Dryas event that lasted from about 11,000 to 10,000 years ago. Oxygen isotope data from the Greenland ice cores suggest that temperature shifts of 7 to 10°C occurred over only a few decades and that dust concentrations and the rate of snow accumulation in these cores show an even more rapid transition. A general circulation model that considered a complex variety of processes which could influence isotope ratios was used to attempt to reproduce the measured variabilityof the ratio. The model results suggest that the variability cannot be explained by changes in the North Atlantic thermohaline circulation alone, and that a number of moisture sources contribute to snowfall over Greenland. In addition, evidence of climate change in the Southern Hemisphere during the same period suggests that any explanation must take into account a climatic change much more widespread than the North Atlantic region alone.

Reference: Glacial-Interglacial Changes in Moisture Sources for Greenland: Influences on the Ice Core Record of Climate, Charles, C. D., D. Rind, J. Jouzel, R. D. Kaster, and R. G. Fairbanks, Science, Vol. 263, pp. 508-518, 1994.

INCREASED VOLCANISM LINKED TO CLIMATIC COOLING DURING THE PERIOD FROM 5000 TO 7000 B.C.

Sulfate concentrations measured in Greenland ice core samples suggest that there were up to three times as many volcanic events during the period of 5000 to 7000 B.C. as over the past two millennia. In addition, these eruptions appear to have produced up to five times higher concentrations of sulfate than the largest known historical eruptions. The results suggest that increased volcanism occurred at circumarctic locations during the millennia following deglaciation. These findings support the suggestion that magma chambers respond to the release of crustal stresses following deglaciation and that this may lead to more explosive volcanism. The overall magnitude and duration of these effects is still uncertain.

Reference: Record of Volcanism Since 7000 B.C. from the GISP2 Greenland Ice Core and Implications for the Volcano-Climate System, Zielinski, G. A., P. A. Mayewski, L. D. Meeker, S. Whitlow, M. S. Twickler, M. Morrison, D. A. Meese, A. J. Gow, and R. B. Alley, Science, Vol. 264, pp. 948-952, 1994.

EVIDENCE FROM THE GREAT BASIN INDICATES A MUCH MOISTER CLIMATE THOUSANDS OF YEARS AGO

Studies of changes in paleo-vegetation and the rise and fall of pluvial lakes (i.e., lakes filled by precipitation and runoff) in the Great Basin indicate that the climate was much moister thousands of years ago and fluctuated significantly over past millennia. These results suggest that the lack of modern day climate fluctuations of the magnitude found in the historical record is unusual. The history of regional paleo floods in Arizona and Utah reveals that the largest floods clustered into distinct time intervals that coincided with periods of cool, moist climate and frequent El Niño episodes.

Reference: A 30,000 Year Record of Vegetation Dynamics at a Semi-arid Locale in the Great Basin, Nowak, C. L., R S. Nowak, R. J. Tausch, and P. E. Wigand, Journal of Vegetation Science, Vol. 5, pp. 579-590, 1994.

5. What Improvements Have Been Made In Predicting Future Changes In Climate?

CLIMATE MODELS PREDICT COOLING EFFECT OF AEROSOLS

For the past two decades, climate models have predicted the amount of increase in global average temperatures as a result of the rising concentrations of greenhouse gases. Global observations indicate that the measured increase of 0.5°C rise since the last century is only about half the increase of model projections. Recent research suggests that increased concentrations of atmospheric aerosols may be counteracting the warming influence of greenhouse gases. This increase in aerosol concentrations is mostly the result of combustion-related emissions of sulfur dioxide, hydrocarbons, and soot from fossil fuel use and biomass burning. The newer climate models, which include the effects of these aerosols, predict that they are exerting a cooling influence on global temperatures. When the effect of aerosol cooling is combined with the effect of greenhouse warming, the magnitude and geographical pattern of the combined changes have considerable similarity to the observed patterns of change.

Reference: Response of the Climate System to Atmospheric Aerosols and Greenhouse Gases, Taylor, K. E., and J. E. Penner, Nature, Vol. 369, pp. 734-737, 1994.

THE GLOBAL WARMING POTENTIAL FOR SEVERAL GREENHOUSE GASES HAS BEEN FOUND TO BE LARGER THAN ORIGINALLY THOUGHT

The Global Warming Potential (GWP) of greenhouse gases was developed as an index for comparing the different magnitude of influence of each greenhouse gas in contributing to climate change. It is useful as a first order tool for policy makers in evaluating mitigation strategies. The GWP of a gas is defined as "the cumulative radiative forcing between the present and some chosen later time 'horizon' caused by a unit mass of gas emitted now, expressed relative to some reference gas (usually carbon dioxide)." For several gases, the GWPs reported by the IPCC in the 1994 report were 10 to 30% larger than those reported in 1992. Uncertainty in the GWPs is about 35%.

Reference: Climate Change 1994: Radiative Forcing of Climate Change and an Evaluation of the IPCC IS92 Emission Scenarios, Intergovernmental Panel on Climate Change, Cambridge University Press, 339 p, 1995.

CLIMATE MODEL REPRODUCES RECENT CLIMATE TRENDS AND CORROBORATES THE INFLUENCE OF AN ENHANCED HYDROLOGIC CYCLE IN THE TROPICS

A remarkable similarity in the predicted and observed climate trends over the most recent portion of the global temperature record (1970-1992) was demonstrated using atmospheric general circulation models forced only with ocean surface temperatures. These results corroborate the suggestions that the observed increase in the globally averaged surface air temperature is a result of enhancement in the tropical hydrologic cycle driven by tropical ocean temperature increases. A trend toward an enhanced tropical hydrologic cycle has been suggested as an early signal of the greenhouse warming effects of increased atmospheric concentrations of CO_2 and other greenhouse gases.

Reference: Simulation of Recent Global Temperature Trends, Graham, N. E., Science, Vol. 267, pp. 666-671, 1995.

NEW PARAMETERIZATION OF OCEAN EDDIES IMPROVES THE COMPUTATIONAL EFFICIENCY OF COUPLED OCEAN-ATMOSPHERE GLOBAL CIRCULATION MODELS

Accurate characterization of mesoscale eddies (those with lengths of 10 to 100 km) in climate models is important because of their role in transporting heat, salinity, and passive tracers used to study ocean circulation. This implies that in order to resolve these important processes, ocean models should have a resolution on the order of 10 km. Most coupled GCMs use ocean grid scales on the order of hundreds of kilometers due to the excessive computational time required for the higher resolution. This new parameterization of mesoscale processes by scientists at the National Center for Atmospheric Research has been demonstrated to yield improved predictions of global temperature distributions, poleward heat fluxes, and deep-water formations without requiring excessive computational resources.

Reference: The Role of Mesoscale Tracer Transports in the Global Ocean Circulation, Danabasoglu, G., J. C. McWilliams, and P. R. Gent, Science, Vol. 264, pp. 1123-1126, 1994.

ADVANCED COMPUTER SYSTEMS ALLOW IMPROVEMENT OF RESOLUTION IN GLOBAL OCEAN MODELS

The development of "eddy-resolving" global ocean general circulation models (OGCMs) is required to accurately simulate the global thermohaline (or "conveyor belt") ocean currents that strongly influence global and regional climate. These high resolution simulations, which divide the globe into grid cells approximately 40 km on a side, were not feasible because of the constraints imposed by limited computing power and modeling capabilities. Global eddy-resolving models have now been developed by USGCRP scientists that take advantage of the latest massively-parallel supercomputer technology to make multi-decade, global simulations of the world ocean circulation. These models are currently being coupled to highly optimized, state-of-the-science atmospheric GCMs to more accurately project climate changes out to centuries in advance.

References: (1) Parallel Ocean General Circulation Modeling, Smith, R. D., J. K. Dukowicz, and R. C. Malone, Physica D, Vol. 60, pp. 38-61, 1992; (2) Implicit Free-Surface Method for the Bryan-Cox-Semtner Ocean Model, Dukowicz, J. K. and R. D. Smith, Journal of Geophysical Research, Vol. 99, pp. 7991-8014, 1994.

THREE DIMENSIONAL OCEAN MODEL DEVELOPED BY THE WORLD OCEAN CIRCULATION EXPERIMENT (WOCE) WINS NATIONAL AWARD

A very realistic numerical model of the global three-dimensional ocean circulation, including important strong currents and eddies and proper representation of coastlines and bathymetry, was developed in order to improve our physical understanding of the ocean and to enable more accurate prediction of climate change. The model output was compared with both in-situ and satellite observations and found to be in very good agreement with what actually happened. The agreement of predicted surface height variability with that observed by the TOPEX POSEIDON satellite altimeter was especially impressive. Model output was distributed to more than thirty research groups worldwide for further analysis and additional scientific uses. Video animations of ocean currents, height, temperature, and salinity have also been sent to hundreds of individual scientists, educators and others who requested them. The importance of this model development has been widely recognized, including a national award for "Breakthrough Computational Science" from the Smithsonian Institution. An even higher resolution model running on a massively parallel computer won a similar Smithsonian Award in the "Science" category a year later. (see also previous item).

Reference: Ocean General Circulation Model from a Global Eddy-Resolving Model, Semtner, A. and R. Chervin, Journal of Geophysical Research, Vol. 97, 5493-5550, 1992.

NEW LABORATORY TO BE DEVOTED TO LARGE CLIMATE SIMULATIONS FOR COMPREHENSIVE EARTH SYSTEM MODELING

A large climate model simulation requires hundreds to thousands of processor hours for its completion and often produces many gigabytes of model output that must be archived for analysis and intercomparison with other simulations and with observations. The Climate Simulation Laboratory is a special use, dedicated climate system modeling computing facility. CSL's purpose is to provide high performance computing and data storage systems to support large-scale, long-running simulations of the Earth's climate system (defined as the atmosphere, oceans, land and cryosphere, and associated biogeochemistry and ecology, on time scales of seasons to a century), including simulations of both the coupled system and appropriate model components.

Reference: The NCAR Climate Simulation Laboratory - A National Computing Facility for Climate System Modeling for the U.S. Global Change Research Program, Buzbee, W., 1995

6. What New Evidence is there that the Climate is Changing in Response to Societal Activities?

OBSERVED CHANGES IN THE TIMING OF THE SEASONS MAY SIGNAL GREENHOUSE EFFECT

A 340-year record (1651-1991) of monthly average temperatures from central England has provided the first evidence that the timing of the annual temperature cycle had been advancing by a little more than a day each century up until 1940; this result was confirmed in other records and is expected as a result of the very slow shifts in the variations of the Earth's orbit about the Sun. However, since 1940 the timing of the seasons as measured in the central England and many other Northern Hemisphere records has shifted much more rapidly, suggesting some other effect is now becoming dominant. The timing of the seasonal cycle of temperature at any given location results from the interplay between changes in the solar and infrared heating of the Earth and transport of heat from elsewhere on the globe. The greatly accelerated rate of change in the timing of the seasonal cycle seems to be occurring because local climates are becoming more dominated by the radiative mode, as might be expected from the enhanced concentrations of greenhouse gases in the atmosphere reinforcing winter-time solar heating. The timing of the seasons in the Southern Hemisphere has been less affected, as expected, because the radiative influence of the greenhouse gases and solar radiation and the transport modes are currently more nearly in phase.

Reference: The Seasons, Global Temperature, and Precession, Thomson, D. J., Science, 268, 59-68, 1995.

LOCAL WARMING LEADS TO ICE SHELF DISINTEGRATION

On February 27th, 1995, the British Antarctic Survey (BAS) announced that an ice shelf that formerly blocked the Prince Gustav channel between James Ross Island and the Antarctic Peninsula had disintegrated, and an enormous iceberg had broken off the Larsen Ice Shelf further south. BAS scientists have ascribed the cause of the events to a 2.5°C warming of the regional climate since the 1940's. Climate models have predicted enhanced warming at the poles, associated with the buildup of greenhouse gases.

The ice shelf in the Prince Gustav channel spanned approximately 270 square miles prior to its disintegration. The iceberg broken from the Larsen ice shelf is roughly 1,150 square miles in size (the size of Rhode Island), and approximately 656 feet thick. BAS scientists also stated that the Wordie ice shelf on the west coast of the Antarctic peninsula also recently disintegrated. BAS scientists also maintain that there is little doubt that the retreat of these ice shelves is, in the short term, irreversible.

References: (1) British Antarctic Survey Press Release, February 27, 1995; (2) Rapid Disintegration of Wordie Ice Shelf in Response to Atmospheric Warming, Doake, C.S.M., and D. G. Vaughan, Nature, Vol. 350, pp. 328-330, 1991.

REDUCTION IN NORTHERN HEMISPHERIC SNOW COVER OVER THE LAST 20 YEARS AND ENHANCED SURFACE WARMING IN NORTHERN LATITUDES

The extent of annual snow cover over all three continental-scale regions of the Northern Hemisphere has declined by about 10% over the past 20 years. This reduction in snow cover, primarily in the spring months, has altered the amount of outgoing long-wave radiation and the surface albedo, creating a positive feedback effect that is further warming surface air temperatures.

Reference: Observed Impact of Snow Cover on the Heat Balance and the Rise of Continenial Spring Temperatures, Groisman, P., T. R. Karl, and R. W. Knight, Science, Vol. 263, pp. 198-200, 1994.

INCREASE IN WATER VAPOR MAY BE LINKED TO CLIMATE WARMING

Water vapor in the lower stratosphere above Boulder, Colorado has increased significantly, a tendency consistent with model predictions. The measurements taken at Boulder should be representative of the stratosphere over the highly populated northern mid-latitudes. An increase of 0.34 to 0.84% per year from 1981 to 1994 has been observed for altitudes from 9 to 27 kilometers. The water vapor increase was greatest in the region from 20-25 kilometers, with an average annual increase of 1%. The increase in water vapor below 20 kilometers is larger than might be expected from the stratospheric oxidation of increasing concentrations of atmospheric methane (methane is broken down chemically to produce water vapor). This suggests that the increase in water vapor may be the result of the rise in the global temperature that has been observed over the past few decades. Recent work also indicates that the water vapor concentration determines the effectiveness of the chemical reactions that destroy ozone in the lower stratosphere. Thus, an increase in water vapor could be contributing to ozone losses. This fifteen-year study also demonstrates that there is now excellent agreement between satellite-derived data (UARS and SAGE II satellites) and balloon-borne data regarding water vapor.

Reference: Increase in Lower-Stratospheric Water Vapor at a Mid-Latitude Northern Hemisphere Site from 1981 to 1994, Oltmans, S. J., and D. J. Hofmann, Nature, Vol. 374, p. 146-149, 1995.

CHANGES IN ATLANTIC OCEAN TEMPERATURES

In measurements made along a transect across the central North Atlantic, oceanographers funded by the USGCRP found a distinct warming in the upper 2500 meters, compared to the original measurements made in 1957 and 1981. This transect is also the approximate route of Columbus' first voyage to the New World. This warming could represent some of the first evidence of a large-scale change in the ocean, but could also be indicative of a shifting of masses of warmer water in the Atlantic. It should be noted that another set of repeat ocean sections in the northeast Atlantic showed marked cooling between 1962 and 1991. An extensive series of cruises in the Atlantic is being planned for 1996-97 as part of the World Ocean Circulation Experiment (WOCE) to examine these possibilities.

