OUR CHANGING PLANET

THE FY 1997
U.S. GLOBAL CHANGE RESEARCH PROGRAM

An Investment in Science for the Nation's Future

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

A Supplement to the President's Fiscal Year 1997 Budget

On the Front Cover

The Earth gleams brightly against the stark black backdrop of space, as photographed by the Apollo 16 astronauts during their Earth-Moon roundtrip. The United States and other parts of North America are clearly visible in this photograph.

Figure courtesy of the National Aeronautics and Space Administration.

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About the National Science and Technology Council

President Clinton established the National Science and Technology Council (NSTC) by Executive Order on November 23, 1993. This cabinet-level council is the principal means for the President to coordinate science, space, and technology policies across the Federal Government. The NSTC acts as a "virtual" agency for science and technology to coordinate the diverse parts of the Federal research and development enterprise. The NSTC is chaired by the President. Membership consists of the Vice President, the Assistant to the President for Science and Technology, Cabinet Secretaries and Agency Heads with significant science and technology responsibilities, and other senior White House officials.

An important objective of the NSTC is the establishment of clear national goals for Federal science and technology investments in areas ranging from information technology and health research, to improving transportation systems and strengthening fundamental research. The Council prepares research and development strategies that are coordinated across Federal agencies to form an investment package that is aimed at accomplishing multiple national goals.

To obtain additional information regarding the NSTC, contact the NSTC Executive Secretariat at 202-456-6100 (voice).

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The Committee on Environment and Natural Resources (CENR) is one of nine committees under the NSTC, and is charged with improving coordination among Federal agencies involved in environmental and natural resources research and development, establishing a strong link between science and policy, and developing a Federal environment and natural resources research and development strategy that responds to national and international issues.

To obtain additional information about the CENR, contact the CENR Executive Secretary at 202-482-5917 (voice).

About the Office of Science and Technology Policy

The Office of Science and Technology Policy (OSTP) was established by the National Science and Technology Policy, Organization, and Priorities Act of 1976. OSTP's responsibilities include advising the President on policy formulation and budget development on all questions in which science and technology are important elements; articulating the President's science and technology policies and programs; and fostering strong partnerships among Federal, State, and local governments, and the scientific communities in industry and academia.

To obtain additional information regarding the OSTP, contact the OSTP Administrative Office at 202-456-6004 (voice).

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 FY1997 U.S. Global Change Research Program*. This annual report was prepared under the auspices of the President's National Science and Technology Council (NSTC).

The U.S. Global Change Research Program (USGCRP) is crucial to understanding, predicting, and assessing global environmental changes and their consequences for human health, food production, ecological systems, and sustainable economic development. The USGCRP has advanced our understanding of key global environmental science issues, including: seasonal to interannual climate variability; climate change over decades to centuries; changes in ozone, UV radiation, and atmospheric chemistry; and changes in land cover and in terrestrial and marine ecosystems. As the National Academy of Sciences noted in its recent review of the program: "A great deal of extremely high-quality science that is recognized worldwide for its excellence has resulted from the USGCRP."

The past year has brought significant new findings about the causes and consequences of global change. New results include demonstration of strong El Niño impacts on crop yields and rangeland conditions in Utah and Idaho, and compelling new evidence of links between climate change, weather, and negative human health effects, including increases in heat-related mortality and in exposure to both vector and non-vector-borne diseases. Perhaps most important is the widespread agreement reached this year among leading researchers that the balance of evidence suggests that there is a discernible human influence on global climate.

The USGCRP, a coordinated interagency effort established by President Reagan and elevated to a Presidential Initiative by President Bush, was codified by Congress in the Global Change Research Act of 1990. President Clinton is continuing this strong bipartisan tradition of support. The FY1997 Budget Request demonstrates the Administration's ongoing commitment to the program. The President and the Vice President believe that global change research is critical to our future as we head into the 21st century.

I commend Dr. Robert Corell of the National Science Foundation, Chair of the NSTC Subcommittee on Global Change Research, the members of the Subcommittee, and all of the participants in government, academia, and industry for their efforts in making this program a success.

John H. Gibbons
Director

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Overview of the U.S. Global Change Research Program

The Earth's environment is constantly changing. Scientific evidence indicates that these changes are the result of a complex interplay among a number of natural and human-related systems.

While the complexity of the Earth system and the interconnections among its components make understanding and prediction a very difficult challenge, the development of scientific knowledge and research capabilities are greatly advancing the understanding of global environmental change and the role of human activities in contributing to and responding to change.

Humans have come to play a powerful and expanding role as agents of environmental change and human activities are also substantially impacted by global-scale environmental changes. The current and future state of the Earth system is inexorably linked to human activities.

The United States, through the U.S. Global Change Research Program (USGCRP), along with other nations, supports the research needed to characterize and understand global environmental change and to provide answers to important questions about the Earth system (including human activities), how it is changing, and the implications of global change for society and the natural ecosystems and managed resource systems on which society depends.

To assess the state of scientific information and identify research needs, the United States participates actively in national and international evaluations of the scientific understanding of global change issues. These assessments bring together large numbers of scientists representing a broad spectrum of research specialties and viewpoints to prepare carefully and widely reviewed reports that encompass the range of qualified scientific findings and perspectives.

In 1995, the Intergovernmental Panel on Climate Change (IPCC) approved its Second Assessment Report, which, among other conclusions, stated that "the balance of evidence suggests that there is a discernible human influence on global climate."

This follows on a 1994 scientific assessment of ozone depletion organized by the World Meteorological Organization (WMO) and United Nations Environment Programme (UNEP), which found that the "conclusion that anthropogenic chlorine and bromine compounds, coupled with surface chemistry on natural polar stratospheric particles, are the cause of polar ozone depletion has been further strengthened."

Since its establishment as a Presidential Initiative in the FY90 budget, the USGCRP has been responsible for directing Federal support for scientific research to address key uncertainties about global environmental change and the Earth system.

The goal of the U.S. Global Change Research Program is:

- To observe and document changes in the Earth system
- To understand what changes are occurring and why
- To improve predictions of future global change
- To analyze the environmental, socioeconomic, and health consequences of global change
- To support state-of-the-science assessments of global environmental change issues.

The USGCRP budget request for FY97 is $1.73 billion, with 10 agencies participating in the program. A few of the agencies support research on the broad range of scientific areas relating to the global environment, while others support research that has a more mission-oriented focus. The programmatic contributions of the USGCRP agencies are coordinated and closely matched to agency missions and areas of expertise.

In response to requests from the Subcommittee on Global Change Research and from Congressional committee chairs in both the House and Senate, the National Research Council (NRC) of the National Academy of Sciences (NAS) has been conducting a major program review of the USGCRP.

In a September 1995 interim report, the NRC concluded, "The scientific and societal motivations of the program remain compelling, and the USGCRP should be aggressively pursued." The report stated that, "A great deal of extremely high-quality science that is recognized worldwide for its excellence and leadership has resulted from the USGCRP."

The NRC also made a number of recommendations. The Subcommittee on Global Change Research and the USGCRP participating agencies have been moving aggressively to respond to the NRC recommendations on program integration and strategic research directions.

Key Global Change Environmental Science Issues

In response to the development of scientific understanding and research capabilities that has occurred over the life of the program, the USGCRP is moving to focus research efforts on what the NRC has termed "...priority issues in four mature areas of Earth system science that are of great scientific and practical importance." These priority environmental science issues follow:

1) **Seasonal to Interannual Climate Variability**, with the goal of obtaining a predictive understanding and the skills to produce forecasts of short-term climate fluctuations and to apply these predictions to problems of social and economic development in the United States and abroad.

   Progress toward this goal will provide improved predictions that can, among other direct benefits, help farmers maintain their agricultural productivity in spite of extreme climatic events such as droughts and floods, help water resource managers to ensure reliable water deliveries and optimal reservoir levels, help in planning fishery harvests, and help foresters allocate resources effectively to safeguard forests (and the public) from fire during droughts.

   Scientists can now predict with reasonable certainty, up to 1 year in advance, the onset of episodes of the phenomenon known as the El Niño/Southern Oscillation (ENSO) in the tropical Pacific Ocean. This interaction between the ocean and atmosphere is linked to fluctuations in precipitation and temperature throughout the tropics and into higher latitudes, including the United States. These fluctuations can result in severe flooding and harsh droughts. As evidenced by the 1996 drought in the southwestern United States, extreme climatic events have serious implications for economic and social systems. The USGCRP plays a leading role in an ongoing global endeavor to develop and enhance prediction capabilities, and to apply experimental forecasts to real problems of economic planning and development in climate sensitive sectors such as agriculture, water, and public health.

2) **Climate Change over Decades to Centuries**, with the goal of understanding, predicting, assessing, and preparing for changes in the climate and the global environment that will result from the influences of projected changes in population, energy use, land cover, and other natural and human-induced factors.

Progress toward this goal will provide information needed by decisionmakers considering adaptive or mitigative responses to the projected changes in climate and the associated environmental and societal impacts. The information will also assist planners and managers with responsibilities for the design of infrastructure and other major facilities, sustained management of natural resource-based systems, and long-term planning in the financial sector.

The scientific community, through the IPCC Second Assessment Report, projects that during the next century and beyond human influences will alter the climate to an extent almost as great as the changes associated with going from past glacial to interglacial periods. This unprecedented rate of change will likely have significant impacts on forests, agriculture, water supplies, and human health. While much scientific progress has been made over the past few decades in developing a broad-scale understanding of the causes of global climate change, significant gaps remain, particularly with regard to estimating regional changes and understanding potential consequences and how society can mitigate or adapt to these changes. The USGCRP will continue to play a leading role in reducing scientific uncertainties in the understanding of the physical climate system while broadening research to improve the understanding of the impacts of climate change on natural resources and socioeconomic sectors.

3) **Changes in Ozone, UV Radiation, and Atmospheric Chemistry**, with the goal of understanding and characterizing the chemical changes in the global atmosphere and their consequences for human health and well-being.

Progress toward this goal will provide information to assist policymakers in protecting human health, preserving the cleansing and protective qualities of the atmosphere, and ensuring that new compounds do not lead to inadvertent environmental consequences.

The USGCRP provides a framework for a comprehensive and integrated research effort that provides information of great value to policymakers. For example, through USGCRP-supported research, emissions of chlorofluorocarbons (CFCs) from human activities have been unambiguously identified as the cause of the Antarctic ozone hole. Projections that large increases in CFC emissions would lead to large losses of stratospheric ozone underlie the agreement to phase out CFC

use, and observations of declining CFC concentrations demonstrate the efficacy of policies adopted to protect the ozone layer.

4) **Changes in Land Cover and in Terrestrial and Marine Ecosystems**, with the goal of providing a stronger scientific basis for understanding, predicting, assessing, and responding to the causes and consequences of changes in terrestrial and marine ecosystems resulting from human-induced and natural influences.

   Progress toward this goal will provide a stronger scientific basis for developing environmental and natural resource practices that are environmentally sound and practical, and that will ensure ecosystems yield sustainable benefits to humankind.

   The USGCRP supports research projects to inventory the current land cover of the Earth and to document changes; to improve understanding of the dynamics of land-cover and land-use change and how terrestrial ecosystems react to change; and to document and understand chemical, physical, and biological processes in the oceans and their relationship with the carbon cycle and marine life.

Integrating Research Themes, Scientific Information, and Outreach Responsibilities

To provide the basis for continuing advancement in scientific understanding and to fulfill the U.S. commitment to international leadership in global change research, the USGCRP supports a number of essential ongoing integrative and cooperative efforts:

1) **Observing and Monitoring Global Change**, with the goal of ensuring the availability of a long-term, high-quality observational record of the state of the Earth system, its natural variability, and changes that are occurring over extended time scales.

   These observations of the atmosphere, oceans, and land surface, and their interactions, will provide the basis for understanding and monitoring changes in the Earth system.

   The United States supports a diverse set of surface, *in situ*, and satellite systems, including the Earth Observing System (EOS) series of satellites and surface and satellite measurement capabilities that contribute to multiple goals, including weather and climate prediction, hazard warning, and documentation of changes in the global environment. These capabilities

already provide a substantial base of information. Planning is underway to move toward an even more comprehensive system for observing and monitoring the changing state of the Earth system.

2) **Global Change Data, Products, and Information Services,** with the goal of providing all users ready and affordable access in useful forms to the full spectrum of global change data, products, and information.

   Achieving this goal will accelerate scientific progress while also greatly enhancing public and private sector access to data that can make the economy more resilient to changes and fluctuations, help education at all levels, allow adaptation to changes, and aid resource managers in management and planning.

   This user service activity includes the identification, assembly, documentation, archiving, and dissemination of data and information gathered from many types of observational platforms and research programs. It primarily focuses on providing user access to Federal agency sources of data and information, but has links to international and other sources.

3) **Earth System Science,** with the goal of supporting the long-term, integrated and exploratory research needed to gain a predictive understanding of the interactions among the physical, chemical, geological, ecological, and solar processes that determine the functioning of the Earth system and its trends and fluctuations on global and regional scales.

   Pursuing this goal provides the basis for continuing advances in fundamental understanding of the world around us and helps to identify emerging issues and potential changes of low probability but high impact (often referred to as surprises).

   The USGCRP supports the advance of understanding of the Earth system through experiments that explore the working of physical, chemical, geological, solar, and biological processes, and through Earth system modeling to interrelate and tie together the many processes into a unified representation of the atmosphere-ocean-land-ecological system.

4) **Human Contributions and Responses to Global Change,** with the goal of identifying, understanding, and analyzing how human activities contribute to changes in natural systems, how the consequences of natural and human-induced change affect the health and well-being of humans and their institutions, and how humans could potentially respond to problems associated with environmental change.

Progress toward this goal will provide an improved scientific basis for decisionmakers considering how society should respond to global-scale environmental change.

Research on human contributions and responses is a small, but critical and growing, component of the USGCRP. The USGCRP supports a diverse range of studies by leading researchers in universities, research institutions, and Government laboratories across the United States, in both basic and applied settings.

5) **International Research Cooperation**, with the goal of supporting and assisting the program and its participating scientists and agencies in their interactions with related international research, observing, and assessment activities and in the full and open international sharing of data and research findings.

Progress toward this goal will enhance the cooperative effort to improve understanding of global change, which can best be achieved by aggregating and coordinating the capabilities and resources of various nations.

In support of this cooperative effort, the USGCRP participates in and supports the three major international nongovernmental global change research programs that are initiated within the scientific community. The USGCRP has also developed a range of global, regional, and bilateral mechanisms to provide a framework within which U.S. scientists and colleagues in other countries can cooperate to address specific research issues and to study specific regions of mutual interest.

6) **Global Change Education and Communication**, with the goal of increasing public awareness of the Earth system and how it is changing and to promote global change education.

Progress toward this goal will help ensure that societal decisionmaking is based on an informed understanding of global change, and will serve society's vital interest in the education of young scientists.

The USGCRP has a multi-pronged approach to promote the dissemination and use of global change research and information; to promote the development of the next generation of scientists; to integrate global change information into the existing formal and informal educational systems; and to support professional development programs for educators on Earth system science.

1. Overview of the U.S. Global Change Research Program

A great deal of extremely high-quality science that is recognized worldwide for its excellence and leadership has resulted from the USGCRP.

—National Academy of Sciences/National Research Council, 1995[1]

The Earth System

The Earth's environment is in a state of continuous change. Continents drift, mountains are driven upwards and erode, animal and plant species evolve, terrestrial and marine ecosystems change, the Earth's orbit about the Sun varies, and the atmosphere and oceans adjust in response to these and numerous other forces that act on our planet. Large changes such as these generally occur very slowly and are the result of major natural forces beyond human influence or control. Over periods of decades to centuries, however, natural changes have been relatively small, at least for the several thousand years before the onset of large-scale agricultural and industrial activities.

Although we are relative newcomers to the scene, humans have now become powerful agents of environmental change, at least initially on time scales of decades to centuries. The chemistry of the atmosphere has been altered by the agricultural and industrial revolutions. Erosion of soils, sediment loading of rivers, and shoreline contours have been influenced dramatically by agriculture and construction. The production and release of toxic chemicals as well as changes in land use and land management have affected the health and distribution of populations of living organisms. The development of water resources has affected patterns of natural water storage, evaporation, and river flow on the world's continents.

With the increasing world population, the expanding global economy, and the development of new technologies, the role of humans as agents of environmental change is likely to become even more significant

[1]National Research Council, Board on Sustainable Development, Committee on Global Change Research. *A Review of the U.S. Global Change Research Program and NASA's Mission to Planet Earth/Earth Observing System* (Washington, DC, National Academy Press, 1995), p.7.

in the future. The use of fossil fuels is changing atmospheric composition and exerting an increasing warming influence on the global climate. The destruction of forests and certain agricultural practices also contribute to changes in the atmospheric composition and to climate change. Changes in land use alter the ability of the land to provide ecological services, including water purification and habitat for wildlife. The emissions of CFCs and other chlorine- and bromine-containing gases have led to depletion of stratospheric ozone that will take decades to reverse. All of these factors and more are leading to changes in the global environment that could have profound consequences.

Scientific research is the means for developing an understanding of these changes and their causes. Scientific evidence accumulated over the last few decades indicates that the rate, magnitude, and extent of environmental changes are the result of a complex interplay among a number of natural and human-related systems. Understanding what is occurring and what will occur in the future thus requires an understanding of all of the components of what has come to be called the Earth system.

The components of the Earth system include the atmosphere, the oceans, the continents, the biological life, and the regions of ice and snow. The state of these components is controlled by "forcing agents" that lead to changes in their state, thus to changes in the overall Earth system. The components are linked by an amazing diversity of physical, chemical, and biological processes that transmit change throughout the system. Most of these are natural processes, but some—for example, changes in land use that result in land-cover changes and the production of greenhouse gases—are strongly influenced by human activities.

Changes in any single element of the Earth's environment cannot be understood by studying that component alone. For example, the Earth's climate involves not only temperature, winds, and clouds in the atmosphere, but also the interactive effects of ocean currents and surface temperatures; the biosphere (living organisms and the environment that supports them); atmospheric composition; the Earth's orbital characteristics; the reflective properties of the planet; the distribution of water between the atmosphere, hydrosphere (oceans and freshwater), and cryosphere (snow and ice); and numerous other factors. Similarly, other important occurrences, such as changes in the productivity of the oceans or land surface or the incidence of volcanic eruptions, are linked to a variety of interactive phenomena.

Given the complexity of the Earth system and the many feedbacks among its components, understanding and predicting climatic and environmental change is an exceedingly difficult challenge. For

example, human-induced increases in atmospheric carbon dioxide (CO_2) and other trace gas concentrations are major forcing factors for climate change. However, because CO_2 is the primary raw material for photosynthesis, an increased CO_2 concentration is also likely to influence the character, extent, and distribution of the Earth's vegetative cover. This, in turn, will affect solar and terrestrial radiation (processes of energy transfer), the biogeochemical budget (distribution and circulation of chemicals, such as carbon and nitrogen, between the Earth's crust and the cells of living organisms), and the hydrological budget (distribution and circulation of water). These changes can alter climate in ways that can serve either to enhance or ameliorate the effects of the original CO_2 forcing. Such complexities make prediction anything but straightforward.

Over the past decade, the development of scientific insight and research capabilities has greatly advanced the understanding of global change. The growing understanding—among scientists and nonscientists alike—that the current and future state of the Earth system is inexorably linked to human activities, and the growing societal concern about the implications of global environmental change, underscore the need for and importance of these scientific efforts. The results of research supported by the USGCRP are providing both quantitative and qualitative information about important questions involving the Earth system (including humans), how it is changing, and the implications of global environmental change for society.