References: (1) Rising Temperatures in the Subtropical North Atlantic over the Past 35 Years, Parrillo, G., A. Lavin, H. Bryden, M. Garcia and R. Millard, Nature, Vol. 369, pp. 48-51, 1994; (2) Cooling and Freshening of the Subpolar North Atlantic Ocean Since the 1960's, Read, J. and J. Gould, Nature Vol. 360, pp. 55-57, 1992.

7. What has been Learned about the Potential Consequences of Climate Change?

SIGNIFICANT HUMAN HEALTH EFFECTS MAY BE LINKED TO CHANGING CLIMATE

A link has been suggested between the patterns and impacts of disease and changes in temperature, rainfall, and the pattern of extreme weather events. Potential health effects include not only those associated with heat stress, but increases in vector-borne diseases, such as those carried by mosquitoes and rodents. Evidence that extended heavy rainfall precedes outbreaks of vector borne disease includes the 1974 epidemic of West Nile fever in southern Africa, the 1973 encephalitis outbreak in India, and major epidemics of malaria in Ecuador, Peru, and Bolivia in 1983.

Reference: Health and Climate Change, Epstein, P. and D. Sharp, editors, Special Issue of The Lancet, 1994.

SEA LEVEL RISE FOUND TO ENDANGER TIDAL MARSH ECOSYSTEMS

Studies in the state of Louisiana show that tidal marsh deterioration is brought on by the stress of water-logging of vegetation associated with sea level rise. Death of vegetation caused by increased flooding leads to the loss of wetlands and pond formation. Along the Gulf Coast, salinity stress would accompany increased flooding. Significant genetic variation in baldcypress's tolerance of combined flooding and salinity indicates that certain moderately salt-tolerant baldcypress seedlings could be used in coastal restoration projects. However, permanent flooding renders baldcypress more vulnerable to defoliation by the fruittree leafroller insect pest. Fifty thousand acres of baldcypress-dominated wetlands in southern Louisiana were nearly totally defoliated by this insect in 1993. The area affected by defoliation is expected to increase with an increase in permanently flooded forests. An increase in atmospheric carbon dioxide is also likely to enhance the production of algae and other plants, possible changing natural communities along the Gulf coast.

Reference: Global Climate Change: Implications for Submerged Aquatic Vegetation, Rizzo, W. M., and H. A. Neckles, in Gale, R. U., W. U. Catallo, R. C. Hohanty, and J. B. Johnston (Eds.), Environmental Concerns, Public Policies and Remediation Technologies, Proceedings of the 3rd Annual Convention of the American Society of Environmental Science, Baton Rouge, LA, 1994.

SAGEBRUSH REPLACES SHRUBS IN ALPINE MEADOW IN CLIMATE WARMING EXPERIMENT

In experimentally heated plots in a Rocky Mountain meadow that were designed to help study the responses of montane meadow vegetation to climate warming, above-ground biomass of sagebrush increased in the drier habitat, while shrubs increased in the wetter habitats. These results, as well as others, suggest that the increased warming expected under an atmosphere with a concentration of CO_2 twice that of pre-industrial levels could change the dominant vegetation of a widespread alpine meadow habitat. The findings suggest that during a climate warming the competitive status of shrubs is enhanced, sagebrush growth is enhanced at the expense of meadow forbs which now dominate such alpine meadows, and elongation rate is enhanced. Pollen records spanning the last 100,000 years of Earth history also show intervals of increased abundance of sagebrush during times of climate warming, consistent with the results of this present work.

Reference: Shifting Dominance Within a Montane Vegetation Community: Results of a Climate-Warming Experiment, Hart, J., and R. Shaw, Science, Vol. 267, pp. 876-880, 1995.

DECLINE OF PLANKTON IN SOUTHERN CALIFORNIA DUE TO OCEAN WARMING

A recent study based upon 43 years of observations (1951-1993) along the coast of southern California indicates that the biomass of large zooplankton has decreased by 80% during this interval of time. This decline has occurred in conjunction with the surface layers of the ocean having warmed in this region (by 1.5°C in some places), and the warming seems a likely cause of the changes. This decline represents a major disruption in the biotic web of this region because large zooplankton are a significant part of the food web and are the main diet of some birds and many schooling, commercially important species of fish. As a result of the surface-intensified warming, the vertical stratification separating the upper ocean mixed layer from the ocean depths was substantially intensified. Consequently, less cold (and nutrient-rich) waters were carried upward to come into contact with the atmosphere in the upwelling zones. With less upward displacement of water, shallower layers of water bearing fewer nutrients are exposed to light and photosynthetic processes, leading to less new biomass production and ultimately to decreases in zooplankton. Thus, the mechanism is not a decrease in the volume of upwelled waters, but rather, it is that the waters that upwell come from shallower depths, and are therefore, warmer and less nutrient rich. It should be underscored that a suppression of nutrient supply by enhanced oceanic stratification is not a mechanism confined to coastal ocean regions. If there is an average global temperature rise of 1 to 2°C in the next 40 years and stratification becomes more widespread, the impacts on fisheries and other marine life could be significant.

Reference: Climatic Warming and the Decline of Zooplankton in the California Current, Roemmich, D., and J. McGowan, Science, Vol. 267, p. 1324-1326, 1995.

NEW INDICATORS OF FISH DISTRIBUTION DEVELOPED BY THE GLOBEC PROGRAM TO STUDY THE EFFECTS OF OCEAN CLIMATE CHANGES

The GLOBEC Georges Bank Program has included study of: (i) proliferation of cell nuclear antigen as a measure of growth in fish and zooplankton, (ii) development of new genetic markers to identify populations of copepods around the north Atlantic, and (iii) development of high-frequency acoustics and towed video cameras that provide extraordinarily detailed pictures of the distribution of planktonic organisms. Coupled physical-biological models are now run in prognostic mode, which makes possible the testing of various regional climate-change scenarios, including analysis of how changes in wind speed and direction, storms, increased heating and early water column stratification may influence community structure on Georges Bank. The influence of changes in the position and strength of the Gulf Stream and Scotian Shelf currents will be examined next year. These GLOBEC efforts are being carried out in collaboration with other coastal ocean programs, including a study of the role of heavy fishing in changing ecosystem structure on Georges Bank. Results of these programs will be used to produce integrated assessments of the relative importance of over-fishing vs. climate variability as factors controlling fluctuations in fish populations, and an assessment of how the recent closure of the fishery has changed the socio-economic structure of local fishing communities.

References: (1) Topical studies in Oceanography - U.S. GLOBEC: Global Ocean Ecosystem Dynamics, Deep-Sea Research, Vol. 41, pp. 1-227, 1994; (2) Special Issue on U.S. GLOBEC Georges Bank Program, Deep-Sea Research, in preparation, 1995.

BOREAL FOREST GROWTH RATE STALLED

A four-year study of growth rings in trees near the timberline in northern and central Alaska indicates that the response of tree growth to climate change is not simple and linear. Based on records of tree-ring growth and weather station and borehole temperatures, the far-northern climate has warmed by roughly 2°C since the 1880s (mostly in the fall, winter, and spring, as predicted by global climate models). Records from trees indicate that by the middle of this century the boreal regions were warmer than at any other time in the last 300 years. This warming is much faster than is occurring in the rest of the world, providing an important opportunity to examine ecological responses. What has been found is that as high latitudes have warmed over the past 100 years, tree growth at first accelerated, as anticipated, but then flattened, even though the climate continued to warm. Unexpectedly, the most recent decades of warming, instead of encouraging significant growth, may be stressing northern forests by speeding up moisture loss and perhaps subjecting them to more frequent insect attacks, especially by insects that were previously restricted to lower, warmer latitudes. Since the 1970s Alaska's forests have suffered from severe outbreaks of bark beetles, which have devastated millions of acres of forest. Warmer temperatures can shorten the reproductive cycle of the bark beetle, for example, from two years to one, thus increasing the population of bark beetles significantly. Insect pest survival benefits from warmer temperatures.

Reference: Boreal Forest Growth Rate Stalled, Jacoby, G., and R. D'Arrigo, Global Biogeochemical Cycles, in press, 1995.

SURVEYS OF TROPICAL FORESTS FIND THAT THEY ARE CHANGING MUCH MORE RAPIDLY NOW THAN THEY HAVE IN THE PAST

The measured turnover rate of tropical forest trees since 1934 suggests that there has been a significant increase in forest turnover since about 1960. The increase appears to have been accelerated during the 1980s. The likely cause is environmental changes from increased extreme weather events, adjacent deforestation, and elevated productivity which has resulted from increased atmospheric CO_2. This increased turnover rate has implications for tropical biodiversity and possibly for the tropical carbon cycle. Faster forest turnover could lead to a dominance of climbing plants and gap-dependent tree species, which are most likely to benefit from increased CO_2. Many of these species have less dense wood than shade-tolerant species, suggesting that tropical forests could eventually become less of a sink for carbon than they currently are.

Reference: Increasing Turnover Through Time in Tropical Forests, Phillips, O. L., and A. H. Gentry, Science, Vol. 263, pp. 954-958, 1994.

FIRST VISIT TO NORTH POLE STATION BY NORTH AMERICAN SURFACE VESSELS FINDS THAT THE ARCTIC HAS A MUCH HIGHER BIOLOGICAL PRODUCTIVITY THAN EXPECTED

Preliminary biological measurements, made by the joint U.S.-Canadian Arctic Ocean Section of Arctic System Science (ARCSS), suggest that the Arctic Ocean is a far more productive area than had previously been thought, as evidenced by the abundance of phytoplankton and their nutrients. Hydrographic measurements also suggest that the influence of the Atlantic Ocean on the central part of the Arctic Ocean is much larger than suspected from historical data. It is not yet known if this represents a major change in the Arctic Ocean, possibly as a consequence of warming, or a deficiency in the earlier data. The remarkably warm temperatures in the Atlantic layer (ca. 200- 400 meters) were also found on the Eurasian side of the Lomonosov Ridge, where the water in this layer is a full half degree warmer than observed there in 1991.

Reference: Active Cycling of Organic Carbon in the Central Arctic Ocean, Wheeler, P.A., et al., Nature, in press, 1995.

8. What New Information is there Regarding the Potential for Society to Adapt to and Mitigate Climate Change?

INTEGRATED MODEL OF THE FORESTRY SECTOR SUGGESTS THAT INCREASED TIMBER GROWTH COULD OFFSET CARBON EMISSIONS BY 2020

An integrated modeling framework has been developed to link climate change scenarios, an ecosystem model, an economic model of the forest sector, and a carbon accounting model. Initial results indicate that elevated carbon dioxide and increasing temperature could generally increase net primary productivity and timber growth in the U.S., change land use and timber consumption by lowering prices, and could potentially offset an expected flux of carbon dioxide to the atmosphere from forest lands beginning about 2020. Changes in net ecosystem productivity under these modeled conditions are uncertain due to a lack of understanding about their effects on soil respiration.

References: (1) Forest Sector Impacts from Changes in Forest Productivity under Climate Change, Joyce, L. A., J. R. Mills, L. S. Heath, A. D. McGuire, R. W. Haynes, and R. A. Birdsey, Journal of Biogeography, in press, 1995; (2) Global Change and Forest Resources: Modeling Multiple Forest Resources and Human Interactions, Fosberg, M. A., L. A. Joyce, and R. A. Birdsey, In J. M. Reilly and M. Anderson (ed.) Economic Issues in Global Climate Change, Westview Press, Boulder, CO, pp. 235-251, 1992; (3) Past and Prospective Carbon Storage in United States Forests, Birdsey, R. A., A. J. Plantinga and L. S. Heath, Forest Ecology and Management, Vol. 58, pp. 33-39, 1993.

ELEVATED CO_2 FOUND TO PARTIALLY PROTECT SOME CROPS FROM THE EFFECTS OF AIR POLLUTION

Elevated atmospheric carbon dioxide protects at least some crops from air pollution damage. Soybean growth and yield is decreased by the air pollutant O_3 and increased by elevated CO_2. For example, ambient O_3 reduced yield by 17% at current levels of CO_2 compared to the yield in air free of O_3. On the other hand, elevated CO_2 (up to a doubling of current levels) increased yield up to 36%. When mixtures of the two gases were tested, it was found that CO_2 enrichment partially protected soybeans from the O_3 effect. However, more CO_2 was required to produce a given level of protection as the O_3 concentration increased. Similar results were obtained in greenhouse studies with snap beans and tomatoes. This research provides information needed to estimate the negative impact of O_3, the positive impact of CO_2, and the interactive effects at present and future concentrations of these gases.

References: (1) The Combined Effects of Elevated Carbon Dioxide and Ozone on Crop Systems, Miller, J. E., A. S. Heagle, S. R. Shafer and W. W. Heck, In C.V. Mathai and G. Stensland (ed.) Global Climate Change: Science, Policy, and Mitigation Strategies, Proc. Air, & Waste Management Assn. Int. Specialty Conference, 5-8 April 1994, Phoenix, AZ. VIP-40. Air & Waste Management Assn., Pittsburgh, PA. (Extended abstract), pp. 557-558, 1994; (2) Photorespiration in Soybean Treated with Elevated Carbon Dioxide and Ozone in Open-Top Chambers, Booker, F. L., S. Brunschon-Harti, C. D. Reid, E. L. Fiscus, and J. E. Miller, Plant Physiology, Submitted, 1995; (3) Vegetative Growth of Soybean as Affected by Elevated Carbon Dioxide and Ozone, Reinart, R. A., and M. C. Ho, Environment and Pollution, in press, 1995.

ELEVATED ATMOSPHERIC CO_2 FOUND TO AFFECT GROUND PROCESSES IN AGRO-ECOSYSTEMS

Significant responses in plant root systems and their rhizospheres have been observed in CO_2 enriched agro-ecosystems. Experiments in controlled environments, in open top chambers, and in free-air CO_2 enrichment systems have generally shown crop growth and development to respond positively to elevated CO_2. More allocation of carbon to biomass below the ground was observed. Root length and weight densities increased and overall root architecture was different. The rhizosphere of field-grown cotton growing in CO_2-enriched air was altered; total soil microbial activity and saprophagous nematode populations were observed to increase. Such shifts are linked to soil carbon storage and could be important in terms of plant diseases. Soil respiration was enhanced for sorghum and soybean crops grown at elevated concentrations of CO_2, probably reflecting enhanced rooting.

Ground water quality could also be affected in agro-ecosystems growing in higher levels of CO_2 as more and deeper root proliferation may translate directly into more efficient uptake of water and nutrients. Response of root structure and function leads immediately to implications for changes in rhizosphere populations and activities, potential shifts in soil carbon sequestration and dynamics as well as redistribution of carbon within the soil profile, and possible effects on the soil itself. Such phenomena could well impact below ground plant competition and could certainly be important in future climates.