The U.S. Global Change Research Program

The USGCRP was established by President Reagan and included as a Presidential Initiative in the FY90 budget by President Bush as a high-priority research effort:

- To address key uncertainties about changes, both natural and human-induced, in the Earth system
- To monitor, understand, and predict global change
- To provide a sound scientific basis for national and international decisionmaking on global change issues.[2]

Congress codified the USGCRP in the Global Change Research Act of 1990, in order to provide for the following:

- "Development and coordination of a comprehensive and integrated U.S. research program that will assist the Nation and the

[2]Committee on Earth Sciences, U.S. Global Change Research Program. *Our Changing Planet: The FY 1990 Research Plan*, July 1989.

world to understand, assess, predict, and respond to human-induced and natural processes of global change"

- "Increasing the overall effectiveness and productivity of Federal global change research efforts."[3]

The Global Change Research Act defines global change 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."

This mandate for the USGCRP makes it clear that the program is to have a broad scope and consider the full set of issues dealing with actual and potential global environmental change. This broad approach recognizes the profound economic, social, and ecological implications of global changes and the need for U.S. leadership in this area.

Since its inception, the USGCRP has been directed toward strengthening research on key scientific issues, and has fostered much improved insight into the processes and interactions of the Earth system. The results of research supported by the USGCRP play an important role in international scientific assessments, including assessments of climate change and stratospheric ozone depletion. The USGCRP research results provide the scientific information base that underpins consideration of possible response strategies, but the USGCRP does not recommend policies on global change issues, nor does it include support for research and development of energy technologies, development of mitigation strategies, or the Climate Change Action Plan.

The underlying premise of the USGCRP is that appropriate use of the Earth for human habitation and survival is inextricably linked to an improved understanding of the systems that are undergoing change in response to natural and human-influenced processes. Presidents Bush and Clinton, and Congress, have supported the USGCRP as a high priority in the national scientific research agenda.

For FY97, the President's budget requests appropriations of $1.73 billion for the USGCRP. See Appendix A for a description of the overall USGCRP budget request. See Appendix B for a description of global change research budget requests for individual USGCRP-participating agencies.

Program Direction and Agency Research Contributions

The Subcommittee on Global Change Research (SGCR) of the Committee on Environment and Natural Resources (CENR), a component of the

[3]Global Change Research Act of 1990, 15 USC 2921.

National Science and Technology Council (NSTC), provides overall direction and executive oversight of the USGCRP. Within this framework, agencies manage and coordinate Federally supported scientific research on global change. The Global Change Research Act specifies a minimum of 14 Federal agencies as well as planning and oversight offices of the Executive Office of the President to be represented in the oversight of global change research.

In FY97, 10 agencies will be supporting research as part of the USGCRP. A few of the agencies support research on a broad range of issues, while others have a more specialized focus. Programmatic contributions are closely matched to agency missions and areas of expertise.

Global environmental issues are very complex and require a wide range of expertise. Close cooperation among agencies is required because of the wide range of challenges to be addressed, the differing interests and capabilities of each agency, and the need to make the most

The Subcommittee on Global Change Research

- Department of Agriculture (USDA)
- Department of Commerce/National Oceanic and Atmospheric Administration (DOC/NOAA), also representing the National Institute of Science and Technology (NIST)
- Department of Defense (DoD)
- Department of Energy (DOE)
- Department of Health and Human Services/National Institutes of Health (HHS/NIH)
- Department of the Interior (DOI)
- Department of State (DOS)
- Department of Transportation (DOT)
- Environmental Protection Agency (EPA)
- National Aeronautics and Space Administration (NASA)
- National Science Foundation (NSF)
- Smithsonian Institution (SI)
- Tennessee Valley Authority (TVA)
- Office of Management and Budget, Executive Office of the President (OMB)
- Office of Science and Technology Policy, Executive Office of the President (OSTP)
- Intelligence Community

effective use of available budgetary resources to implement a strong research program.

Thus, for example, NASA leads efforts relating to satellite observations of the Earth as well as research to interpret and understand these observations; NOAA leads efforts relating to its interests in improving predictions of atmospheric and oceanic behavior; DOE focuses on research to predict the behavior of the global climate system on decadal to centennial time scales in response to changes in atmospheric composition, and to evaluate the contribution of energy-based emissions to climate change; NSF focuses on broadly based fundamental research to improve understanding of the Earth system; USDA focuses on the roles of and consequences for agriculture, food production, and forests of global-scale environmental change; NIH focuses on potential health-related impacts; DOI focuses on climate system history and impacts on water resources and public lands; EPA focuses on ecosystem and societal impacts of global change; DoD focuses on prediction of seasonal climate anomalies affecting its national security operations; and the Smithsonian Institution focuses on improving knowledge of the natural processes involved in global change.

USGCRP Goal

It is crucial to have a sound, widely accepted, integrated scientific approach to investigating global change. The USGCRP presented a detailed scientific research plan in October 1990.[4] This plan, updated annually in *Our Changing Planet*, which is submitted to Congress each year as a supplement to the President's budget, has served as an important guide to research efforts over the past several years. The research programs that have been developed since this plan was published emphasize the search for a better predictive understanding of the world around us through increased interagency, bilateral, and multilateral cooperation.

The USGCRP is preparing a new multi-year research plan that is responsive to the advancement of scientific understanding, the recommendations of the National Academy of Sciences in its 1995/96 review of the program, and the Global Change Research Act. Concurrently, the USGCRP has drafted an updated statement of the overall goal of the program.

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[4]Committee on Earth and Environmental Sciences, U. S. Global Change Research Program, *Our Changing Planet: The FY 1991 Research Plan*, October 1990.

Goal of the U.S. Global Change Research Program

- To observe and document changes in the Earth system
- To understand what changes are occurring and why
- To improve predictions of future global change
- To analyze the environmental, socioeconomic, and health consequences of global change
- To support state-of-the-science assessments of global environmental change issues

National Academy of Sciences Review of the USGCRP

In response to requests from the Subcommittee on Global Change Research and from Congressional committee chairs in both the House and the Senate, the National Academy of Sciences asked its operational arm, the National Research Council, to initiate a major program review of the USGCRP; the first phase was begun in the summer of 1995. This review was undertaken by the NRC Board on Sustainable Development and its Committee on Global Change Research, which convened a joint 2-week meeting in July 1995, and continued their deliberations at meetings in November 1995 and March 1996.

The NRC issued an interim report in September 1995, entitled *A Review of the U.S. Global Change Research Program and NASA's Mission to Planet Earth/Earth Observing System.* In this first phase, the review considered the scientific foundations and progress to date of the USGCRP, and the role of the Earth Observing System and the EOS Data and Information System (EOSDIS) in meeting the USGCRP's need for global observations.

Since receiving the NRC interim review in September 1995, the SGCR and the USGCRP agencies have been moving aggressively to respond to the NRC recommendations on program integration and strategic research directions. The SGCR has presented its plans for streamlining its interagency structure to the NRC for consideration and is moving to ensure a stronger set of contacts with the scientific community through the NRC. Interagency teams have been formed to draft focused components of a new USGCRP multi-year plan, which is being prepared for review and approval during 1996.

With the President's FY97 budget request, NASA will be able to sustain the planned launch schedule of MTPE satellites. The overall

National Research Council 1995 Review Recommendations on the USGCRP

Among other comments, the NRC report offered the following key recommendations:

Program Support

- "Assessing accurately the current state of the global environment and increasing our predictive capabilities to aid in anticipating how this environment may evolve are enduring challenges to science....The scientific and societal motivations of the program remain compelling, and [the USGCRP] should be aggressively pursued."

Program Integration

- "The USGCRP must be implemented as an integrated program of observations, process research, modeling, prediction, information management, and assessment. In order to achieve this, enhanced collaboration and cooperation are required among the scientific community, the Congress, Federal agencies, and the Executive Office of the President to ensure that all elements of the program are considered in the context of the integrated program as a whole."

Program Priorities

- "The program should focus on priority issues in four mature areas of Earth system science that are of great scientific and practical importance [seasonal to interannual climate prediction, atmospheric chemistry, ecosystems, and decadal to centennial climate]."
- "Implement the first group of Mission to Planet Earth (MTPE)/ Earth Observing System (EOS) components: Landsat-7, AM-1, PM-1, Chemistry-1 (CHEM-1), and Tropical Rainfall Measuring Mission (TRMM)."
- "Implement a future framework for MTPE that incorporates advanced instrumentation and vehicle technologies, such as small satellites and remotely piloted vehicles...."
- "Streamline [and] reconfigure EOSDIS...."

National Research Council 1995 Review Recommendations on the USGCRP (Cont.)

Program Funding

- "Success in attacking the long-term scientific challenges of the USGCRP requires an adequate and stable level of funding that promotes management efficiency and encourages rational resource allocation."
- "The Congress should ensure that program authorizations and resource allocations to individual agencies are consistent with the implementation of an integrated program...[and] provide a mechanism for bipartisan, bicameral oversight of the effectiveness of the program in meeting the information needs of the Nation."

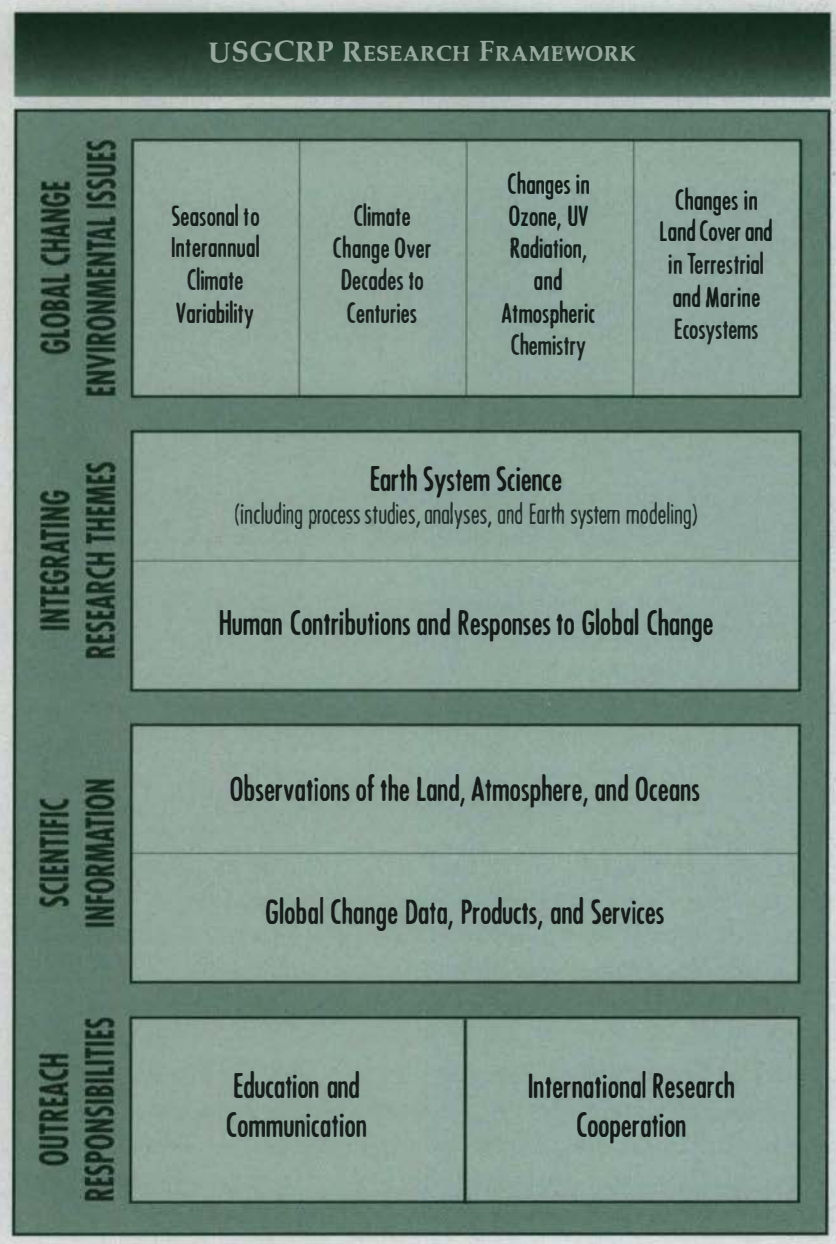
EOS program has been restructured to include opportunities for small satellite missions to both initiate new science studies and to test new instrument technologies. Planning for streamlining and reconfiguring EOSDIS is underway.

Research Framework

The accompanying figure presents a schematic diagram of the USGCRP research framework. This framework is designed to strengthen the integration of scientific activities and to aid in achieving strategic direction for future research program efforts.

The top row of the diagram indicates the major issue-oriented thrusts of the USGCRP. These focused research efforts on key global change environmental science issues depend on a set of integrating activities, including observations and data management, process studies, predictive modeling, environmental and human consequences research, and support for assessments to provide a scientific underpinning for societal decisionmaking as appropriate to each issue.

These activities are represented by the supporting layers in the diagram, which define the activities and perspectives central to program integration. These integrating activities and perspectives contribute in varying ways to all of the program thrusts on key environmental science issues. In addition, the diagram indicates ongoing program responsibilities pertaining to international research cooperation and to global change education and communication.



Within each of these areas, the USGCRP emphasizes the following:

- Identification of new research opportunities that will advance the overall objectives for their areas
- Coordination of agency programs.

The SGCR has program direction and oversight responsibility for ensuring integration and balance in the efforts of these panels.

2. Global Change Environmental Science Issues

Enhancing the USGCRP Focus on Priority Issues

In its 1995 review of the USGCRP, the National Research Council recommended that, in order to be most effective, the USGCRP "...should focus on priority issues in four mature areas of Earth system science that are of great scientific and practical importance."

A USGCRP internal review had suggested similar steps be taken, to more closely integrate scientific research with the objectives and needs of societal decisionmaking. The FY96 edition of *Our Changing Planet* includes a description of the scientific basis for these environmental science issues and a summary of key recent findings in each area.

As a consequence of these external and internal reviews, the USGCRP is moving aggressively to focus research efforts on the four interrelated environmental science issue areas that were identified:

1) **Seasonal to Interannual Climate Variability**, with the goal of obtaining a predictive understanding and the skills to produce forecasts of short-term climate fluctuations and to apply these predictions to problems of social and economic development in the United States and abroad
2) **Climate Change over Decades to Centuries**, with the goal of understanding, predicting, assessing, and preparing for changes in the climate and the global environment that will result from the influences of projected changes in population, energy use, land cover, and other natural and human-induced factors
3) **Changes in Ozone, UV Radiation, and Atmospheric Chemistry**, with the goal of understanding and characterizing the chemical changes in the global atmosphere and their consequences for human health and well-being
4) **Changes in Land Cover and in Terrestrial and Marine Ecosystems**, with the goal of providing a stronger scientific basis for understanding, predicting, assessing, and responding to the causes and consequences of changes in terrestrial and marine ecosystems resulting from human-induced and natural influences.

The remainder of Chapter 2 provides an overview of research and program activities and directions for each of these key issues. For additional

information on recent progress in each of these environmental areas, the *Our Changing Planet* for last year (reporting on the FY96 budget proposal) provided an introductory discussion of each of these issues and reported on recent research accomplishments. Additional detail on planning in each of these areas for the next 5 to 10 years will be included in the full National Global Change Research Plan, which is being prepared by interagency teams for review by the NRC before submission to Congress pursuant to the Global Change Research Act of 1990.

Seasonal to Interannual Climate Variability

Understanding Year-to-Year Climate Fluctuations: Forecasts and Applications

Climatic records and human experience demonstrate that the Earth's climate is a naturally dynamic system. Variations in climate occur on time scales of seasons to years, and decades to centuries. These natural fluctuations in the patterns and amounts of precipitation, temperature, and other climatic measures significantly influence agricultural productivity and economies around the world.

Meteorologists currently track and forecast the weather—that is, the state of the atmosphere at a given time and place. These forecasts provide the public with useful information about expected near-term precipitation, temperature, and wind conditions. Until recently, meteorological forecasting skill was limited to predicting weather changes over the next several days. Now, scientists are gaining the skill to forecast prevailing precipitation and temperature conditions in particular regions over periods of time from a season out to even a year.

Scientists are making exciting breakthroughs in understanding climate fluctuations that occur on time scales of seasons to years. These breakthroughs could ultimately revolutionize the relationship between human activities and the natural environment. The USGCRP plays a leading role in an ongoing international endeavor to develop and enhance prediction capabilities and to apply experimental forecasts to real problems of the management of increasingly scarce water resources, agricultural production, forests and other managed ecosystems, emerging and re-emerging vector-borne diseases (carried by insects, rodents, and other organisms), and coastal fisheries.

Variations in rainfall and temperature patterns that occur on time scales of seasons to years can lead to extreme climatic conditions, such as droughts and floods. Extended periods of drought and heat can increase the susceptibility of urban settlements and forest and rangelands to fire, disrupt food production and water supplies, and, in developing regions, 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.

Extreme weather events, such as the recent flooding in Oregon, Washington, Montana, and Idaho, the multi-year drought in California in the late 1980s and early 1990s, and the very snowy winter of 1996 in the eastern United States are not necessarily due to random chance, as

was once believed. There is tantalizing evidence that many of these extreme events are linked to a natural phenomenon known as the El Niño/Southern Oscillation. When an El Niño event—the anomalous warming of the eastern tropical Pacific Ocean—interacts with its atmospheric counterpart, the Southern Oscillation, temperature and precipitation patterns are affected throughout the tropics and into at least the lower reaches of the higher latitudes.

Although the ENSO is believed to be the most important contributor to year-to-year climate variability in many regions of the world, other phenomena are also believed to play a significant role in some regions:

- The Asian summer monsoon regime and its possible links to both the ENSO and to higher latitude events that affect Himalayan/Tibetan snow cover
- Variability of equatorial Atlantic sea temperatures and their relationship to drought in northeastern Brazil and the African Sahel
- The Quasi-Biennial Oscillation in the upper atmosphere and its linkages (along with the ENSO) to tropical cyclone activity in the North Atlantic region
- Land surface vegetative and hydrological conditions and their role in the persistence of summer droughts in the United States and elsewhere
- The relationship between early season snow cover and subsequent temperature and precipitation regimes over continents.

Seasonal to Interannual Climate Variability Program Goal

The goal of the seasonal to interannual climate variability component of the USGCRP is to obtain a predictive understanding and the skills to produce forecasts of short-term climate fluctuations and to apply these predictions to problems of social and economic development in the United States and abroad.

Progress toward this goal will provide improved predictions that can, among other direct benefits, help farmers maintain their agricultural productivity in spite of extreme climatic events such as droughts and floods; help water resource managers to ensure reliable water deliveries and optimal reservoir levels; help in planning fishery harvests; and help foresters allocate resources effectively to safeguard forests (and the public) from fire during droughts.

Much progress has been made by the scientific community in developing the capability to predict, with reasonable certainty, incipient

El Niño events and the related teleconnections (related atmospheric linkages to distant effects). These experimental El Niño forecasts are already being used with documented success in the tropics (where current prediction skill is highest) to maintain the productivity of the agricultural sector during ENSO-related periods of anomalous rainfall and temperature. Peruvians have been able to sustain the gross output of their agricultural sector, increasing it by 3% in 1987 in spite of the moderate 1986-87 ENSO event (in contrast to a 14% decrease in 1983, which accompanied the devastating 1982-83 event). In Ceara, Brazil, during the drought of 1991-92, a systematic effort to organize the timing of seeding, based on prediction information, maintained agricultural production close to the historical annual mean.

These early applications projects in Brazil and Peru demonstrate the potential social and economic returns from a continued national (and international) investment in "end-to-end" seasonal to interannual climate research. "End-to-end" refers to the application of research-based products to real issues of socioeconomic development and sustainability, with feedback from the information users to the scientific community to guide future research directions.

The U.S. economy is both directly and indirectly affected by climate fluctuations associated with ENSO. The economic benefits of improved forecasts of ENSO to the agricultural sector of the southeastern United States have been estimated to exceed $100 million per year. The economic value of improved forecasts to other U.S. regions is also likely to be large. Indirect effects of ENSO on the U.S. economy arise because the United States is part of the global marketplace. Many countries affected by ENSO events are developing countries with a high dependence on the agricultural and fisheries sectors as major sources of food supply, employment, and foreign exchange. Current assessments of these issues strongly suggest that research to support improved ENSO forecasting will bring significant benefits to the Nation.