References: (1) Plant Responses to Atmospheric CO_2 Enrichment with Emphasis on Roots and the Rhizosphere, Rogers, H.H., G.B. Runion and S. V. Krupa, Environment and Pollution, Vol. 83, pp. 155-159, 1994; (2) Elevated Atmospheric Carbon Dioxide Effects on Sorghum and Soybean Nutrient status, Reeves, D.W., H.H. Rogers, S.A. Prior, C.W. Wood and G.B. Runion, Journal of Plant Nutrition, Vol. 17, pp. 1939-1954, 1994.

ALTERNATIVE FOREST MANAGEMENT PRACTICES CAN HELP STORE CARBON AND SLOW THE RATE OF CLIMATE CHANGE; FOREST REMOVAL CAN ACCELERATE GREENHOUSE GAS BUILD-UP

Low-cost forest management could create a sink for substantial amounts of atmospheric carbon. As much as 10% of current U.S. annual emissions could be captured (sequestered) with such low-cost measures. Increased concentrations of atmospheric CO_2 will alter the carbon allocation of forests, resulting in increased carbon sequestration, particularly to the below-ground pools. Agricultural soils can also be managed to sequester carbon, as well as providing for erosion control. Conversion of natural tropical forests to farm and ranch land has the potential to increase nitrous oxide (N_2O) emissions from that land by as much as a factor of three. N_2O is a greenhouse gas with a global warming potential per unit mass that is 120 - 330 times greater than CO_2 over the next 100 years; because much less N_2O is emitted than CO_2, this will be most important in cases whose CO_2 emission reductions are imposed.

Reference: Reesburgh et al., in Global Atmosphere-Biosphere Chemistry, in press, 1995

RICE PRODUCTIVITY TO INCREASE WITH CHANGING CLIMATE, INCREASING EMISSIONS OF METHANE

Rice is one of the world's most important grain crops. However, rice cultivation is also the second strongest anthropogenic source of methane to the atmosphere, emitting about 20% of the total. New research is underway to develop new varieties of rice and to design and demonstrate improved rice cultivation practices that reduce methane emissions. Increased concentrations of atmospheric CO_2 are likely to enhance productivity of major rice varieties, providing more food, but also leading to greater emissions of methane. The associated climate changes are also predicted to substantially alter the relations between major insect pests of rice and their natural predators, potentially creating significant pest management problems. Research on new rice varieties and crop management practices are thus needed to enhance rice production without accelerating climate change.

Reference: Third Annual Internatinal Rice Research Institue (IRRI) Program Progress Report, EPA, Olszyk et al., 1995.

ESTABLISHING SHELTERBELTS CAN PROTECT CROPS FROM CLIMATE CHANGE

A model has been produced that describes crop yield on the Great Plains as a function of the presence or absence of shelterbelts. The model indicates that shelterbelts will increase yields of several crops under scenarios of increased temperature and decreased precipitation.

Reference: Assessment of Climate Change on a Mixed Agriculture Landscape on the North American Great Plains, Brandle, J.R., et al. pp. 15-18 in National Institute for Global Environmental Change (NIGEC) annual report, University of California, Davis, 1994.

NEW TECHNOLOGIES FOR MITIGATING GREENHOUSE GAS EMISSIONS FOUND TO BE COST-EFFECTIVE

A new cleanup process for generating electrical power by fuel cells from methane emitted by landfills has been evaluated and found to be a feasible way of capturing the benefit of "clean" energy production. This process enables the conversion of methane to CO_2, and, in effect, reduces the GWP of methane. Another promising technology to produce alternative transportation fuels (methanol) from biomass which appears cost-competitive with gasoline has been identified.

Reference: Landfill Gas Pretreatment for Fuel Cell Applications, Sandelli, G.J., J.C. Trocciola, and R.J. Spiegel, Journal of Power Sources, Vol. 49, pp. 143-149, 1994.

WORLD AGRICULTURE CAN BETTER ADAPT THAN PREVIOUSLY ESTIMATED IF CROP PRODUCTION CAN SHIFT

Agriculture is among those sectors of the economy that are most sensitive to climate change but there is also much evidence that farmers can adapt to a gradually changing climate through changes in crops and cultivars, tillage and harvesting practices, and planting schedules. While climate change like that simulated by $2xCO_2$ experiments of GCMs may cause crop yield losses that average 20 to 30 percent worldwide if there were no adaptation, if farmers successfully adapt to the changing climate conditions it may be possible to avoid much or all of this crop loss. Enhanced crop growth due to the direct effects of CO_2 on plant growth may contribute further to offsetting crop losses or to improvements in yield. Adaptation will involve large changes in the types of crops grown in different parts of the world and the net effects will vary widely depending on the region. Adaptation may also involve abandonment of production in some areas and expansion of production into new areas. When such expansion of cropping into new areas occurs it may further disrupt natural systems that may, by then, be suffering stress from climate change. Better data on global land resources, soil quality, weather and climate, and water resources are needed to further resolve the potential for agricultural production to be maintained under multiple stresses such as climate change, tropospheric ozone, acid deposition, soil degradation, and increasing competition for scarce freshwater resources.

References: (1) World Agriculture and Climate Change: Economic Adaptations, Darwin R., M. Tsigas, J. Lewandrowski, and A. Raneses, Agricultural Economic Report Number 703, Economic Research Service, USDA, 1995; (2) Potential Implications of Climate Change for U.S. Agriculture, ERS Staff Paper, Economic Research Service, USDA, forthcoming, H.M. Kaiser, S.J. Riha, D.S. Wilkes, and R. Sampath; (3) The Impact of Global Warming on Agriculture: A Ricardian Analysis, Mendelsohn R., W.D. Nordhaus, and D. Shaw, American Economic Review, vol. 84, No. 4, (Sept., 1994).

C. STRATOSPHERIC OZONE DEPLETION AND UV RADIATION

1. What new observational information is there about the depletion of stratospheric ozone?
2. What has been observed recently about the levels of ozone depleting compounds in the atmosphere?
3. What has been learned about the physical and chemical processes that lead to ozone depletion?
4. What new information is there about increased UV radiation at the surface?
5. What are some recent findings on the consequences and mitigation of stratospheric ozone depletion?

1. What New Observational Information is there about the Depletion of Stratospheric Ozone?

LOWEST CONCENTRATIONS OF OZONE MEASURED BY SATELLITE OVER THE SOUTH-CENTRAL U.S. DURING 1994

A combination of above normal temperatures and a persistent subtropical jet stream may be responsible for unusually low ozone concentrations over the south-central U.S. during November, 1994. The Total Ozone Mapping Spectrometer (TOMS) aboard the Meteor-3 satellite and the satellite-based TIROS Operational Vertical Sounder recorded the low ozone concentrations, as did ground-based instruments in North Carolina, Georgia, and Washington, D.C. Ground observations also confirmed that the low ozone persisted through December, although the concentrations were not as low as those in November.

During the previous winter, ozone concentrations appeared to have returned to the winter values seen prior to the eruption of Mt. Pinatubo.

Reference: NOAA Climate Analysis Center, U.S. Monthly Climate Summary, Weekly Climate Bulletin, Vol. 94, p. 5, November, 1994.

1993 OZONE MEASUREMENTS OVER ANTARCTICA CONFIRMED AS THE LOWEST ON RECORD

Data from the Total Ozone Mapping Spectrometer (TOMS) instrument on the Nimbus 7 satellite showed that globally averaged concentrations of total ozone had decreased to unprecedented low values beginning in mid-1992 and continuing through early 1993. The ozone hole over Antarctica produced the lowest values of ozone ever recorded in 1993. During the same period, record levels of UV light were measured at the surface in Antarctica. At one monitoring site, UV-B, the part of the spectrum believed to be the most harmful to living organisms, was recorded at levels 44 percent higher than in 1992. 1994 ozone concentrations were also reported to be as low as the 1993 concentrations.

References: (1) Record Low Ozone at the South Pole in the Spring of 1993, D. J. Hofmann et al., Geophysical Research Letters, Vol. 21, pp. 421-424, 1994,; (2) Ozone Measurements, in Scientific Assessment of Ozone Depletion, World Meteorological Organization Global Ozone Research and Monitoring Project Report 37, Geneva, Switzerland, 1995,.

LONGEST SATELLITE-BASED STRATOSPHERIC OZONE PROFILE DATA SET CREATED

The longest satellite-based ozone data set ever assembled has been created by combining observations from NASA's Solar Backscatter Ultraviolet Radiometer (SBUV) and NOAA's SBUV/2. The merged global data set covers the period 1978 to 1994 and is being used to evaluate global ozone trends. The data set of ozone vertical distribution obtained by the Solar Backscatter Ultraviolet (SBUV/2) instrument on the NOAA-11 operational meteorological satellite was reprocessed, leading to the currently available version (Version 6) data set.

Reference: Calibration of the NOAA 11 Solar Backscatter Ultra Violet (SBUV/2) Ozone Data Set from 1989 to 1993 Using Inflight Calibration Data and SSBUV, Hilsenrath E. et al., Journal of Geophysical Research, Vol. 100, pp. 1351-1366, 1995.

LIDAR, BALLOONS, AND SATELLITE MEASUREMENTS SHOW RESPONSE OF TROPICAL OZONE TO MT. PINATUBO ERUPTION

Data on tropical ozone amounts taken before and after the Mt. Pinatubo eruption (June, 1991) show that there were significant decreases in lower stratospheric ozone in the year following the eruption. By comparing ozone measurements taken from airborne lidar and balloon ozonesondes during September 1991 and May-August, 1992 with sonde and satellite data taken previously, these changes were quantified. In September, 1991, the reduction in the 16-28 km region was some 33% (29±9 Dobson Units, DU) from pre-Pinatubo amounts. Comparable changes (33±7 DU) were observed in the summer of 1992.

Reference: Aerosol-Associated Changes in Tropical Stratospheric Ozone Following the Eruption of Mount Pinatubo, Grant, W. B. et al., Journal of Geophysical Research, Vol. 99, pp. 8197-8211, 1994.

2. What has been Observed Recently about the Levels of Ozone Depleting Compounds in the Atmosphere?

SPACE SHUTTLE DATA SHOW LONG-TERM INCREASE IN CONCENTRATIONS OF STRATOSPHERIC HALOGENS

Observations of hydrogen chloride (HCl) and hydrogen fluoride (HF) in the upper stratosphere and lower mesosphere (altitude greater than 50 km) were carried out by the Atmospheric Trace Spectroscopy (ATMOS) sensor on the ATLAS-1 mission in March-April, 1992, and compared to measurements by the ATMOS instrument on the Spacelab-3 flight in April-May, 1985. At these altitudes, nearly all of the chlorine and fluorine atoms in the stratosphere are found in the form of HCl and HF, respectively, making these molecules good indicators of the total burdens of halogens in the stratosphere. Mixing ratios of 3.44 and 1.23 parts per billion by volume (ppbv) were obtained, corresponding to a 37% and 62% increase since the Spacelab-3 flight. The derived trend in HCl is in good agreement with the model-predicted increase in chlorine loading of 0.13 ppbv/year. This consistency lends further support to previous observations that the Mt. Pinatubo eruption did not deposit significant chlorine into the stratosphere. The fluorine increase can only be interpreted as being due to anthropogenic sources, such as CFCs, HCFCs, and halons.

Reference: Increase in Levels of Stratospheric Chlorine Loading Between 1985 and 1992, Gunson, M. R., et al., Geophysical Research Letters, Vol. 21, pp. 2223-2226, 1994.

THE RATE OF INCREASE OF CFCs IN THE ATMOSPHERE IS SLOWING

Global atmospheric measurements continue to confirm decreases in the growth rates of the ozone depleting chemicals CFC-11, CFC-12, and several halon compounds. The rates of increase in total organic chlorine and bromine in the troposphere have slowed significantly over the past few years. These measurements indicate that actions taken in response to the Montreal Protocol and its amendments are having the desired effect. Total stratospheric chlorine/bromine loading is expected to peak in the late 1990s, followed by a slow recovery of the ozone layer over the next few decades.

Reference: Decrease in the Growth Rates of Atmospheric Chlorofluorocarbons 11 and 12, Elkins, J. W., et al. Nature, Vol. 364, pp. 780-783, 1993.

FIRST GLOBAL DISTRIBUTION OF STRATOSPHERIC HYDROGEN FLUORIDE DETERMINED

Hydrogen fluoride (HF) is the end breakdown product of fluorine which reaches the stratosphere from industrial gases such as chlorofluorocarbons (CFCs) and hydrogen-containing CFCs (HCFCs). There are no natural sources of stratospheric hydrogen fluoride, so its presence in the stratosphere is a clear manifestation of the ability of CFCs and related molecules to reach the stratosphere. The Halogen Occultation Experiment (HALOE) instrument on UARS provided the first-ever global distribution of hydrogen fluoride in the stratosphere. Previous measurements of this quantity were exceedingly limited in spatial and temporal coverage, as well as vertical resolution (aircraft and ground measurements obtain only total column). The dynamical signatures in the observed HF fields show that in much of the atmosphere it serves as a conserved tracer. Amounts observed are significantly higher than those observed from space by the Atmospheric Trace Spectroscopy (ATMOS) instrument in 1985, corresponding to an exponential growth rate of 4.9-6.6%/year.

Reference: Observations of Stratospheric Hydrogen Fluoride by the Halogen Occultation Experiment (HALOE), Luo, M., R. Cicerone, J. M. Russell III, and T. Y. W. Huang, Journal of Geophysical Research, Vol. 99, pp. 16,691-16,705, 1994.

BIOMASS BURNING FOUND TO BE A SIGNIFICANT SOURCE OF METHYL BROMIDE, AN EFFICIENT DEPLETOR OF STRATOSPHERIC OZONE

Human initiated biomass burning is estimated to be a significant source of the emissions of methyl bromide globally. Because a bromine atom is about 40 times as efficient as a chlorine atom in destroying stratospheric ozone, understanding its emission sources is critical. Other major anthropogenic sources of methyl bromide include soil fumigation and exhaust from automobiles using leaded gasoline. Further research is needed to major uncertainties in quantifying methyl bromide sinks. Recent amendments to the Montreal Protocol call for a January 1, 1995 freeze in methyl bromide production at 1991 levels.

Reference: Emission of Methyl Bromide from Biomass Burning, Mano, S. and M. O. Andreae, Science Vol. 263, pp. 1255-1257, 1994.

3. What has been Learned about the Physical and Chemical Processes that Lead to Ozone Depletion?

NEW STUDIES OF THE CATALYTIC DESTRUCTION OF OZONE IN THE LOWER STRATOSPHERE SUGGEST A REORDERING OF THE CATALYTIC CYCLES

Recent in-situ observations (from ER-2 flights) suggest that nitrogen radicals may not be as dominant in the catalytic destruction of ozone in the lower stratosphere as previously thought. In addition, observations from the AASE II and SPADE airborne field experiments have shown that sulfate aerosols have quantitative effects on NOx chemistry in the lower stratosphere. These findings suggests a reordering of the catalytic cycles with primary importance on the reaction of ozone with HO_2, and increased importance of halogen-radicals (ClO and BrO) over that of NO_x in ozone depletion. In order to assess the environmental impacts on the ozone layer of anthropogenic emissions, such as nitrogen oxide effluent from supersonic transports, further research will be necessary to extend this quantitative ordering of ozone destruction cycles to a larger range of altitudes, latitudes and seasons and to understand how the system behaves in more homogeneous chemistry of the middle stratosphere.