Seasonal to Interannual Climate Variability Research Objectives

Due in large part to the international Tropical Oceans/Global Atmosphere (TOGA) program that was conducted from 1985-95, scientists can now predict with reasonable certainty (up to 1 year in advance) the onset of El Niño episodes in the tropical Pacific Ocean (see the figure on the back cover for an example of forecast skill). TOGA produced fundamental new knowledge of the processes that couple the tropical Pacific Ocean to the global atmosphere, and ultimately led to

the emerging prediction capability. The USGCRP will continue in the coming year to build upon the success of TOGA as it participates in the Global Ocean-Atmosphere-Land System (GOALS) project of the international program on Climate Variability and Predictability (CLIVAR), undertaken under the auspices of the World Climate Research Programme (WCRP). In addition, the USGCRP will advance research geared to provide a greater predictive understanding of other climate processes that play a role in short-term climate fluctuations, through projects such as the Global Energy and Water Cycle Experiment Continental-Scale International Project (GEWEX/GCIP).

In FY97 and over the next several years, the USGCRP will build on its initial successes and support research activities geared to achieve the following objectives.

Objective 1—Improve Prediction Skills, particularly over the United States

While the TOGA program 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 and its related climate impacts. Forecast skill is highest in the tropics, near the source of an El Niño, and diminishes at higher latitudes (e.g., over North America) where other processes may play a greater role. The international GOALS program is designed to continue research necessary for continuous improvements of El Niño predictions and 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 on seasonal to interannual climate variability, particularly at higher latitudes.

Objective 2—Monitor the Tropical Pacific Ocean in Order 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 monitor constantly the state of the tropical Pacific Ocean and transmit data to research and operational centers in real-time. These data on current conditions provide the critical initial conditions needed in order to make more accurate forecasts.

Objective 3—Map Global Precipitation and its Relationship to Climate Fluctuations

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, land surfaces, and the oceans (see figure on page 27). 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 reliable maps of global precipitation. These developments were advanced by the international TOGA program, the International Satellite Cloud Climatology Project (ISCCP), TRMM science activities, and the International Satellite Land Surface Climatology Project (ISLSCP). Continued improvements in mapping global precipitation, advanced in part by the GEWEX/GCIP initiative, will benefit the global community through improved management of water resources and through better understanding of and ability to predict the climate system, to understand the controlling processes relevant to climate on seasonal to interannual time scales and regional to global spatial scales, and to develop predictive climate models.

Objective 4—Incorporate Field Data into Models in Order to Improve Forecasts of Climate Variability

Air-sea interaction processes in the western tropical Pacific Ocean are important to the evolution of the ENSO phenomenon. High-quality data sets resulting from a recent international field campaign in the western Pacific are being analyzed in order to improve understanding of the coupling between the ocean and the atmosphere in this climatically important region. Process-based models will be modified to incorporate improvements in understanding.

Objective 5—Assess Human Vulnerability to Climate Variations and Identify Options for Adaptation Based on Improved Information from Predictions

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

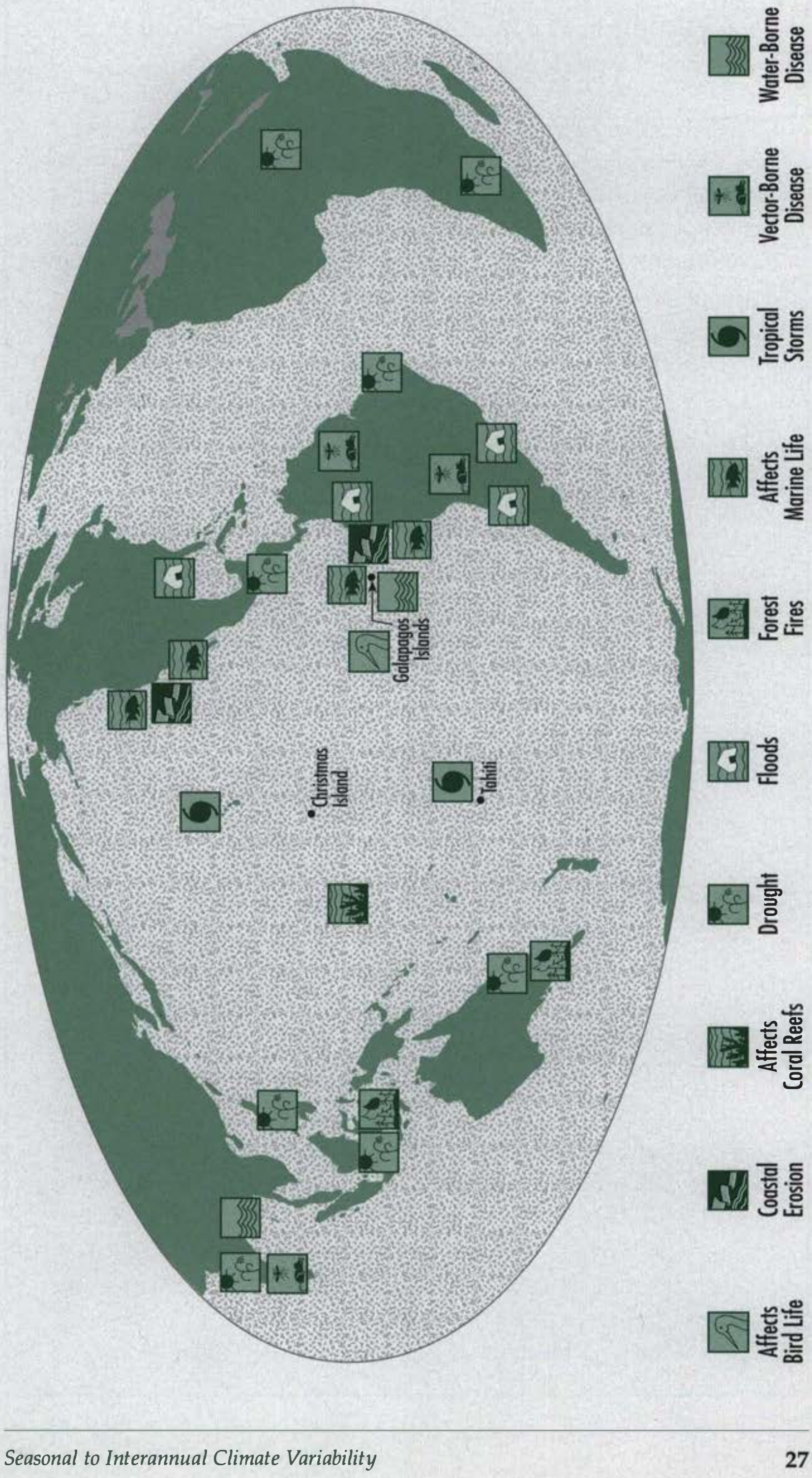
analysis and predictive capability, climate information needs to be incorporated into management decisions in climate-sensitive sectors (e.g., hydropower, insurance, transportation, fisheries, and agriculture). Moreover, lessons learned from adapting to natural variability will help society to be prepared to deal with the possibility that longer term climate change may manifest itself as changes in the frequency and magnitude of extreme events.

Objective 6—Establish a Network of Research Centers to Improve Forecast Model Development and Diagnostics, and the Application of Predictive Information to Socioeconomic Planning Processes

To ensure that advances in climate prediction continue and are suited to the specific needs of affected populations, within and outside the United States, the USGCRP, led by NOAA, has established a Seasonal-to-Interannual Climate Prediction Program (SCPP), based on the evolution of existing USGCRP efforts to observe, research, model, and assess the interactions of the ocean, atmosphere, and land surfaces. The SCPP is based on an integrated approach that addresses climate variability from its origins in coupled atmospheric and oceanic behavior through its physical manifestations and socioeconomic impacts.

ON THE FACING PAGE

El Niño events cause fluctuations in temperature and rainfall patterns in the Pacific basin and beyond. These periodic variations that occur as a result of the interaction between the ocean and the atmosphere in the tropical Pacific region can affect ecosystems and human lives in far flung regions of the globe. This ocean-atmosphere phenomenon, known as the El Niño/Southern Oscillation (ENSO), affects climate-sensitive human activities such as agriculture and fisheries. The symbols on this map indicate the types of impacts associated with "warm" ENSO events, such as occurred in 1982-83 and during the early 1990s, in which ocean waters in the eastern tropical Pacific Ocean warm by only one to a few degrees above their normal conditions. That these relatively small changes cause such significant responses indicates how sensitive the climate, ecosystems, and society are to these natural fluctuations. The effects of a La Niña event (an anomalous cooling of the waters off the coast of South America) also can cause climatic and ecological disruptions; in some regions, the impact of La Niña is the opposite of that caused by El Niño. The figure is courtesy of the NOAA Office of Global Programs.


Galapagos Islands
Christmas Island
Tahiti
Affects Bird Life
Coastal Erosion
Affects Coral Reefs
Drought
Floods
Forest Fires
Affects Marine Life
Tropical Storms
Vector-Borne Disease
Water-Borne Disease

Highlights of Recent Research on Seasonal to Interannual Climate Fluctuations

USGCRP-sponsored research continues to advance the predictive and comprehensive understanding of seasonal to interannual fluctuations in the climate, including the socioeconomic implications of applying experimental predictions to agriculture and water management. The FY96 edition of *Our Changing Planet* included a summary of recent key findings. Highlights of more recent findings follow:

- The TOPEX/Poseidon satellite mission is providing the first precise global information on the state of the ocean. The instrument can measure changes in ocean height, which is a good indicator of ocean temperature and movement. This information is being used to test the computer models that predict ENSO events. Testing and refinement of the models is important, because ENSO events have been shown to disturb the temperature and precipitation systems in the tropics, lower latitudes, and parts of the United States, and affect agricultural production, fisheries, and water resources.
- The USGCRP led the world in a critical step toward the development of an International Research Institute for climate prediction that will generate experimental forecasts of the ENSO phenomenon and make them available for socioeconomic applications around the world. Representatives of more than 40 countries and 20 international organizations gathered in Washington, DC, to address the creation of an IRI with the capability to transform scientific information into products that can be applied in real-time to economic planning associated with water management, agriculture, natural disasters, and public health.
- The GEWEX Continental-Scale International Project is a multi-year field experiment underway in the Mississippi River Basin. The experiment focuses on improving predictions of changes in water resources on monthly, seasonal, annual, and interannual time scales. Considerable progress has been made in the development of better representations of soil moisture and vegetation cover in regional coupled models. While regional in design, GCIP findings are starting to provide important information for the water and agricultural sectors throughout the United States.

Highlights of Recent Research on Seasonal to Interannual Climate Fluctuations (Cont.)

- A unique effort has been launched in the U.S. Pacific Northwest to bring together a multidisciplinary team of researchers with expertise in water management, coastal activities, fisheries, forestry, hydrologic modeling, institutional arrangements, and climate prediction. The scientists are developing an integrated approach to analyzing the impacts of seasonal to intradecadal climate variations on different social, economic, and ecological sectors with the aim of determining how climate forecasts can be used to improve decisionmaking in these sectors for the benefit of society.
- Preliminary analyses of climate-crop relationships in Utah and Idaho indicate that extreme values of precipitation and temperature have the most significant impact on crop yields. These analyses further demonstrate the impact of ENSO events on crop yields, rangeland conditions, and the duration of forage harvest for grazing. A framework for assessing the relationship between climate and land use in the states of California, Oregon, Washington, Nevada, Idaho, Utah, Colorado, and Wyoming is now under development.

A fundamental component of the SCPP is the establishment of a multinational network of research and application centers to develop and issue experimental seasonal to interannual climate predictions based on global ocean-atmosphere modeling of interannual processes. One of these research centers will serve as the International Research Institute (IRI) for seasonal to interannual climate prediction, which will disseminate forecasts to nations and regions that are particularly affected by climate variability associated with the ENSO. Application centers will refine the global forecasts and tailor guidance to the specific conditions and needs of the localities they serve. At a high-level meeting convened by the United States in November 1995 (the International Forum on Forecasting El Niño: Launching the International Research Institute), countries and international organizations confirmed their support for the IRI and established an *ad hoc* working group to design an action plan.

Agency Contributions

Reflecting the complexity of the issue, several Federal agencies are associated with the USGCRP's endeavor to understand and predict seasonal to interannual climate variability. NOAA, NSF, and NASA are major contributors to this component of the USGCRP. DoD, USDA, DOI, and other agencies provide additional focused contributions. Each agency brings unique strengths and expertise to this coordinated effort:

- NOAA has the primary responsibility within the USGCRP for routinely providing forecasts of seasonal to interannual climate variability, especially extreme events, to the Nation. To fulfill this role, NOAA is implementing prediction systems for systematic delivery of climate forecasts for the United States and the international community; maintaining a climate observing and data delivery system to provide data routinely for forecasts and analysis; conducting research to improve predictive skill of climate models; and assessing socioeconomic impacts of climate forecasts. In the area of short-term climate variability, NOAA is a key agency in supporting the GOALS component of CLIVAR and the GEWEX/GCIP efforts.
- NSF-funded research includes basic studies directed at describing and understanding the physical processes responsible for short-term climate variability and its predictability, thus providing the scientific foundations for extending the range and accuracy of seasonal to interannual climate predictions.
- NASA operates the Ocean Topography Experiment (TOPEX)/Poseidon satellite, a joint U.S.-France mission, which is making global sea level measurements with unprecedented accuracy, providing the most precise measurements ever of El Niño's effect on the ocean surface and its progress as a broad, low-amplitude "wave" across the Pacific. The soon-to-be-launched TRMM satellite, a cooperative U.S.-Japan venture, will measure the diurnal variation of rainfall in the global tropics and help establish an accurate tropical rainfall climatology. Several instruments onboard the planned EOS-AM and -PM launches will also contribute to the measurement of clouds, water vapor, atmospheric temperatures, and other parameters needed for understanding and prediction of seasonal to interannual variability. NASA continues to develop new measurement technologies and methods for assimilating space-based and *in situ* data into coupled ocean-atmosphere-land models to provide research-quality data sets

that contribute to the understanding of seasonal to interannual climate fluctuations.

- DoD-sponsored research concurrently satisfies Defense mission requirements and the USGCRP charge to understand and predict seasonal to interannual climate variability. Research in high-latitude dynamics and regional-resolving models coupled with unique observing systems is supported.
- USDA conducts research on the effects of climate variability on the frequency of extreme events—drought, wildfire, and insect infestation—in forested systems. Scientists are integrating climate scenarios with effects research into growth and disturbance models to understand the implications of climate variability and extreme events on forest health and productivity.
- DOI research focuses on the linkages between large-scale atmospheric and oceanic patterns and regional hydrologic variability, as well as on the development of improved flood-frequency estimation techniques, in support of operational water resources management.
- DOE funds research that relates the value of improved seasonal and interannual forecasting to better strategies for energy production and use.

Climate Change Over Decades to Centuries

Predicting Climate Change and Understanding its Implications for Society and the Environment

The growth and sustainability of human activities and the character of our environment are strongly influenced by the Earth's prevailing climate. Climate strongly affects the viability of agriculture, the extent of forests and rangelands, the diversity of flora and fauna, the availability of water, the spread of insects and rodents that carry human disease organisms, the intensity and frequency of floods and severe weather events, and much more. These forces influence the social and economic characteristics and success of societies.

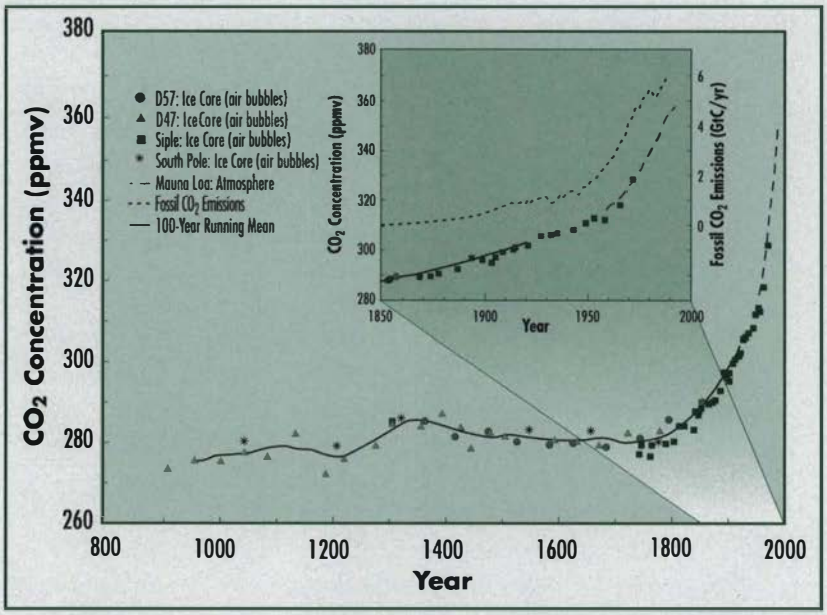
Historical and geological records provide extensive evidence that climate has changed in the past in ways that have (or would have) significantly affected human activities. Research has provided important insights into the natural factors that caused major changes in the climates of the past. These factors tend to cause modest climate fluctuations on time scales of years to centuries and large-scale changes, with few exceptions, on time scales of millennia and longer.

Since the start of the Industrial Revolution 2 centuries ago, human activities have been having an effect on atmospheric composition. The current concentration of CO_2 is about 30% above preindustrial levels as a result of combustion of coal, oil, and natural gas and as a result of clearing of land and plowing of soils for agriculture (see figure on facing page). The current concentration of methane is more than twice the preindustrial level due to land- and energy-related activities. One hundred years ago, rising emissions of CO_2 spurred the Swedish scientist Svante Arrhenius to make the first quantitative estimate of the potential temperature change from an enhanced greenhouse effect. The estimate he made with respect to climate sensitivity is only slightly higher than current estimates; however, the change is occurring much more rapidly than his estimate, which was based on energy use at that time.

Extensive research, much of it funded during the last 20 years by the set of U.S. agencies that participate in the USGCRP, has been carried out to develop more precise and detailed estimates of how human activities will affect the long-term climate. To provide internationally recognized and authoritative scientific information about global climate change, its potential consequences for the environment, and the interactions between climate and society, the United States participates in the Intergovernmental Panel on Climate Change. The IPCC was established

in 1988 by the United Nations Environment Programme and the World Meteorological Organization.

The IPCC provides a mechanism for conducting a comprehensive assessment of the scientific literature on global climate change and its consequences and significance. To prepare these assessments, the IPCC brings together the leading researchers representing a wide range of disciplinary backgrounds and perspectives. It is asked to consider the findings from the world scientific community and, where possible, to reconcile competing views, to characterize alternative perspectives and viewpoints when consensus is not achievable, and to analyze the potential implications of uncertainties. In this way, the IPCC assessments



The atmospheric carbon dioxide concentration has risen from about 280 parts per million by volume (ppmv) to about 360 ppmv in the period from before the Industrial Revolution to the present. This rise of nearly 30% in the atmospheric concentration is a result of emissions of carbon dioxide from human activities, both from combustion of fossil fuels and from the clearing of forested land for agriculture and other uses. Emissions now total about 6 billion tons of carbon per year (GtC/yr). That the rise in concentrations is occurring is confirmed by many types of measurements, including those of the carbon dioxide concentration in the air over the past 40 years and in air bubbles trapped in glacial ice over the past 1,000 years. The figure is from the Working Group I contribution to the IPCC Second Assessment Report (1995).

Key Findings of the IPCC Second Assessment Report

During 1995, the Intergovernmental Panel on Climate Change prepared its Second Assessment Report. U.S. scientists and research findings played a pivotal role in the development of this assessment. The following conclusions about climate change, its consequences, and the potential for adaptation and mitigation are extracted from the report. The IPCC findings provide important guidance for decisionmakers and identify critical research questions that need to be pursued.