Reference: Removal of Stratospheric O_3 by Radicals: In Situ Measurements of OH, HO_2, NO, NO_2, ClO, and BrO, Wennberg, P.O., et al., Science, Vol. 266, pp. 398-404, 1994.

LABORATORY STUDIES CONFIRM THAT HYDROFLUORO-CARBON SUBSTITUTES FOR CFCs POSE A NEGLIGIBLE THREAT AS A CATALYST FOR OZONE LOSS IN THE STRATOSPHERE

As chlorofluorocarbons (CFCs) are phased out in compliance with the Montreal Protocol and its amendments, hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs) have been proposed as substitutes. Many HFCs contain the functional group CF_3, which was considered to have a possible catalytic role in ozone depletion. Laboratory investigations have shown that the reaction cycles involving the CF_3 fragment are unimportant in the stratosphere and hence HFCs containing that functional group contain negligibly small ozone depletion potentials (ODP) (less than 0.0001). The results confirm that these compounds satisfy the requirements of the Clean Air Act Amendments that halocarbon substitutes have an ODP less than 0.2.

A combination of laboratory and computational studies has also verified that the Ozone Depletion Potential (ODP) of HFC-134a is very small, demonstrating that emissions of this substance destroy far less ozone than the CFCs it replaces. This puts to rest a recent hypothesis to the contrary, thus avoiding what would have been an unfounded halt in the use of this HFC in automobile air conditioners.

Reference: Do Hydrofluorocarbons Destroy Stratospheric Ozone?, Ravishankara, A.R., et al., Science, Vol. 263, pp. 71-74, 1994.

NEW SUBSTITUTE FOR OZONE-DEPLETING SUBSTANCES

Since the interim solutions, HCFCs (hydrochlorofluorocarbons), will be phased out in the future, attention needs to be paid to the environmental and economic consequences of any proposed substitutes.

Computer modeling, laboratory chemical and physical property evaluations, and performance evaluations of substitutes for HCFCs will be continued through future studies. These substitutes include pure chemicals, azeotropes, zeotropes, and non-chemical alternatives (also called not-in-kind substitutes). A major concern is the potential effects of substitutes on climate-related parameters.

References: (1) Predictions of Azeotropes from Fluorinated Ethers, and Propanes, Gage, C. L. and Kazachi, G. S., Proceedings of the 1992 International Refrigeration Conference, Purdue University, 1993; (2) Investigation of HFC-236fa as CFC-114 Replacements in High Temperature Heat Pumps, Kazachki, G. S., Gage, C. L., Hendriks, R. V. and Rhodes. W. J., 1994. Proceedings of the International Conference "CFC the Day After', Padova, Italy, 21-23, September 1994; (3) Evaluation of HFC-245fa as a potential Alternative for CFC-11 in Low Pressure Chillers, Smith, N.D. et al., Proceedings of the 1994 International CFC and Halon Alternatives Conference, Washington, D.C., 24-26, October, 1994.

STRATOSPHERIC NITRIC ACID EXPLAINS INTERHEMISPHERIC DIFFERENCES IN POLAR OZONE DEPLETION

The importance of denitrification in the catalytic destruction of ozone has become evident through a long sequence of ground-based, balloon-borne, and aircraft-borne studies. The presence of nitric acid (HNO_3) in the polar lower stratosphere affects the cumulative amount of chlorine-catalyzed ozone destruction in two major ways. First, in the low temperatures of polar winter, HNO_3 condenses to form polar stratospheric clouds (PSC) which trigger conversion of stratospheric chlorine to chemically-reactive forms that destroy ozone. Second, photolysis of HNO_3 releases NO_2 which quenches ClO and reduces ozone destruction. Removal of stratospheric HNO_3 either temporarily through condensation or permanently through the sedimentation of PSC particles, reduces the availability of NO_2 and allows chlorine to remain activated longer.

The Microwave Limb Sounder (MLS) aboard the Upper Atmospheric Research Satellite (UARS) has provided the first-time ever hemispheric observations of HNO_3 spanning the full winter season. Previously, nitric acid concentrations were either inferred from other in situ data or measured in snapshots from airborne instruments. MLS measurements of HNO_3, along with ClO and O_3 give a global set of simultaneous commonly calibrated data directly addressing the relationship between nitric acid and ozone depletion by chlorine chemistry.

A sizable decrease in HNO_3 is observed over Antarctica by early June and remains through November, during which time the Antarctic ozone hole forms. Similar losses of HNO_3 in the Arctic are less intense, more transient and localized. However, future cooling of the stratosphere due to increasing concentrations of greenhouse gases could lead to increased denitrification over the Arctic, leading to greater ozone depletion there.

Reference: Interhemispheric Differences in Polar Stratospheric HNO_3, H_2O, ClO, and O_3, Santee, M.L., et al., Science, Vol. 267, pp. 849-852, 1995.

CLIMATOLOGY OF POLAR STRATOSPHERIC CLOUDS DETERMINED FROM SATELLITE DATA

A climatology of polar stratospheric cloud (PSC) occurrence was determined using data from the Stratospheric Aerosol Measurement II (SAM II) instrument on the Nimbus 7 spacecraft over the period 1978 to 1989. PSCs are important because they provide the catalytic surfaces mainly responsible for high latitude ozone-depleting chemistry. The SAM II measures atmospheric extinction by using the solar occultation technique, and obtains data at high latitudes in both the Arctic and Antarctic. This climatology utilizes data from all years in this time period except times strongly perturbed by the El Chichon eruption in 1982 (Arctic in 1982, 1983; Antarctic in 1983). The PSC season in the Antarctic was shown to run from mid-May to early November, with a maximum zonal average PSC probability of 0.6 occurring in August at 18-20 km. In the Arctic, the PSC season is appreciably shorter, running from late November to early March, with a maximum probability of occurrence of 0.1 in early February at 20-22 km. There is considerable year-to-year variability in PSC occurrence in the Arctic, while in the Antarctic the main year-to-year variability is seen in the number of late season clouds. In both hemispheres the maximum frequency of PSCs occurs along the Greenwich meridian (90°E - 90°W). Temperatures associated with PSC formation remain constant over the Arctic winter, while they decline in the Antarctic in the 15-20 km region, consistent with dehydration and denitrification of the stratosphere.

Reference: Polar Stratospheric Cloud Climatology Based on Stratospheric Aerosol Measurement II (SAM II) Observations from 1978 to 1989, Poole, L. R. and M. C. Pitts, Journal of Geophysical Research, Vol. 99, pp. 13,083-13,089, 1994.

WINTERTIME POLAR VORTICES CALCULATED TO BE WELL ISOLATED FROM MID-LATITUDES

A significant uncertainty in studies of stratospheric chemistry is how much air is exchanged between the wintertime polar vortices and mid-latitudes. Since air inside the polar vortexes typically has very different chemical composition than air outside, significant transport and exchange of air could have important implications for mid-latitude ozone amounts. It is therefore critical that this exchange be quantified. Calculations by several investigators have shown exceedingly strong evidence, corroborated by several lines of observational data, that air inside the vortex is well isolated from air outside through most of the stratosphere (above approximately the 400° Kelvins potential temperature surface). In the Northern Hemisphere, the isolation of the vortex is much less complete in December and March (corresponding to vortex spin-up and breakdown, respectively) than it is in January and February, however.

References: (1) The Permeability of the Antarctic Vortex Edge, Chen, P., Journal of Geophysical Research, Vol. 99, pp. 20,563-20,571, 1994; (2) Climatology of Large-Scale Isentropic Mixing in the Arctic Winter Stratosphere from Analyzed Winds, Dahlberg, S. P. and K. P. Bowman, Journal of Geophysical Research, Vol. 99, pp. 20,585-20,599, 1994.

CALCULATIONS SHOW EVIDENCE OF STRONG DESCENT IN ARCTIC AND ANTARCTIC POLAR VORTICES

Observations have shown that there is appreciable descent inside winter polar vortices in both the Arctic and Antarctic, but it is difficult to infer quantitative rates and amounts of descent, as well as to demonstrate year-to-year ranges and comparisons between hemispheres. This is important because the amount of ozone in the stratosphere depends strongly on altitude. A set of calculations carried out using two techniques quantitatively analyzed this descent in the Arctic for the winters of 1988-89 and 1991-92 and in the Antarctic for fall-winter periods in 1987 and 1992. These calculations used temperature data from the National Meteorological Center along with radiative and trajectory codes. In the Northern Hemisphere, air parcels starting on November 1 inside the vortex at altitudes of 18, 25, and 50 km, by March 21 would have descended by 6, 9, and 27 km, respectively. In the Antarctic, air parcels starting on March 1 at those same altitudes would have descended by 3, 5-7, and 26-29 km by the end of October, respectively. The results for recent years are consistent with those from the Upper Atmosphere Research Satellite (UARS).

Reference: Computations of Diabatic Descent in the Stratospheric Polar Vortices, Rosenfield, J. E. et al., Journal of Geophysical Research, Vol. 99, pp. 16,677-16,689, 1994.

4. What New Information is there about Increased UV Radiation at the Surface?

SATELLITE OZONE DATA USED TO INFER SURFACE ULTRAVIOLET RADIATION AMOUNTS

Most of the interest in stratospheric ozone amounts has come from the role which it plays in absorbing ultraviolet radiation that would otherwise reach the Earth's surface. While ozone amounts have been well characterized from both space- and ground-based platforms, the available data set of high quality surface ultraviolet radiation measurements is much more limited. The possibility of using space-based measurements to infer this quantity holds out the possibility of dramatically increasing our knowledge of the distribution of surface UV radiation and how it has changed with time. Scientists have recently developed an algorithm relating radiances measured by the Total Ozone Mapping Spectrometer (TOMS) instruments to ultraviolet radiation reaching the Earth's surface. The algorithm, which applies to both cloud-free and cloudy scenes, was tested by comparisons with the Brewer spectrophotometer in Toronto, Canada. For example, the agreement between the inferred and measured UV irradiance at 310 nm for the time period April - November 1990 corresponds to a root mean square difference of only 6.0% averaging over a half month.

Reference: Satellite Estimation of Spectral UVB Irradiance Using TOMS Derived Total Ozone and UV Reflectivity, Eck, T. F. et al., Geophysical Research Letters, Vol. 22, pp. 611-614, 1995,.

FEDERAL AGENCIES WORK TOGETHER TO CREATE A UV MONITORING NETWORK AND TO ISSUE UV INDEX

Federal agencies, including USDA, EPA, National Biological Service (NBS), NSF, NASA, the Smithsonian, and NIST and NOAA in the Department of Commerce have formed an interagency panel under the USGCRP to develop a national network for UV monitoring. The panel is developing a quality assurance program to ensure that all UV measurements from the network will be inter-comparable and of known accuracy and precision The first US government wide instrument intercomparison was held last September. Since June, 1994, a national UV Index has been issued for 58 cities across the US.

Reference: The U.S. Interagency UV Monitoring Plan, USGCRP-95-01, 1995

5. What are some Recent Findings on the Consequences and Mitigation of Stratospheric Ozone Depletion?

INCREASES IN UV RADIATION CONFIRMED TO BE AN IMPORTANT PUBLIC HEALTH PROBLEM

One of the side-effects of depletion of the Earth's ozone layer is the increase in ultraviolet radiation (UV) reaching the Earth's surface. What then is the impact of UV radiation on skin cells? Scientists have recently discovered that the vast majority of grainy lesions that are often a precursor of skin cancer found on sun-exposed patients, had the kind of p53 gene mutations that are found in squamous cell carcinoma, a common form of skin cancer. By using animal studies, it was shown that UV radiation can act in two ways to cause the development of cancer. First, UV radiation mutates the p53 tumor-suppressing gene. Second, by stimulating cells with healthy p53 genes to kill themselves, UV radiation helps to select cells that have a greater chance of becoming cancerous. Thus, sunlight can act twice: as a tumor initiator and tumor enhancer.

Reference: Sunburn and p53 in the Onset of Cancer, Ziegler, A., A. S. Jonason, D. J. Leffell, J. A. Simon, H. W. Sharma, J. Kimmelman, L. Remington, T. Jacks, and D. E. Brash, Nature, Vol. 372, pp. 773-777, 1994.

ICE COVER IN THE ANTARCTIC MAY PROTECT PHYTOPLANKTON FROM ADVERSE IMPACTS OF INCREASED UVB

It has previously been suggested that increased springtime UVB radiation caused by stratospheric ozone depletion is likely to reduce primary production and induce changes in the species composition of Antarctic marine phytoplankton. Experiments conducted in the Arctic revealed a reduction in primary productivity at present and increased levels of UVB. Laboratory studies have also shown that most plankton species under laboratory conditions are sensitive to high UVB levels, although the level at which growth or photosynthesis is inhibited is variable. Stratospheric ozone depletion, with resultant increased springtime UVB irradiance, has been occurring with increasing severity since the late 1970's. The phytoplankton community has therefore been exposed to increased levels of UVB for 20 years. Recent findings from assemblages of dead phytoplankton shells indicate that compositional changes in the diatom (phytoplankton with silicon shells) component of phytoplankton cannot be distinguished from long-term natural variability, although there is evidence of a decline in the production of some sea-ice diatoms. These results suggest that in places in the Antarctic coastal region where ice cover is thick, and the timing of the phytoplankton bloom does not coincide with increased levels of springtime UVB radiation, these phytoplankton are less affected by increased UVB radiation. These results do not suggest that increased UV is not a concern for phytoplankton outside these regions.

Reference: Minimal Effects of UVB Radiation on Antarctic Diatoms Over the Past 20 Years, McMinn, A. H. Heljnis, and D. Hodgson, Nature, Vol. 370, pp. 547-549, 1994.

OZONE DEPLETORS AND THEIR SUBSTITUTES BROKEN DOWN BY SOIL MICROBES

Potentially toxic by-products of ozone-destroying chlorofluorcarbons (CFCs), appear to be decomposed into harmless products by microbes found in some soils. The reactivity of the CFC alternatives has raised concerns that their degraded by-products might be harmful to the environment and life. The findings of this work indicate that certain bacteria found in some lakes and salt marsh bottoms can render some potentially dangerous CFC by-products harmless.

Reference: Degradation of Trifluoroacetate in Oxic and Anoxic Sediments, Visscher, P. T., Culbertson, C. W., and Oremland, R. S., McMinn, A., H. Heljnis, and D. Hodgson, Nature, Vol. 369, p. 729-731, 1994.

SOME FISH FOUND TO BE ESPECIALLY TOLERANT TO INCREASES IN UV RADIATION

Certain fish are very tolerant of increased levels of UV-B radiation associated with the depletion of the ozone layer. Other fish, such as the endangered Lahontan cutthroat trout, are injured at current levels of UV-B solar radiation. Skin from UV-B tolerant fish has up to four times the amount of photoprotective factor than that of sensitive species of fish. This factor may well serve as a bio-marker for susceptibility to UV-B radiation among diverse species from a variety of ecosystems.

Reference: Skin Component May Protect Fish from Ultraviolet-B Radiation, Fabacher, D. L., and E. E. Little, Environmental Science and Pollution Research, in press, 1995.