Effects of Human Activities on Regional and Global Climate, and on Sea Level

- Human activities are increasing the atmospheric concentrations of CO_2 and other greenhouse gases that tend to warm the atmosphere and, in some regions, of aerosols that tend to cool the atmosphere.
- The Earth's climate is changing. The surface temperature this century is as warm or warmer than any other century since at least 1400 AD; the global average surface temperature has increased by 0.3 to 0.6°C (about 0.5 to 1°F) over the last century; the last few decades have been the warmest this century; sea level has risen 10 to 25 cm (about 4 to 10 inches); and mountain glaciers have generally retreated this century.
- Models that account for the observed increases in the atmospheric concentrations of greenhouse gases and sulfate aerosols are simulating the recent history of observed changes in surface temperature and its vertical distribution with increasing realism.
- The balance of evidence suggests that there is a discernible human influence on global climate.
- Without specific policies that reduce the growth of greenhouse gas emissions, the Earth's average surface temperature is projected to increase by about 1 to 3.5°C (about 2 to 6.5°F) by 2100—a rate of warming that would probably be greater than any seen in the last 10,000 years.
- The reliability of regional-scale predictions is still low, and the degree to which climate variability may change is uncertain.
- Sea level is projected to rise by 15 to 95 cm (6 to 38 inches) by 2100.

Key Findings of the IPCC Second Assessment Report (Cont.)

- The long atmospheric lifetime of many greenhouse gases, coupled with the thermal inertia of the oceans, means that the warming effect of anthropogenic emissions will be long-lived.
- Even after a hypothetical stabilization of greenhouse gas concentrations, temperatures would continue to increase for several decades, and sea level would continue to rise for centuries.

Potential Health and Environmental Consequences of Climate Change

- Human-induced regional and global changes in temperature, precipitation, soil moisture, and sea level add important new stresses on ecological and socioeconomic systems that are already affected by pollution, increasing resource extraction, and non-sustainable management practices.
- Most systems are sensitive to both the magnitude and rate of climate change.
- Many regions are likely to experience adverse effects as a result of climate change, some of which are potentially irreversible; however, effects of climate change in some regions may be beneficial.
- The projected changes in climate include potentially disruptive effects that will affect the economy and the quality of life for this and future generations:
  - *Human Health* will be adversely affected through an increase in the rate of heat-related mortality and in the potential for the spread of vector-borne diseases such as malaria, dengue, yellow fever, and encephalitis and non-vector-borne diseases such as cholera and salmonellosis.
  - *Food Security* will be threatened in some regions of the world, especially in the tropics and subtropics where many of the world's poorest people live. On the whole, the effects of climate change over the next century on total global food production may be small to moderate in comparison to the effects of population change and demands for improved nutrition.
  - *Water Resources* will be increasingly stressed, leading to substantial economic, social, and environmental costs,

Key Findings of the IPCC Second Assessment Report (Cont.)

especially in regions that are already water-limited and where there is strong competition among users.
  - *Human Habitat Loss* will occur in regions where small islands and coastal plain and river areas are particularly vulnerable to sea level rise.
  - *Natural Ecosystems* will be degraded because the composition, geographic distribution, and productivity of many ecosystems will shift as individual species respond to changes in climate. This may lead to reductions in biological diversity and in the goods and services ecosystems can provide for society.
- Developing countries are more vulnerable than developed countries to climate change because of their socioeconomic conditions.
- Impacts will be hard to quantify with certainty because of uncertainties in regional climate projections, the complicating effects of multiple stresses, and a lack of understanding of some key processes.

Approaches to Mitigate or Adapt to Climate Change

- Adaptation—which involves adjustments in practices, processes, or structures of systems—can be helpful in reducing adverse impacts or in preparing to take advantage of potential beneficial changes in climate.
- Successful adaptation will depend upon education, technological advances, institutional arrangements, availability of financing, technology transfer, information exchange, and incorporation of climate change concerns into resource-use and development decisions. Potential adaptation options for many developing countries are extremely limited due to the limited availability of technological, economic, and societal capabilities.
- Options such as migration corridors to assist adaptation of natural ecosystems to new climate conditions are, however, currently limited and their effectiveness is generally unproven.
- Stabilization of the atmospheric concentrations of CO_2 at three times the pre-industrial concentration or less will eventually require human-induced emissions of greenhouse gases to be cut below today's levels.

Key Findings of the IPCC Second Assessment Report (Cont.)

- Gains in energy efficiency of 10-30% above present levels are feasible at little or no cost in many parts of the world through technical conservation measures and improved management practices over the next 2 to 3 decades.
- Significant reductions in net greenhouse gas emissions can be achieved utilizing an extensive array of technologies, and policy measures that accelerate technology development, diffusion, and transfer in all sectors.
- Flexible, cost-effective policies relying on economic incentives and instruments, as well as internationally coordinated instruments, can considerably reduce mitigation and adaptation costs.

serve two major purposes: (i) They provide a summary of the current state of the science for consideration by decisionmakers, and (ii) they enable the scientific community to take stock of current knowledge, identify areas of agreement and disagreement, and define areas for future research that will help to clarify such differences and advance knowledge to reduce key uncertainties.

The research sponsored by the USGCRP on climate change, together with the results of the research programs of nations around the world, provides the supporting information for the IPCC assessments. The first comprehensive assessment was conducted in 1990. Interim reports were issued in 1992 and 1994 on special aspects of the issue. The Second Assessment Report was completed in 1995.

In its most recent scientific assessment, the IPCC came to a number of new conclusions. For example, the IPCC concluded that human activities most likely have caused an influence on the global climate over the last century that is becoming discernible from natural variations and that the human-induced effect is becoming larger than the natural climatic variations that have occurred over the past 1,000 years. The IPCC assessment, after reviewing the state of climate modeling, projected that during the next 2 centuries and beyond human influences will cause the climate to change more rapidly than during any known period in the last 10,000 years of human settlement. While some new opportunities for taking advantage of these changes are expected to emerge, human-induced climate change is currently projected, on

balance, to cause significant disruptions to resource systems, societies, economies, and the environment (see the accompanying box and the FY96 *Our Changing Planet* for an introduction to scientific understanding of the potential for human-induced climate change).

Among the results of the IPCC assessment is the identification of limitations in scientific understanding and of areas where additional research would be particularly helpful in resolving remaining questions. In formulating the USGCRP research activities in this element of the program, the agencies focus on addressing the findings of the IPCC and the uncertainties identified by the National Academy of Sciences and the broader scientific community in their consideration of this issue.

Climate Change Program Goal

The goal of the climate change element of the USGCRP is to understand, predict, assess, and prepare for changes in the climate and the global environment that will result from the influences of projected changes in population, energy use, land cover, and other natural and human-induced factors.

Progress toward the goal will provide information needed by decision-makers considering adaptive or mitigative responses to projected changes in climate and the associated environmental and societal impacts. The information will also assist planners and managers with responsibilities for the design of infrastructure and other major facilities, sustained management of natural resource-based systems, and long-term planning in the financial sector.

Research to achieve this goal requires a wide range of activities:

- Global observations of the climate system, including monitoring long-term changes in the climate and in factors that force climatic change (through ground-, airborne-, ocean-, and space-based measurements)
- Compilation of inventories of greenhouse gas and aerosol emissions, and their precursors, resulting from human activities
- Understanding of the processes that cause climatic changes and fluctuations (through laboratory studies, site-specific research, and field campaigns)
- Incorporation of that understanding into predictive models that can test the extent of understanding, reveal deficiencies in model simulations, and predict future climatic and environmental responses to various emissions scenarios

- Determination of the consequences of climate change for human activities and resource systems, including economic and natural resource systems
- Development of analytical tools to evaluate the potential effectiveness and viability of alternative approaches to adapt to or mitigate such consequences
- Synthesis and critical review of the findings and their integration for use by decisionmakers.

Together, these studies will provide a set of predictive tools and capabilities that can provide information for use by policymakers as they consider various options for responding, mitigating, or adapting to climatic change. The scientific ability to predict, even in a limited way, how the climate is likely to change will provide valuable information for decisionmakers seeking to ensure our continued prosperity, to reduce the exposure of the human population to health-related stresses, and to protect the overall vitality of the environment on which society depends. Increased understanding and enhanced prediction capabilities are required in order to provide the information needed by decisionmakers in considering actions to moderate future changes and to promote efficient adaptation to the changes that do occur.

Climate Change Research Objectives

Significant progress has been made over the past few decades in providing a broad-scale understanding of the role that human activities are playing and will play in the future in changing the global climate. While we have learned that human activities are changing the climate and that significant changes will occur in the future, significant gaps remain in understanding the regional patterns of climate change and the potential consequences and implications of climate change for the environment and for society. In FY97 and over the next several years, the USGCRP will continue to address significant uncertainties through support for research activities oriented toward the following key objectives.

Objective 1—Quantify the Natural and Human-Induced Factors that Change Atmospheric Composition and Radiation

The most important human-induced factors that are forcing climate change include gases and aerosols (small particles) that are modifying the Earth's natural greenhouse effect by altering the fluxes of solar and

infrared (heat) radiation balance. Changes in the land surface and its vegetation are also altering the Earth's reflectivity and hydrology. Quantifying the character and trends in these climate forcing factors is vital to understanding the causes of past changes and to predicting more accurately future changes in climate. In addition, understanding what is causing the changes in these factors will provide the basis for quantifying the effects of various mitigation options.

The most important results from recent research indicate 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 from the increase in the concentrations of greenhouse gases. In 1997, the USGCRP will continue to support studies of the cycles of greenhouse gases and of the generation and distribution of aerosols; these studies will be carried out in coordination with the atmospheric chemistry research component of the USGCRP. Studies to refine understanding of the global carbon cycle will focus on the role of terrestrial systems in carbon uptake and will be carried out in coordination with the land cover and ecosystem change research component of the USGCRP. Studies of volcanic and solar variability will be carried out to document natural factors that influence the climate.