1994 SCIENCE ASSESSMENT ON OZONE DEPLETION PUBLISHED

The latest science assessment on stratospheric ozone depletion prescribed under the provisions of Article 6 of the Montreal Protocol on Substances that Deplete the Ozone Layer has been published. This report, prepared under the international auspices of the World Meteorological Organization and the United Nations Environment Program, has chapters devoted to Ozone Measurement; Source Gases: Trends and Budgets; Polar Ozone; Tropical and Mid-Latitude Ozone; Tropospheric Ozone; Model Simulations of Stratospheric Ozone; Model Simulations of Global Tropospheric Ozone; Radiative Forcing and Temperature Trends; Surface UV Radiation; Methyl Bromide; Subsonic and Supersonic Aircraft Emission; Atmospheric Degradation of Halocarbon Substitutes; and Ozone Depletion Potentials, Global Warming Potentials and Future Chlorine-Bromine Loading.

Reference: Scientific Assessment of Ozone Depletion: 1994, World Meteorological Organization, Geneva, Report 37, 1995.

D. CHANGES IN LAND COVER AND TERRESTRIAL AND MARINE ECOSYSTEMS

1. What new research is there on monitoring land-cover change ?
2. What are some of the effects of land-cover and land-use changes?

1. What New Research is there on Monitoring Land-Cover Change ?

NEW MAPS OF GLOBAL LAND COVER

Although new conventional maps of vegetation and land cover are being generated at the local and national levels, the distribution of global land cover and vegetation types at any one time is poorly known. For large areas of the world, maps of land cover are often out of date, inaccurate or at a scale inappropriate for global change studies. Ecosystem process models currently require a classification of land cover types. Coarse resolution multi-temporal satellites provide a means for generating up-to-date global and regional data sets. Improved global data sets from the Advanced Very High Resolution Radiometer (AVHRR) are being made available to the science community. Daily global orbit data are being processed and compiled into time series data sets at scales ranging from one degree to one kilometer. Phenological differences represented by vegetation indices from the satellite data are being used to discriminate different vegetation types. Multi-spectral data are also being used to discriminate different land cover types. Validation of these new global maps is being undertaken by the use of sample high resolution data. The U.S. is also currently contributing to an international global 1 km land cover data set production and validation effort coordinated by the IGBP.

Reference: NDVI-Derived Land Cover Classifications at a Global Scale, Defries, R. S., and J. R. G. Townshend, International Journal of Remote Sensing, Vol. 15, pp. 3567-3586, 1994.

OVERVIEW OF THE AREAL EXTENT AND GEOGRAPHIC PATTERN OF EXTREME ANTHROPOGENIC PERTURBATIONS OF THE TERRESTRIAL BIOSPHERE

Since the development of agriculture some 9000 years ago, an ever-increasing proportion of the Earth's surface has been expropriated for the production of food crops. Conversion to cultivated systems has resulted in wholesale restructuring of biotic communities and the pathways of energy and nutrient flow that they control. The table below summarizes the areal extent and geographical pattern of extreme anthropogenic perturbations of the terrestrial biosphere. Sisk et al. (pp. 592-604) argue that species extinctions are most likely to occur where such areas coincide with high biological diversity. Attempts to identify areas of broad and intense perturbation of native habitats should be an integral part of any effort to identify priority areas for conservation.

BREAKDOWN BY VEGETATION CLASS

Class	Pre-agricultural area (square kilometers)	Post-agricultural area (square kilometers)	Percentage converted to agriculture
Forest	49,992,600	42,100,100	15.79
Woodland	12,334,000	10,440,000	15.36
Shrubland	13,163,700	12,143,000	7.75
Tundra	7,294,000	7,294,000	0.00
Grassland	34,150,500	27,197,650	20.36
Desert	15,910,000	15,580,000	2.07
Cultivation		18,090,050	
Total ice-free land area	**132,844,800**	**132,844,800**	**13.62**

Reference: Mapping Human Impacts on the Global Biosphere, Imhoff, M. L., BioScience, Vol. 44, p. 598, 1994.

GLOBAL LAND COVER ANALYSIS BY SATELLITE

A simple new logic for classifying vegetation using satellite data is a crucial step towards characterizing the Earth's biosphere for input into general circulation models. This classification is based on fundamental, morphological aspects of the vegetation, such as leaf shape and longevity. It is a classification that lends itself easily to biophysical measurements, such as leaf area index and total biomass. The data source is the 1 km Advanced Very High Resolution Radiometer (AVHRR).

Reference: A Remote Sensing Based Vegetation Classification Logic for Global Land Cover Analysis, Running, S. W., T. R. Loveland, L. L. Pierce, R. R. Nemani, and E. R. Hunt, Jr., Remote Sensing of the Environment, Vol. 51, pp. 39-48, 1995.

BIOMASS DENSITY INFERRED OVER NUMEROUS TEST SITES USING A NEW SATELLITE REMOTE SENSING ALGORITHM

A new satellite remote sensing algorithm is used to infer a group of forest biophysical characteristics key to studies of land-use change, energy, water and carbon cycling in communities of black spruce (Picea mariana), the most common boreal forest dominant. The algorithm is based on geometric radiative transfer models and spectral linear mixing models. The algorithm infers values for the sunlit canopy fraction, sunlit background fraction and shadow fraction in forest stands, based on their visible and near infrared reflectance in Thematic Mapper bands 3 and 4. Using relations between these fractions and the stand biophysical characteristics, biomass density is inferred over 31 test sites, with very good results.

Reference: Remote Sensing of Forest Biophysical Structure in Boreal Stands of Picea Mariana Using Mixture Decomposition and Geometric Reflectance Models, Hall, F. G., Y. E. Shimabukuro, and K. F. Huemmrich, Ecological Applications, in press, 1995.

THE CHANGE IN CLOSED CANOPY CONIFEROUS FOREST DUE PRIMARILY TO CLEAR CUTTING WAS GREATEST IN THE PRIVATE LAND AND LEAST IN PUBLIC RESERVES

The process of fragmentation was examined in a managed forest landscape by comparing rates and patterns of disturbance (primarily clear-cutting) and regrowth between 1972 and 1988 using Landsat imagery. A 2589 square kilometer managed forest landscape in western Oregon was classified into two major forest types, closed-canopy conifer forest (CF - typically greater than 60% conifer cover) and other forest and nonforest types (OT - typically less than 40-year-old or deciduous forest).

The percentage of CF declined from 71% to 58% between 1972 and 1988. Declines were greatest on private land, least in public reserves, and intermediate in public nonreserves. High elevations (greater than 914 meters) maintained a greater percentage of CF than lower elevations (less than 914 meters). The percentage of the area at the edge of the two cover types increased on all ownerships and in both elevational zones, whereas the amount of interior habitat (defined as CF at least 100 meters from OT) decreased on all ownerships and elevational zones. By 1988 public lands contained roughly 45% interior habitat while private lands had 12% interior habitat. Mean interior patch area declined from 160 to 62 hectares. The annual rate of disturbance (primarily clear-cutting) for the entire area was 1.19%, which corresponds to a cutting rotation of 84 years. The forest landscape was not in a steady state or regulated condition, a situation that is not projected to occur for at least 40 years under current forest plans. Variability in cutting rates within ownerships was higher on private land than on nonreserve public land. However, despite the use of dispersed cutting patterns on public land, spatial patterns of cutting and remnant forest patches were nonuniform across the entire public ownership. Large remaining patches (less than 5000 hectares) of contiguous interior forest were restricted to public lands designated for uses other than timber production such as wilderness areas and research natural areas.

Reference: Dynamics and Pattern of Managed Coniferous Forest Landscape in Oregon, Spies, T. A., W. J. Ripple, and G. A. Bradshaw, Ecological Applications, Vol. 4, pp. 555-568, 1994.

A NEW APPROACH TO MONITORING DEFORESTATION AND URBANIZATION

Thermal infrared surface temperature measurements, in conjunction with remote measurements of vegetation index, are being used for the first time to study changes in surface hydroclimate brought about by urbanization or deforestation. Two land surface parameters, the surface moisture availability and the fractional vegetation cover, are obtained from satellite measurements. These parameters, varying within numerical limits of zero to one, are useful in two ways. First, they reflect most of the variation in the turbulent heat flux between the land surface and atmosphere; as such, they constitute robust measures as key input quantities in climate models. Second, the two parameters, being sensitive to changes in the land surface cover, serve as joint indices of urbanization and deforestation. Thus, baseline images of these parameters can be created and their evolution charted over periods such as a decade or more. Consequently, changes in land surface character can be monitored. Studies over target areas in Pennsylvania (urbanization) and Costa Rica (deforestation) have been initiated using these parameters to monitor changes in land use.

Reference: Thermal Remote Sensing of Surface Soil Water Content with Partial Vegetation Cover for Incorporation into Climate Models, Gillies, R. R., and T. N. Carlson, Journal of Applied Meteorology, 34, 745-756, 1995.

FOREST FRAGMENTATION STUDIES SUGGEST CARBON FLUXES FROM THE BRAZILIAN AMAZON MAY HAVE BEEN OVERESTIMATED

Landsat satellite imagery was used to measure deforestation and forest fragmentation for 1978 and 1988 in the Brazilian Amazon Basin. The deforestation was concentrated in a crescent along the southern and eastern fringe of the Amazon forest. The area deforested increased from 78,000 square km to 230,000 square km from 1978 to 1988. This result agrees closely with independently derived estimates made by the Brazilian Space Agency (INPE) and is lower than a number of recent estimates in the published literature. It also demonstrated the previous estimates based on coarse resolution (AVHRR) satellite data overestimated Brazilian deforestation by about 50 percent. These estimates will be used to refine assessments of net flux of carbon from land clearing and biomass burning. Model estimates based on higher deforestation values are probably too high. In addition, many deforested areas are in stages of regrowth following abandonment, and if this regrowth is widespread, estimates of net carbon flux may need to be further reduced because of carbon accumulation in this regrowing biomass. Work to produce similar estimates for other parts of the humid tropics continues under the multi-agency Landsat Pathfinder Program.

In this same study, fragmented forest was also estimated. Fragmented forest was defined as areas of less than 100 square km surrounded by deforestation, and edge effects of 1 km into forest from adjacent areas of deforestation. The area of fragmented forest increased from 162,000 square km to 588,000 square km. This much larger area that is impacted by deforestation has serious implications with regard to other land-atmosphere interactions as well as biological diversity.

Reference: Tropical Deforestation and Habitat Fragmentation in the Amazon: Satellite Data from 1978 to 1988, Skole, D., and Compton Tucker, Science, Vol. 260, pp. 1905-1910, 1993.

2. What are some of the Effects of Land-Cover and Land-Use Changes?

DEMONSTRATION OF THE POTENTIAL FOR CARBON SEQUESTRATION AT GLOBAL SCALES USING FOREST REGENERATION OR BY SLOWING DEFORESTATION

Forest systems cover more than 4.1 billion hectares of the Earth's land area. Globally, forest vegetation and soils contain about 1150 billion tones (GtC) of carbon, with approximately 37% of this carbon in low-latitude forests, 14% in mid-latitudes, and 49% at high latitudes. Over two-thirds of the carbon in forest ecosystems is contained in soils and associated peat deposits. In 1990, deforestation in the low latitudes emitted 1.6 GtC per year, whereas forest area expansion and growth in mid- and high-latitude forests sequestered 0.7 GtC of carbon per year, for a net flux to the atmosphere of 0.9 GtC of carbon per year. Slowing deforestation, combined with an increase in forestation and other management measures to improve forest ecosystem productivity, could conserve or sequester significant quantities of carbon. Future forest carbon cycling trends attributable to losses and regrowth associated with global climate and land-use change are uncertain. Model projections and some results suggest that forests could be carbon sinks or sources in the future.

Reference: Carbon Pools and Flux of Global Forest Ecosystems, Dixon, R. K., S. Brown, R. A. Houghton, A.M. Solomon, M. C. Trexler, and J. Wisniewski, Science, Vol. 263, p. 185-190, 1994.

NEW STUDIES SUGGEST THAT PRECISION FARMING CAN CONTRIBUTE TO CLIMATE PROTECTION

The soil carbon in agricultural lands of the world is an important consideration to researchers trying to understand relationships between land use and climate change. It is generally thought that the conversion of natural ecosystems to agriculture results in the release of approximately 0.6 - 3.6 GtC/yr to the atmosphere as carbon dioxide (CO_2). Generally, the tilling of soil associated with agriculture leads to increased oxidation of soil organic matter. However, field experiments at specific locations have demonstrated that there is a potential for reducing soil carbon losses from cultivated soils through changes in agricultural practices. For example, reduced or no-till methods, use of cover crops, and manure amendments can sometimes increase soil carbon levels and enhance soil fertility while maintaining crop yield.

A newly developed, process-based model of carbon and nitrogen in agricultural soils now allows both site-specific and large-scale evaluations of the quantitative impacts of changes in agricultural practices on soil carbon dynamics and CO_2 emissions from agricultural soils. The results, for a variety of climate and soil conditions, showed that the best protection against soil carbon loss is manure amendments; however, the results were very sensitive to soil texture. Increased nitrogen fertilization and reduced tillage generally enhanced the retention of soil carbon. The ultimate soil organic content is sensitive to climate and increases with decreasing soil temperature, increasing clay content, nitrogen fertilization, manure amendments and crops with higher residue yields. Efforts to enhance carbon retention and buildup in agricultural soils require comprehensive understanding of soil biogeochemical dynamics.

Reference: Modeling Carbon Biogeochemistry in Agricultural Soils, Li, C., S. Frolking, and R. Harriss, Global Biogeochemical Cycles, Vol. 8, pp. 237-254, 1994.

HUMAN ENGINEERING OF FRESH WATER SYSTEMS MAY BE CONTRIBUTING TO SEA LEVEL RISE

Global compilations of tide records indicate that sea level has been rising throughout the twentieth century, with potentially serious consequences for low coastal areas if the rate of rise continues. Thermal expansion of ocean water, as well as the melting of alpine glaciers, are responsible for some of this change, but human activities such as ground water withdrawal, surface water diversion, and land-use changes may also have influenced sea level directly. Sea level is suggested to have risen 10 to 25 centimeters (cm) this century, of which about 1 cm (range -5 to +7 cm) may have been due to the direct effects of humans in changing land use. This rise in sea level would have been about 50% larger if large quantities of water had not been stored in reservoirs and channeled into aquifers by irrigation projects. Human activity also affects the water storage capacity of soils, forests, and wetlands. These and other human activities appear to have caused the net increase in sea level over this past century. The combination of ground water withdrawal, surface water diversion, and land-use changes has caused at least a third of the observed rise in sea level. This work suggests that we need to continually monitor and manage the movement of fresh water.

Reference: Direct Anthropogenic Contributions to Sea Level Rise in the Twentieth Century, Sahagian, D. L., F. W. Schwartz, and D. K. Jacobs, Nature, Vol. 367, p. 54-57, 1994.

FIRE DISTRIBUTION AND ASSOCIATED EMISSIONS

Fire is an important ecosystem process and one which is poorly documented in the tropical world. Distributions of fire as a disturbance regime are needed as input for ecosystem process models. The extent of burning and change in the frequency of fire will have implications for the inventory of emissions and global biogeochemical cycles. Daily coarse resolution satellite data are being used to monitor the occurrence of fire and its timing in the southern African savannas. High resolution satellite data are being used to validate the fire maps and calibrate the data to derive improved estimates of total area burned over a yearly cycle. When linked to models of fuel load and ground measurements of emission factors these data can be used to generate improved estimates of trace gas and particulate emissions. The improved availability of global multiyear satellite data sets means that such information can now be provided on an annual basis.

Reference: Emissions of Trace Gases and Aerosol Particles Due to Vegetation Burning in Southern Hemisphere Africa, Scholes, R. J., D. Ward, and C.O. Justice, Journal of Geophysical Research, in press, 1995.

SOIL ORGANIC CARBON IN THE U.S. FOUND TO HAVE INCREASED SINCE 1950

A study of soil carbon in agricultural ecosystems of the United States (40% of the land area and 60-70% of the agricultural cropland of the U.S.), has been conducted using the CENTURY model for a 124-year simulation (1907-2030). The results suggest that there was a continuous decrease in soil organic carbon following land conversion to agriculture in 1907, that this ended 1950, and was followed by a slight increase in soil organic carbon through 1970. Significant soil organic carbon increases are expected through 2030. It was also found that conservation tillage practices can significantly increase soil carbon, but the impacts are highly variable from region to region. Cover crops were found to lead to significant increases in soil carbon in crop soil and climate regimes where they are feasible and appropriate, especially in the southern and eastern regions of the U.S.

Reference: Alternative Management Practices Affecting Soil Carbon in Agroecosystems of the Central U.S., Donigian, A. S., T. O. Barnwell, Jr., R. B. Jackson IV, A. S. Patwardhan, K. B. Weinrich, A. L. Rowell, R. V. Chinnaswamy, and C.V. Cole, EPA Report 600/R-94/067, 1994.

SURVEYS OF TROPICAL FORESTS FIND THAT THEY ARE CHANGING MUCH MORE RAPIDLY NOW THAN THEY HAVE IN THE PAST

The measured turnover rate of tropical forest trees since 1934 suggests that there has been a significant increase in forest turnover since about 1960. The increase appears to have been accelerated during the 1980s. The likely cause is environmental changes from increased extreme weather events, adjacent deforestation, and elevated productivity that has resulted from increased atmospheric CO_2. This increased turnover rate has implications for tropical biodiversity and possibly for the tropical carbon cycle. Faster forest turnover could lead to a dominance of climbing plants and gap-dependent tree species, which are most likely to benefit from increased CO_2. Many of these species have less dense wood than shade-tolerant species, suggesting that tropical forests could eventually become less of a sink for carbon than they are currently.

Reference: Increasing Turnover Through Time in Tropical Forests, Phillips, O. L., and A. H. Gentry, Science, Vol. 263, pp. 954-958, 1994.

APPENDIX A

The Proposed USGCRP Budget for Fiscal Year (FY) 1996

The FY 1996 interagency budget request for the USGCRP remains roughly constant at the FY1995 level of about $1.8 billion. The core USGCRP activities focus on developing a predictive understanding of climate change, stratospheric ozone depletion, natural variations in climates over seasons to years, and large-scale changes in global land cover and in terrestrial and marine ecosystems.

For comparison with earlier years, several changes deserve attention. Coincident with the establishment of the Committee on Environment and Natural Resources, NOAA now includes global change funding for the NOAA fleet of oceanographic vessels, the NOAA Corps that crews these vessels, the NOAA laboratories, and the National Undersea Research Program within the USGCRP budget. For FY 1995 and FY 1996, these expenses add $60.7M and $60.9M, respectively, to the Department of Commerce and to the overall USGCRP budget. For the Smithsonian Institution and EPA, several programs that were included in last year's total are now included under the purview of other CENR subcommittees and do not appear here. Another important adjustment has been made to recognize that NASA has assumed more responsibility for the Landsat program. As a result of these changes, comparisons with earlier fiscal years require a careful, program-by-program analysis. Such information is available upon request from the Office of the USGCRP.

In addition to the focused USGCRP budget request which follows, the President's full FY 1996 global change budget request of about $2.15B includes funding proposed for NASA launch and satellite costs (about $50M in FY 95 and $80M in FY 96) and funding for DOE environmental technologies (about $245M in each year) and other minor additions related to programs within the Department of Transportation and the USDA.

Figure A

FY 1995-1996 U.S. Global Change Research Program

Budget by Agency
(Dollars in Millions)

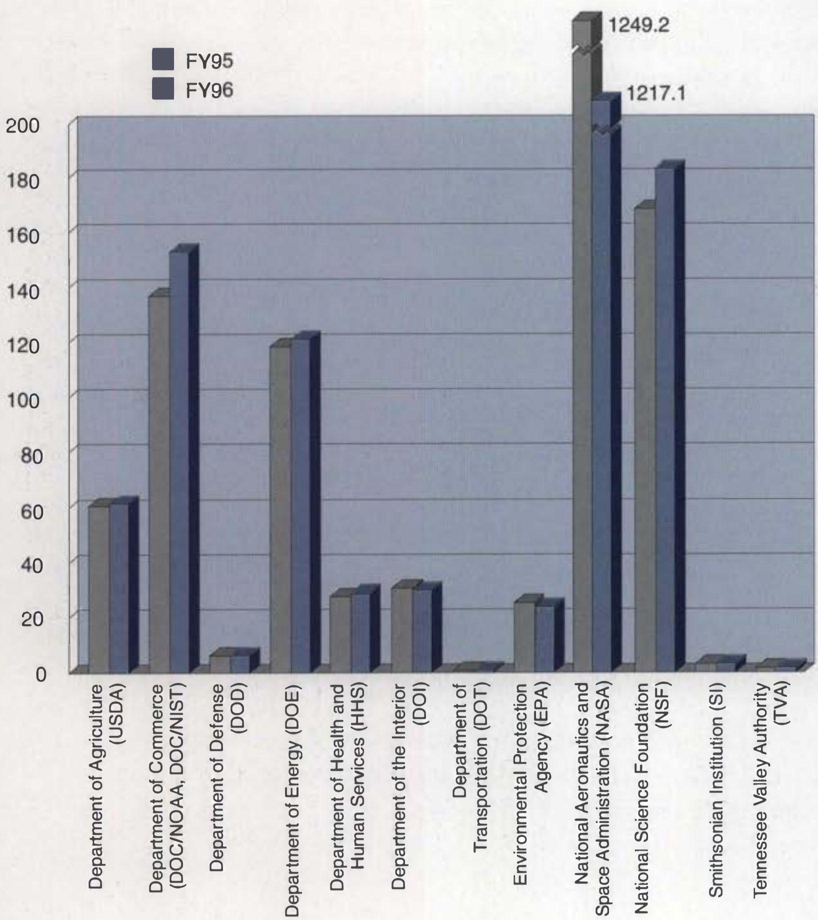


Figure B

FY 1995-1996 U.S. Global Change Research Program

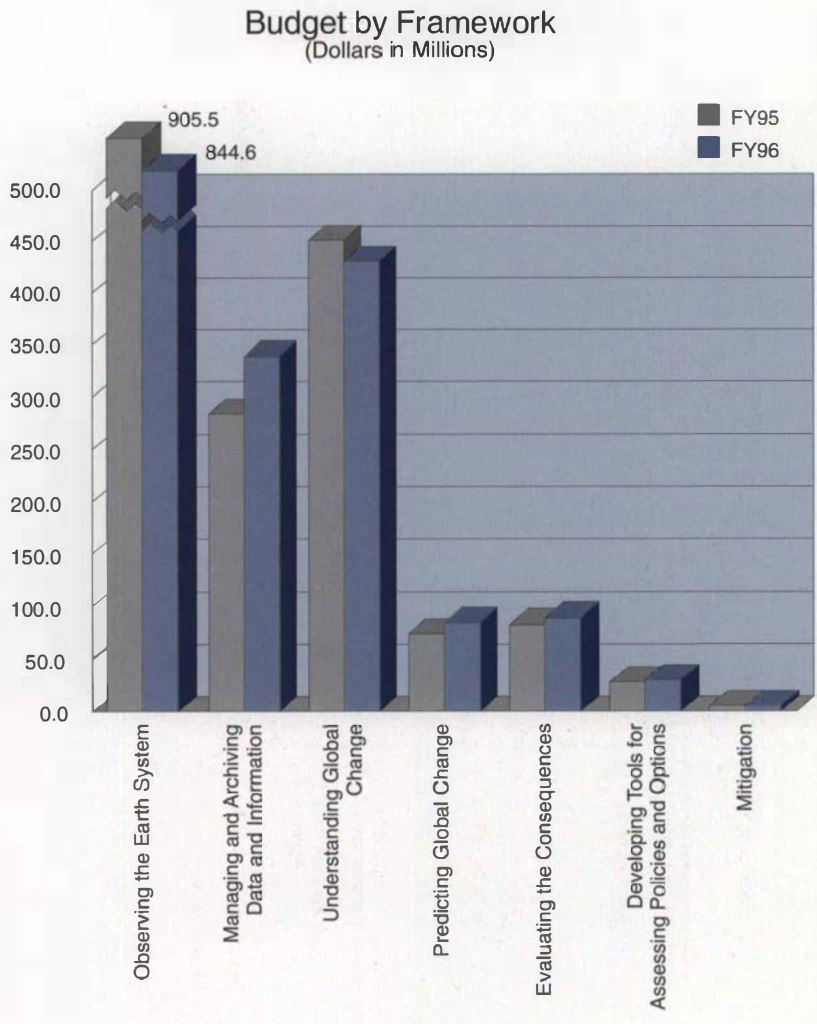


Table A

FY 1995-1996
U.S. Global Change Research Program

Budget by Agency
(Dollars in Millions)

AGENCY	FY95	FY96
Department of Agriculture (USDA)	60.9	61.5
Department of Commerce (DOC/NOAA, DOC/NIST)	136.8	153.0
Department of Defense (DOD)	6.4	6.4
Department of Energy (DOE)	117.6	122.8
Department of Health and Human Services (HHS)	27.5	28.8
Department of the Interior (DOI)	30.4	30.0
Department of Transportation (DOT)	0.5	0.5
Environmental Protection Agency (EPA)	25.7	23.4
National Aeronautics and Space Administration (NASA)	1249.2	1217.1
National Science Foundation (NSF)	169.0	183.4
Smithsonian Institution (SI)	2.8	2.8
Tennessee Valley Authority (TVA)	1.2	1.2
TOTAL BUDGET	**1827.7**	**1830.9**

Table B

FY 1995-1996
U.S. Global Change Research Program

Budget by Framework
(Dollars in Millions)

FRAMEWORK ELEMENT	FY95	FY96
Observing the Earth System		
Space-Based Observing and Analysis	815.5	748.8
Ground-Based Augmentations of Operational Systems	90.0	95.8
Subtotal for Observing	905.5	844.6
Managing and Archiving Data and Information	283.1	342.9
Understanding Global Change	450.2	433.8
Predicting Global Change	73.7	85.8
Evaluating the Consequences	86.5	91.1
Developing Tools for Assessing Policies and Options	26.0	29.8
Mitigation	3.0	3.0
TOTAL BUDGET	**1827.7**	**1830.9**

Table C

FY 1995-1996 U.S. Global Change Research Program

Budget by Framework and Agency

(Dollars in Millions)

	Total Budget		Observing the Earth System Space-based		Observing the Earth System Ground-based		Managing Data and Information		Understanding Processes		Predicting Change		Evaluating Consequences		Assessing Policies and Options		Mitigation	
Agency	**1995**	**1996**	**1995**	**1996**	**1995**	**1996**	**1995**	**1996**	**1995**	**1996**	**1995**	**1996**	**1995**	**1996**	**1995**	**1996**	**1995**	**1996**
Agency Totals	**1,827.7**	**1,830.9**	**815.5**	**748.8**	**90.0**	**95.8**	**283.1**	**342.9**	**450.2**	**433.8**	**73.7**	**85.8**	**86.5**	**91.1**	**26.0**	**29.8**	**3.0**	**3.0**
DOC	136.8	153.0			73.1	77.0	5.8	4.7	37.2	42.5	15.2	23.3	1.6	1.6	1.3	1.3	2.6	2.6
DOD	6.4	6.4							4.7	4.7	1.7	1.7						
DOE	117.6	122.8			1.2	1.2	1.9	2.3	73.4	75.5	23.5	26.0	8.8	8.9	8.8	8.9		
DOI	30.4	30.0			3.6	3.6	9.5	9.4	12.1	11.9	0.6	0.6	4.6	4.5				
DOT	0.5	0.5											0.5	0.5				
EPA	25.7	23.4			0.8	0.9	0.5	0.5	10.5	7.4	5.3	4.0	8.6	10.6				
HHS	27.5	28.8											27.5	28.8				
NASA	1,249.2	1,217.1	815.5	748.8			264.0	324.6	154.7	129.9	11.0	9.9	4.0	3.9				
NSF	169.0	183.4			7.3	7.3	1.4	1.4	113.1	118.6	16.4	20.3	15.7	17.0	15.1	18.8		
SI	2.8	2.8			1.0	1.0			1.8	1.8								
TVA	1.2	1.2			0.7	0.7			0.1	0.1							0.4	0.4
USDA	60.9	61.5			2.2	4.1			42.7	41.5			15.2	15.2	0.8	0.8		

Table D

FY 1995-1996
U.S. Global Change Research Program

Budget by Budget Function
(Dollars in Millions)

BUDGET FUNCTION	Budget Function Numbers	FY95	FY96
National Defense (DOD)	50	6.4	6.4
General Science, Space & Technology	250		
National Aeronautics and Space Administration (NASA)		1,249.2	1,217.1
National Science Foundation (NSF)		169.0	183.4
Energy	270		
Department of Energy (DOE)		117.6	122.8
Tennessee Valley Authority (TVA)		1.2	1.2
Natural Resources & Environment	300	136.8	153.0
Department of Commerce (DOC)/NOAA & NIST			
Department of Interior (DOI)		30.4	30.0
Environmental Protection Agency (EPA)		25.7	23.4
Department of Agriculture (FS & NRCS)		23.5	23.5
Agriculture	350	37.4	38.0
Department of Agriculture (USDA)			
Department of Transportation (DOT)	402	0.5	0.5
Smithsonian Institution (SI)	503	2.8	2.8
Health	550	27.5	28.8
Department of Health and Human Services (HHS)			
TOTAL BUDGET		**1827.7**	**1830.9**

APPENDIX B

Fiscal Year 1995-1996 USGCRP Budget by Program

The allocation of resources by program reflected in this table are estimates only and are subject to change based on discussions of scientific and programmatic priorities among CENR agencies, their individual advisory mechanisms, and the input of the national and international scientific communities.

These budgets are for programs included in the focused budget of the USGCRP. In addition to these programs, the agencies conduct a broad range of additional activities, the results of which provide important contributing information for the USGCRP. A general description of focused and contributing programs in each of the agencies is also provided.

Department of Agriculture

Areas of Global Change Research. Ground-based research sponsored by USDA focuses on understanding terrestrial systems and the effects of global change (including water balance, atmospheric deposition, vegetative quality, and UV-B radiation) on food and fiber production in agricultural, forest and range ecosystems. It includes research on interactions between terrestrial ecosystems and the atmosphere; the contributions of agricultural sources of methyl bromide to stratospheric ozone depletion and possible alternatives and substitutes for this fumigant; methane generation and nitrous oxide release; soil properties, including moisture, erosion, organic matter, nutrient fluxes and microbes; relationship of global change to forest and range fires, insects and plant pathogens; agricultural management systems; and ground truthing of satellite measurements.

USDA	Program Title	FY95	FY96
ARS	Agriculture and Rangeland Global Change	11.3	10.1
ERS	Economics of Global Change and Agriculture	0.8	0.8
FS	Forest Global Change	22.0	22.0
CSREES	Improved Response Models	10.6	10.5
ARS	Methyl Bromide Substitutes	13.1	13.1
NRCS	Soil Carbon Studies	1.5	1.5
CSREES	UV-B Monitoring Network	1.6	3.5
USDA Total		**60.9**	**61.5**

Related Research. In addition to focused USGCRP research, the USDA sponsors significant research contributing to the assessment of global change effects on the agricultural food and fiber production systems, and on forest and forest ecosystems of the U.S. and worldwide. Programs include: long-term studies addressing the structure, function and management of forest and grassland ecosystems; research in applied sciences including soils, climate, food and fiber crops, pest management, forest fish and wildlife, social sciences; implementation of ecosystem management on national forests and grasslands; and human interaction with natural resources.

Department of Commerce/National Oceanic and Atmospheric Administration and National Institute of Standards and Technology

Areas of Global Change Research. NOAA maintains a balanced program of observations, analytical studies, climate prediction and information management through ongoing efforts in operational in situ and satellite observations with an emphasis on oceanic and atmospheric dynamics (including sea level), circulation and chemistry; focused research on ocean-atmosphere land interactions, the global hydrological cycle, the role of ocean circulation and biogeochemical dynamics in climate change, atmospheric trace gas/climate interactions, and the response of marine ecosystems and living resources to climate change and related stress; improvements in climate modeling, prediction and information management capabilities; projection and assessment of seasonal to interannual and decadal to centennial environmental change; global change economics and human dimensions research; and archival, management and dissemination of data and information useful for global change research. NIST research focuses on physical properties of CFC alternatives, and engineering system design of systems utilizing CFC alternatives.

DOC	Program Title	FY95	FY96
NIST	Ozone and Ultraviolet Radiation: Chemically Induced Changes	2.6	2.6
NOAA	Atmospheric Chemistry Project	7.9	7.9
NOAA	Climate Change Data & Detection	4.7	4.7
NOAA	Climate Dynamics & Experimental Prediction	15.2	23.3
NOAA	Climate Observations	8.0	13.6
NOAA	Climate Variability (CLIVAR-GOALS, ACCP/WOCE)	17.9	20.2
NOAA	Economics and Human Dimensions of Climate Fluctuations	1.4	1.4
NOAA	Global Energy and Water Cycle Experiment (GEWEX)	7.1	7.1
NOAA	Marine Ecosystem Response (GLOBEC)	1.6	1.6
NOAA	NOAA Fleet	14.4	14.4
NOAA	NOAA Labs, NOAA Corps, & National Undersea Research	46.3	46.5
NOAA	Ocean-Atmosphere Carbon Exchange Study (OACES/JGOFS)	3.0	3.0
NOAA	Paleoclimatology (PAGES)	4.2	4.2
NOAA	VENTS	2.5	2.5
DOC Total		**136.8**	**153.0**

Related Research. In addition to focused USGCRP research, NOAA contributing programs include advance short-term weather forecasting and warning services; prediction and observation systems in support of seasonal to interannual climate forecasts; facilitating the dissemination of global change information; and strengthening facets of environmental technology. NIST also has ongoing programs in atmospheric chemistry.

Department of Defense

Areas of Global Change Research. The DOD provides unique capabilities and programs that concurrently satisfy Defense mission requirements and USGCRP goals, involving research in high latitude dynamics, regional resolving models, boundary layer dynamics and ocean ecological systems.

DOD	Program Title	FY95	FY96
ONR	Boundary Layer Dynamics/Marine Aerosols	1.0	1.0
ONR	High Latitude Dynamics/Arctic Lead Ice Dynamics	2.0	2.0
ONR	High Latitude Dynamics/Arctic Sediment History	0.3	0.3
CRREL	High Latitude Dynamics/Impact of Climate Change on Energy Fluxes	0.4	0.4
ONR	Ocean Ecological Dynamics/Marine Light Mixed Layer	1.0	1.0
CRREL	Regional Resolving Models/Coupled Hydrologic & Thermal Models	0.3	0.3
ONR	Regional Resolving Models/Coupled Ocean-Atmosphere Models	1.4	1.4
DOD Total		**6.4**	**6.4**

Related Research. In addition to a modest program identified with USGCRP focused research, DOD contributory research addresses issues in observing, understanding, and predicting global change, including observing and monitoring unique middle and upper atmosphere phenomena; acoustic tomographic measurements of the ocean at basin and hemispheric scales; fundamental research programs in physical oceanography, ocean biology, marine meteorology, air-sea interaction and solar influences; coupled ocean-atmosphere model development at various spatial scales; and a unique program in atmospheric dynamics and global cloud specification/modeling.

Department of Energy

Areas of Global Change Research. DOE research addresses the impacts of energy production and use on the global Earth system primarily through studies of climate response, and includes research in climate modeling, carbon sources and sinks, impacts on vegetation and ecosystems, critical data needs for global change research and for early detection of climatic change, and funding for education and training of scientists and researchers in global change.

DOE	Program Title	FY95	FY96
OHER	Atmospheric Sciences Program	12.3	13.2
OHER	Atmospheric Radiation Measurement (ARM) Program	38.2	38.7
OHER	Greenhouse Gases and Climate	20.7	23.0
OHER	Computer Hardware, Advanced Mathematics and Model Physics	10.3	10.8
OHER	Global Change Education	2.1	2.6
OHER	Information Management	1.9	2.3
POLICY	Integrated Assessments	0.0	0.2
OHER	Integrated Assessments	3.3	3.3
OHER	National Institute for Global Environmental Change (NIGEC)	9.3	10.9
OHER	Oceans Research	11.5	11.5
OHER	Program for Ecosystem Research (PER)	5.0	5.3
OHER	Quantitative Links	2.0	0.0
OHER	Unmanned Aerial Vehicles	1.0	1.0
DOE Total		**117.6**	**122.8**

Related Research. DOE supports research on technologies and strategies to mitigate the increases in CO_2 and other energy-related greenhouse gases, and plays a major role in implementing the President's Climate Change Action Plan on reducing greenhouse emissions through changes in energy supply and improvements in energy efficiency and conservation. In addition, DOE conducts research related to energy issues, including studies of chemical processes in the atmosphere related to energy production and use; atmospheric studies of the lower atmospheric boundary layer; solid Earth processes related to the formation of energy resources and possible changes in surface interactions; long-term solar interaction with the Earth; basic research in plant and microbial biology; technologies to improve energy conservation and use efficiency and alternative energy technologies to reduce or replace carbon-based fuels for energy production; and international environmental policy studies.

Department of Health and Human Services/National Institutes of Health

Areas of Global Change Research. National Institutes of Health (NIH) funding supports research on health effects of CFC replacement chemicals and ultraviolet radiation, including studies in metabolism and toxicity of HCFCs and halogenated hydrocarbons; effects of UV exposure on the pathogenesis of disease and on target organs, especially skin and eyes; repair of solar UV radiation-related DNA damage in human cells; and effects of shorter wavelength UV radiation on photosensitivity in people who use many commonly prescribed drugs.

HHS	Program Title	FY95	FY96
NIH	Human Health Effects of Exposure to UV Radiation	27.5	28.8
HHS Total		**27.5**	**28.8**

Related Research. In addition to focused USGCRP research, NIH conducts research related to human health and other impacts of global environmental change, including toxicity and effects of metals and agricultural chemicals; health effects of air pollutants; metabolism, biotransformation and toxicity of pesticides; and occupational exposure and health effects of materials used in alternative energy production.

Department of the Interior

Areas of Global Change Research. DOI programs include studies of past climates, from which understanding of current changes can be drawn; interaction and sensitivity of hydrologic and ecological systems with climate at local, landscape and regional levels; arid, polar and coastal regions and systems; volcano-atmosphere interactions; methane hydrates; changing land surface characteristics; ocean heat fluxes; assessments of the impacts of global change and the social, environmental and economic consequences on human activities, water resources, coastal wetlands, biological species, ecological systems, and land management; carbon cycle variation; and archival and distribution of space- and land-based Earth science data.

DOI	Program Title	FY95	FY96
USGS	Biogeochemical Exchanges between Terrestrial Systems	2.6	2.6
USGS	Climates of Arid/Semi-Arid Regions	0.7	0.8
USGS	Cold Regions Research	1.2	1.2
NBS	Impacts of Global Change on Coastal Lands & Ecosystems	1.2	1.2
NBS	Impacts of Global Change on Terrestrial Ecosystems	4.1	4.1
USGS	Interaction of Climate & Hydrologic Systems	4.2	4.2
USGS	Land Characterization & Data Management	7.4	7.4
NBS	Impacts of Global Change on Fish and Wildlife	1.7	1.7
USGS	Paleoclimate Research	6.8	6.8
BOR	Sensitivity of Water Resources	0.5	0.0
DOI Total		**30.4**	**30.0**

Related Research. In addition to focused USGCRP research, DOI sponsors contributing research programs addressing the collection, maintenance, analysis and interpretation of short- and long-term land, water, biological and other geological and biological processes and resources through dispersed observing networks; research in land use and land cover, including creation of maps and digital data products; and inventorying and monitoring of biological habitats, resources and diversity.

Department of Transportation

Areas of Global Change Research. The Federal Aviation Administration (FAA) within the DOT, in conjunction with the Atmospheric Effects of Aviation Project of NASA, conducts research to develop an improved scientific basis for assessment of the environmental impacts of subsonic and supersonic aviation, particularly the atmospheric impacts of commercial aircraft cruise emissions. This information is needed to determine the effects aircraft emissions will have, particularly on stratospheric and tropospheric ozone concentrations and on the global climate. The FAA research is coordinated with efforts of national and international organizations and agencies.

DOT	Program Title	FY95	FY96
FAA	Atmospheric Effects of Aviation	0.5	0.5
DOT Total		**0.5**	**0.5**

Related Research. No other research activities focus on the science of global environmental change.

Environmental Protection Agency

Areas of Global Change Research. EPA research supports process-level understanding and modeling capabilities to more confidently predict global change impacts and feedback at the regional scale, and examines the relative risk of global change, especially in climate-sensitive regions (e.g., tundra and forest). EPA sponsors research on evaluating the processes and quantifying the relative contributions of anthropogenic and biological sources of trace gases, quantifying and modeling the consequences of climate change on ecosystems and their feedback to the atmosphere, and the interaction of trace gases in the atmosphere.

EPA	Program Title	FY95	FY96
ORD	Terrestrial Carbon Flux Tracking	9.8	7.0
ORD	Developing Predictive Models	3.0	2.7
ORD	Regional Vulnerabilities	6.0	9.0
ORD	Integrated Assesment Research	2.3	1.3
ORD	Stratospheric Ozone Depletion	3.4	2.5
OARM	Data Management, Access, and Integration	0.5	0.5
OPPE	Policy Assessment Research	0.7	0.4
EPA Total		**25.7**	**23.4**

Related Research. In addition to focused USGCRP research, EPA conducts contributing research including environmental monitoring and assessment; development of ecological assessment methods; effects of tropospheric ozone on forest ecosystems; evaluation of anthropogenic methane mitigation options; evaluation of renewable energy production technologies (biomass, solar, wind); and immunological effects of UV radiation and environmental pollutants and chemicals.

National Aeronautics and Space Administration

Areas of Global Change Research. NASA research efforts in global change involve space-based studies of the Earth as an integrated system, including research and satellite programs studying atmospheric ozone, ocean surface winds, tropical precipitation, and the Earth's upper atmosphere. The space-based activity complements ongoing ground-based research programs in the observation, understanding and modeling of radiation, climate dynamics and hydrology; ecosystem dynamics and biogeochemical cycles; atmospheric chemistry; solid Earth science, and the processing, archiving, retrieval, dissemination and use of global change data. The focus is Earth system science involving focused and interdisciplinary research and coupled modeling. Development of algorithms for retrieval of the information content of space-based, remotely sensed observations is carried on as part of the flight mission.

NASA	Program Title	FY95	FY96
MTPE	Airborne Science Program	26.0	24.0
MTPE	Atmospheric Chemical Modeling	7.5	5.7
MTPE	Atmospheric Dynamics & Remote Sensing	10.8	8.4
MTPE	Atmospheric Hydrology	5.1	4.0
MTPE	Biological Oceanography	7.2	5.6
MTPE	Consortium for International Earth Science Information Network	6.0	6.0
MTPE	Ecological Processes	23.1	17.9
MTPE	EOS Data and Information Systems (EOSDIS)	230.6	289.6
MTPE	EOS Flight Development	418.2	442.6
MTPE	EOS Science	37.3	58.4
MTPE	EOS Special Spacecraft	85.5	69.7
MTPE	General Circulation Models	6.2	4.8
MTPE	Geodynamics	13.5	10.5
MTPE	Geology	2.2	1.7
MTPE	Geophysics and Geopotential Fields	2.0	1.6
MTPE	Ice Sheet and Sea Level Rise	3.9	3.0
MTPE	Information Systems	12.7	9.8
MTPE	Interdisciplinary Research and Analysis	4.7	3.6
MTPE	Land Surface Hydrology	2.5	1.9
MTPE	LANDSAT	87.5	78.8
MTPE	Mission Operations & Data Analysis	26.0	26.6
MTPE	NASA Scatterometer (NSCAT)	15.7	10.3
MTPE	Ocean Color Data Purchase/Sea WIFS	6.7	6.4
MTPE	Oceans and Ice Modeling and Analysis	3.6	2.8
MTPE	Payloads and Instrument Development	19.5	4.9
MTPE	Physical Oceanography	2.8	2.2
MTPE	Radiation Data & Modeling	8.6	6.7
MTPE	Sea Ice in a Global Climate	3.5	2.7
MTPE	Stratospheric Chemistry	22.1	17.1
MTPE	TOPEX/POSEIDON	33.9	23.4
MTPE	Total Ozone Mapping (TOMS)	18.6	11.8
MTPE	Tropical Rainfall Measurement (TRMM)	58.3	29.9
MTPE	Tropospheric Chemistry	7.5	5.8
MTPE	Upper Atmosphere Research Satellite (UARS)	30.0	18.8
NASA Total		**1249.2**	**1217.1**

Related Research. NASA includes all research in support of global change within the focused research program.

National Science Foundation

Areas of Global Change Research. NSF global change research programs support research and related activities that advance fundamental understanding of dynamic physical, biological and socioeconomic systems and the interactions among those systems. In addition to research on Earth system processes and the consequences of changes in those systems, NSF programs facilitate data-acquisition and data-management activities necessary for basic research on global change, the enhancement of modeling designed to improve representations of Earth system interactions, and the advancement of advanced analytic methods to facilitate fundamental research. NSF also supports fundamental research on the general processes used by governments and other organizations to identify and evaluate different types of policies for mitigation, adaptation and other responses to changing global environmental conditions.

NSF	Program Title	FY95	FY96
	Antarctic Ecosystems	1.5	1.5
	Arctic System Science (ARCSS)	14.2	15.0
	Climate Modeling, Analysis & Prediction (CMAP)	11.5	15.5
	Climate Variability and Predictability (CLIVAR)	12.2	12.2
	Earth System History	9.0	10.2
	Ecological Diversity	4.6	6.4
	Ecological Rates of Change (EROC)	3.0	3.0
	Geodata	1.4	1.4
	Global Ocean Ecosystems Dynamics (GLOBEC)	6.7	7.4
	Global Tropospheric Chemistry Program (GTCP)	12.8	12.8
	Greenhouse Gas Dynamics (GGD)	0.2	0.2
	Human Dimensions of Global Change	17.6	19.2
	Institutes/Education	3.1	3.1
	Joint Global Ocean Flux Study (JGOFS)	16.8	17.1
	Land-Margin Ecosystems Research (LMER)	2.9	2.9
	Methods and Models for Integrated Assessment	3.4	5.8
	Polar Ozone Depletion/UV Radiation Effects	5.6	5.6
	Ridge Interdisciplinary Global Experiments (RIDGE)	4.0	4.0
	Sea Level Changes	5.8	5.8
	Solar Influences	6.1	6.4
	Water & Energy: Atmospheric, Vegetative & Earth Interactions	8.9	10.1
	World Ocean Circulation Experiment (WOCE)	17.9	17.9
NSF	**NSF TOTAL**	**169.0**	**183.4**

Related Research. In addition to focused research, NSF conducts contributing research on many topics, including laboratory and field studies of the atmosphere and the factors that affect it; data management for scientific research and modeling activities; generation, transportation and fate of chemicals in natural systems; long-term monitoring and detailed studies of ecosystems; geophysical, hydrological, geological and geochemical processes operating on the Earth's surface; composition, structure and history of ocean floors; and global environmental history.

Smithsonian Institution

Areas of Global Change Research. Within the Smithsonian Institution, research conducted at the Smithsonian Astrophysical Observatory (SAO), the National Air and Space Museum (NASM), the Smithsonian Environmental Research Center (SERC) and the National Museum of Natural History (NMNH) concentrates on monitoring indicators of natural and anthropogenic environmental change on daily to decadal time scales, and on longer term indicators present in the historical artifacts and records of the museums as well as in the geologic record at field sites. The primary thrust of the Smithsonian's work is to improve knowledge of the natural processes involved and to continue to provide a long-term repository for present and future studies.

SI	Program Title	FY95	FY96
NMNH/STRI	Long-Term Environmental Change	1.6	1.6
SAO/NASM/SERC	Monitoring Natural Environmental Change	1.2	1.2
SI Total		**2.8**	**2.8**

Related Research. Contributing research of the Smithsonian Institution on biological diversity and ecosystem functions falls into two broad areas: Tropical Biological Diversity and Ecosystem Response to Fragmentation. Studies of Tropical Biological Diversity are done at the Smithsonian Tropical Research Institute (STRI) and the National Museum of Natural History (NMNH). The Tropical Biological Diversity Program (TROBID), concentrates on inventories of biodiversity and species distribution in tropical forests, monitoring biodiversity through repeated standardized sampling of flora and fauna, and identifying the physical and biological processes of growth and decline of species.

Tennessee Valley Authority

Areas of Global Change Research. TVA research and operations focus on the regional and local scale application of programs and operations, and center on climatic and hydrologic systems, biogeochemical dynamics, climate change impacts assessment and greenhouse gas sources and sinks.

TVA	Program Title	FY95	FY96
NFERC	Analysis of Terrestrial Carbon Sinks	0.4	0.4
NFERC	Reduction of N_2O Emissions from Fertilizers	0.3	0.3
NFERC	Regional Climate Change Impact Assessment	0.3	0.3
TVA Total		**1.2**	**1.2**

Related Research. In addition to focused USGCRP research, TVA sponsors significant contributing research emphasizing environmental and economic concerns, including programs in model improvement for integrated analysis and application for managing water resource systems and power operations; water quality and watershed inventories for water quality improvement; monitoring and assessing water quality and biological health of reservoirs and rivers; constructed wetlands research and demonstration projects in water pollution source cleanup; and formation, impacts and feedbacks of regional troposheric ozone.

APPENDIX C

History of the USGCRP

The U. S. Global Change Research Program was established in 1989 to combine and coordinate the research and policy development interests of 15 departments and agencies of the U. S. Government and Executive Offices of the President. The USGCRP is organized under the auspices of the Subcommittee on Global Change Research (SGCR), which is one of the seven environmental issue subcommittees established by the Committee on Environment and Natural Resources (CENR) [which has replaced the Committee on Earth and Environmental Sciences (CEES)]. In turn, the CENR is one of the 9 committees organized under the National Science and Technology Council (NSTC).

The Subcommittee on Global Change Research includes representatives of the Departments of Agriculture, Commerce (the National Oceanic and Atmospheric Administration and National Institute of Standards and Technology), Defense, Energy, Health and Human Services (the National Institute for Environmental Health Sciences), Interior, Transportation, and State as well as the Environmental Protection Agency, the National Aeronautics and Space Administration, the National Science Foundation, the Smithsonian Institution, the Tennessee Valley Authority, the intelligence community, the Office of Science and Technology Policy, the Council of Economic Advisers, and the Office of Management and Budget.

To implement the activities described in the USGCRP research framework, the SGCR has established Working Groups that bring together representatives of the participating agencies for regular consideration of program coordination, review of program plans, and development of plans for new projects and activities. The Chairs of these groups, along with the Chair and Vice-Chairs of the Subcommittee, form the Executive Committee of the USGCRP. To ensure effective Program integration across these activities, the SGCR established the Office of the USGCRP in July 1993. This office, which is staffed by the participating agencies and departments, is responsible for drafting of the annual edition of *Our Changing Planet* and periodic research plans, as well as facilitating the year-to-year planning and day-to-day coordination and communication needs of the Program.

The planning, coordination, and execution of USGCRP research activities are carried out in close association with and in support of the science priorities of the international research community; particularly those put forth by the Intergovernmental Panel on Climate Change (IPCC); the World Climate Research Programme (WCRP), the Human Dimensions of Climate Change Programme (HDP); and the International Geosphere-Biosphere Programme (IGBP). These efforts underpin the United States participation in and contribution to the international assessments related to aspects of global change.

The USGCRP maintains an active interaction with the National Academy of Sciences through its Board on Sustainable Development, its Committee on Global Change Research, and several other committees and panels of the National Research Council that interface with many of the international scientific research programs.

Program Evaluation

The overall USGCRP is evaluated periodically for scientific merit and continued relevance to the policy process, both domestic and international, by the National Academy of Sciences. Their review draws representatives from academic, institutional, and industrial groups conducting global change research.

Proposed and existing agency programs within the USGCRP are evaluated based on (i) their relevance and contribution to the overall USGCRP goal and objectives, including the needs of decision makers; (ii) scientific merit as documented by peer review; (iii) readiness for implementation and likelihood of early results; (iv) potential for and/or progress toward meeting Program milestones; (v) agency approval for inclusion in the USGCRP; and (vi) conformance to data and information management policies. The framework and evaluation criteria are an essential part of the program and budget development strategy of the USGCRP. They provide the structure through which the USGCRP evaluates and develops: (1) essential, high priority national and international components of the USGCRP in each fiscal year; and (2) the recommended budgets to support those critical components.

In addition to USGCRP review of the overall set of agency research programs, each agency is responsible for the review of individual projects within its programs. These reviews are almost exclusively based on an external peer-review process, which is deemed an important means of assuring continued program quality.

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APPENDIX D

Global Change Related Acronyms

AGENCY ACRONYMS

DOC	**Department of Commerce**
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
DOD	**Department of Defense**
CRREL	Cold Regions Research and Engineering Laboratory
ONR	Office of Naval Research
DOE	**Department of Energy**
OHER	Office of Health & Environmental Research
DOI	**Department of the Interior**
BIA	Bureau of Indian Affairs
BOR	Bureau of Reclamation
FWS	Fish and Wildlife Service
NBS	National Biological Service
USBM	U.S. Bureau of Mines
USGS	U.S. Geological Survey
DOT	**Department of Transportation**
FAA	Federal Aviation Administration
EPA	**Environmental Protection Agency**
OARM	Office of Administration and Resources Management
OPPE	Office of Policy, Planning and Evaluation
ORD	Office of Research and Development
HHS	**Department of Health and Human Services**
NIH	National Institutes of Health
NIEHS	National Institute of Environmental Health Sciences
NASA	**National Aeronautics and Space Administration**
MTPE	Mission to Planet Earth
NSF	**National Science Foundation**
SI	**Smithsonian Institution**
NASM	National Air and Space Museum
NMNH	National Museum of Natural History
NZP	National Zoological Park
SAO	Smithsonian Astrological Observatory
SERC	Smithsonian Environmental Research Center
STRI	Smithsonian Tropical Research Institute
TVA	**Tennessee Valley Authority**
NFERC	National Fertilizer and Environmental Research Center
USDA	**Department of Agriculture**
ARS	Agricultural Research Service
CSREES	Cooperative State Research, Education, and Extension Service
ERS	Economic Research Service
FS	Forest Service
NRCS	Natural Resource Conservation Service

OTHER GLOBAL CHANGE RELATED ACRONYMS

AASE	Airborne Arctic Stratospheric Expedition
ACCP	Atlantic Climate Change Program
ADEOS	Advanced Earth Observing Satellite
ALOS	Advanced Land Observation Satellite
AMIP	Atmospheric Model Intercomparison Project
APN	Asia-Pacific Network
ARCSS	Arctic System Science
ARM	Atmospheric Radiation Measurement
ATMOS	Atmospheric Trace Spectroscopy (satellite instrument)
AVHRR	Advanced Very High Resolution Radiometer (satellite instrument)
BAHC	Biospheric Aspects of the Hydrological Cycle
BAS	British Antarctic Survey
CEES	Committee on Earth and Environmental Sciences
CENR	Committee on Environment and Natural Resources
CEOS	Committee on Earth Observation Satellites
CEPEX	Central Equatorial Pacific Experiment
CFC	Chlorofluorocarbon
CHAMMP	Computer Hardware, Advanced Mathematics and Model Physics
CLIVAR	Climate Variability and Predictability
CMAP	Climate Modeling Analysis, and Prediction
CSL	Climate Simulation Laboratory (at NCAR)
DAAC	Distributed Active Archive Center
DIS	Data and Information Systems
ENRICH	European Network for Research in Global Change
ENSO	El Niño-Southern Oscillation
ENVISAT	Environmental Satellite
EOS	Earth Observing System
EOSDIS	Earth Observing System Data and Information System
EROC	Ecological Rates of Change
ESA	European Space Agency
EUMETSAT	European Meteorological Satellite
FCCC	Framework Convention on Climate Change
GAIM	Global Analysis, Interpretation and Modelling
GCDIS	Global Change Data and Information System
GCM	General Circulation Model
GCOS	Global Climate Observing System
GCRIO	Global Change Research Information Office
GEWEX	Global Energy and Water Experiment
GLOBEC	Global Marine Ecosystem Dynamics Program
GOALS	Global Ocean-Atmosphere-Land System
GOOS	Global Ocean Observing System
GTCP	Global Tropospheric Chemistry Program
GTOS	Global Terrestrial Observing System
GWP	Global Warming Potential
HALOE	Halogen Occultation Experiment (satellite instrument)
HCFCs	Hydrochlorofluorocarbons
HDP	Human Dimensions of Climate Change Programme
HFCs	Hydrofluorocarbons
IAI	Inter-American Institute for Global Change Research
ICSU	International Council of Scientific Unions
IGAC	International Global Atmospheric Chemistry Project
IGBP	International Geosphere-Biosphere Programme
IGFA	International Group of Funding Agencies
INPE	Brazilian Space Agency
IPCC	Intergovernmental Panel on Climate Change
IRI	International Research Institute
ISLSCP	International Satellite Land Surface Climatology Project

ISSC	International Social Sciences Council
ITB	Intergovernmental TOGA Board
JGOFS	Joint Global Ocean Flux Study
LMER	Land Margins Ecosystem Research
LOICZ	Land-Ocean Interactions in the Coastal Zone
LUCC	Land-Use and Land-Cover Change
METOP	Meteorological Operation (satellite)
NADW	North Atlantic Deep Water
NCAR	National Center for Atmospheric Research
NIGEC	National Institute for Global Environmental Research
NSCAT	NASA Scatterometer (instrument)
NSTC	National Science and Technology Council
OACES	Ocean-Atmosphere Carbon Exchange Study
ODP	Ozone Depletion Potential
OGCM	Ocean General Circulation Model
PAGES	Past Global Changes
PER	Program for Ecosystem Research
PSC	Polar Stratospheric Cloud
RIDGE	Ridge Interdisciplinary Global Experiments
SAGE	Stratospheric Aerosol Gas Experiment (satellite instrument)
SAM	Stratospheric Aerosol Measurement (satellite instrument)
SBUV	Solar Backscatter Ultraviolet (satellite instrument)
SCAR	Scientific Committee on Antarctic Research
SCPP	Seasonal-to-Interannual Climate Prediction Program
SeaWiFS	Sea-viewing Wide-field-of-view Sensor (instrument)
SGCR	Subcommittee on Global Change Research
SPADE	Stratospheric Photochemistry, Aerosols, and Dynamics Expedition
SSBUV	Shuttle Solar Backscatter Ultraviolet (space shuttle instrument)
START	SysTem for Analysis, Research and Training
TAO	Tropical Atmosphere-Ocean (observing system)
TECO	Terrestrial Ecology
TIROS	Television Infrared Operational Satellite
TOGA	Tropical Oceans/Global Atmosphere
TOGA-COARE	Tropical Oceans Global Atmosphere-Coupled Ocean Atmosphere Experiment
TOMS	Total Ozone Mapping Spectrometer (satellite instrument)
TOPEX	Topography Experiment (for the ocean)
TRMM	Topical Rainfall Measurement Mission
UARS	Upper Atmosphere Research Satellite
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
USGCRP	U.S. Global Change Research Program
UV	Ultraviolet radiation (including UV-A and UV-B
VENTS	A NOAA Program on Mid-Ocean Ridges
WCP	World Climate Programme
WCRP	World Climate Research Programme
WMO	World Meteorological Organization
WOCE	World Ocean Circulation Experiment

APPENDIX E

Subcommittee on Global Change Research

Robert W. Corell	Chair, National Science Foundation
Robert C. Harriss	Science Vice Chair National Aeronautics and Space Administration
Susan Tierney	Policy Vice Chair, Department of Energy

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