Objective 2—Characterize Natural Climate Variability and the Factors Contributing to Decadal and Longer Period Climate Fluctuations

Climate varies over many time scales. Over periods of a few years to decades, climate can be changed by volcanic eruptions, solar forcing, and natural fluctuations in the climate system. Paleoclimatic records reconstructed from ice cores and other sources of data provide evidence that the Earth's long-term climate varied significantly prior to about 10,000 years ago. However, since that time, the long-term climate has been relatively stable, especially over the past few 1,000 years. It is important to understand why this is the case, and what the prospects might be for a return to a significantly more variable climate.

Although the long-term climate has been stable, the evidence suggests that, during the last glacial period (which ended about 10,000 years ago), shorter term climate changes occurred over periods as short as a few decades. Data from the past 1,000 years suggest that there have been interdecadal swings in climate, creating periods of drought in some regions and excess moisture in others. Determining the character and causes of climate variability is thus essential as context for detecting

that climate change has occurred and for determining the extent to which the changes are due to human activities. The natural variability component of the international CLIVAR program is being designed to improve understanding of natural changes in the climate.

Recent research has provided information on past changes in the Earth's climate (from historical records, ice cores, lake-level data, and other indicators). Evidence 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 periods as short as decades. In 1997, research will even more intensively focus on interactions within the coupled atmosphere-ocean-ice system. The coupled processes appear to be important contributing factors to natural variations in the climate on inter- and multi-decadal time scales. Studies of solar variability and major volcanic eruptions as climate forcing factors on these time scales will also be carried out. Efforts will continue to reconstruct past climates of the Earth to improve understanding of the dynamics of climate change, with emphasis given to the study of warm climates to provide information for comparing to the warm climate now being experienced.

Objective 3—Improve Quantitative Representations of Climate System Mechanisms and Feedback Processes

Predicting climate change requires a quantitative understanding of the climate system and of the mechanisms and feedback processes that determine its state. This understanding is needed to determine how the atmosphere, oceans, and land surface will be affected by the projected changes in greenhouse gases, aerosols, land cover, and other factors that are causing changes in the Earth's radiation balance. Available knowledge clearly indicates that changes in the radiation balance can be amplified or moderated by various feedback processes and mechanisms as the Earth system responds to these diverse forcing factors. Feedback mechanisms control whether the climate will respond strongly or weakly to human-induced changes. They also control how rapidly or slowly the Earth's climate will change. Reducing uncertainty about the magnitude of feedbacks is thus essential to providing more accurate predictions of how climate will change in response to alternative emissions scenarios for greenhouse gases, and to developing the capability to provide more accurate estimates of the regional patterns of climate change.

New and unexpected research results indicate that significantly more solar radiation may be absorbed by the atmosphere, both clear and cloudy, than is currently predicted by theory and climate models.

Because this result is inconsistent with current understanding and is therefore controversial, it requires further observational confirmation. If confirmed, these new findings will require understanding the processes responsible for the currently unpredicted atmospheric solar absorption and a reanalysis of the Earth's radiation balance, and could result in significant improvements in climate models. In 1997 and beyond, just as it has in earlier years, the USGCRP will continue to support broad-based and diversified programs of observations, field studies, analysis, and process-based modeling to improve understanding of coupling and interactions among aerosols, water vapor, and radiation in both cloudy and clear atmospheres; the hydrologic cycle; ocean circulation; biogeochemical cycling; land-surface/atmosphere interactions; and climate-chemistry feedbacks.

Objective 4—Improve Scenario-Driven Predictions of Climate Change and Identification of the Human-Induced Component in the Recent Climate Record

Because of the historical uniqueness of the ongoing human-induced changes in atmospheric composition, predictions of future conditions for particular scenarios require the use of numerical, computer-based Earth system models. It is essential that these models—which are composed of traditional ocean and atmospheric general circulation models (GCMs) augmented by representations of the land surface, vegetation, chemistry, and the cryosphere (glaciers, snow, and ice)—be based on a comprehensive scientific understanding of the functioning of the climate system. The comprehensive understanding needed to develop and apply such models is developing rapidly from observational, process, and modeling studies. Such studies are starting to provide important insights into how the climate system has behaved in the past and how it will respond in the future to natural and human-induced forcing factors.

Over the past 10 years, as a result of USGCRP-sponsored research, atmospheric and oceanic GCMs have improved significantly and have strong potential for continuing advances through improved representations of critical climate processes and finer model resolution for regional-scale predictions. More accurate simulations of past climatic conditions are helping to improve confidence in the models by providing explanations for past changes and a quantitative identification of the human influence on recent climate. In FY97, research will continue to emphasize incorporation of carefully tested modules in climate

models; enhanced use of the most powerful computers; coupling of atmospheric, oceanic, and land surface components of the Earth system; and testing and comparison of model simulations with observations as a means to evaluate the confidence that can be placed in model results. Studies to detect human-induced climate change will be continued with additional studies of the roles of various influences in contributing to climate change.

Objective 5—Develop Improved Measures of the Sensitivity, Vulnerability, and Adaptability of Natural Ecological Systems and Managed Resource Systems and Project the Consequences of Climate Change and Long-Term Variations of the Climate

The potential impacts of climate change on natural and managed systems, human activities, and the economy are of great practical interest. Human activities that inadvertently influence climate are integrally intertwined with natural and managed resource systems. Examples include failure to optimize use of organic and chemical nitrogen fertilizer; degradation and clearing of forests; and shifts in land use between forest, range agriculture, and other uses. Given these many couplings, only limited progress has been made over the past 10 years in projecting the potential consequences to the environment of climate change. In addition, because accurate projections of regional changes in the climate are not available, the near-term focus must be on developing an understanding of the sensitivity and vulnerability of resource and societal systems to hypothetical changes that may occur over the next century.

Recent research results indicate that some plant 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 some species, mitigate the damaging effects of elevated ozone concentrations and improve their water use efficiency. However, some species, such as aspens, become more sensitive to increased concentrations of ozone if CO_2 concentrations are elevated. In 1997, USGCRP studies will be continued that focus on the responses of terrestrial ecosystems (including agriculture, forests, rangelands, and polar ecosystems) and marine ecosystems to large-scale environmental change, including the enhancement of plant growth by the rising CO_2 concentration. These studies will be coordinated with the efforts described in the land cover and ecosystems section of this report. Internationally, research will focus on sensitive ecosystems and regions

that are experiencing multiple stresses in addition to climate change, and will be carried out in coordination with other nations.

Objective 6—Develop Improved Measures of the Sensitivity, Vulnerability, and Adaptability of Socioeconomic Systems, and Project the Societal Implications of Climate Change and Long-Term Natural Variability

In order to develop a stronger capability for assessing the impacts of changes and the implications of alternative societal responses, research on the human dimensions of climate change must be carried out along with research on the behavior of natural and managed systems. An important effort will continue to be the enhancement of integrated assessment capabilities, including, but not limited to, the further development of integrated assessment models. In FY97, research to understand and improve the capabilities for estimating and accounting for the non-market aspects of climate change will be more actively pursued. In addition, efforts will be made to better enable coupling of findings relating to climate change with other aspects of environmental and societal change.

Human society and the natural and managed ecosystems upon which it depends are undergoing continual change as a result of many internal stresses and challenges. Prolonged changes in the climate over periods of decades to centuries will be an additional external influence, leading to further changes in societies and affecting their relationships to these systems. Research will continue to explore these linkages and better define the role of inadvertent human influences on the systems on which we depend.

Links to Users of Information through Assessment

Because climate is such a pervasive influence in human affairs, it is essential in studying climate to be able to assemble and systematically evaluate diverse sets of information—a process called assessment. The United States, through the USGCRP, has joined with other nations in supporting the Intergovernmental Panel on Climate Change as the mechanism for organizing climate change assessments. As explained in the international research cooperation section of this report, the USGCRP agencies have also assisted other nations in understanding their vulnerability to climate change through national studies and participation in the IPCC process.

Highlights of Recent Research on Climate Change

USGCRP-sponsored research continues to advance understanding of the causes, magnitude, and consequences of climate change over decades to centuries. The FY96 edition of *Our Changing Planet* included a summary of recent key findings. Highlights of more recent findings follow:

- Measurements of global surface air temperature over the land and of sea surface temperature over the oceans indicate that 1995 was the warmest year since the beginning of continuous records circa 1860 (see figure on page 47). Despite the century's largest volcanic eruption in 1991, four of the warmest years of the 140-year record occurred during the 1990s. Proxy records from ice cores and other long-term data archives indicate that this century is the warmest in recent history. This evidence that temperatures are rising is further confirmed by indications of receding mountain glaciers and rising sea level.
- Satellite data from the Stratospheric Aerosol and Gas Experiment II (SAGE II) instrument indicate that the very substantial stratospheric aerosol layer caused by the June 1991 volcanic eruption of Mt. Pinatubo had been significantly thinned by early 1994, but that aerosol levels were still nearly 10 times greater than before the eruption, exerting a cooling influence that lasted several years. Data from the Microwave Sounding Unit (MSU) also showed that the stratosphere was warmed and the troposphere was cooled by the Pinatubo eruption, thereby requiring a correction for these events before performing a trend analysis with this data set in search of human-induced climatic change.
- Tropospheric aerosols, both from sulfur dioxide emissions from fossil fuel combustion and from biomass burning, have been demonstrated to have had a regional cooling influence on the climate. Model simulations suggest that, at least near and downwind of source regions, aerosol-induced cooling could be offsetting greenhouse-induced warming, although the patterns of change and the subsequent response of the global climate are complex. Inclusion of the cooling influence of aerosols in

Highlights of Recent Research on Climate Change (Cont.)

model simulations of climate change has improved the agreement between simulated and observed temperature changes over the last century.

- Recent improvements in the ability to compare the spatial and temporal patterns of climate change predicted by models with observations suggest that the geographic pattern of climate change is more likely due to emissions of greenhouse gases and aerosols than to natural variations in the climate. Similarly, the latitudinal and altitudinal pattern of change is more likely to be due to human-induced changes than to changes in natural factors such as volcanic eruptions and solar radiation. Together, these global and regional analyses suggest that a significant fraction of climate change over the last century is due to human rather than natural influences.

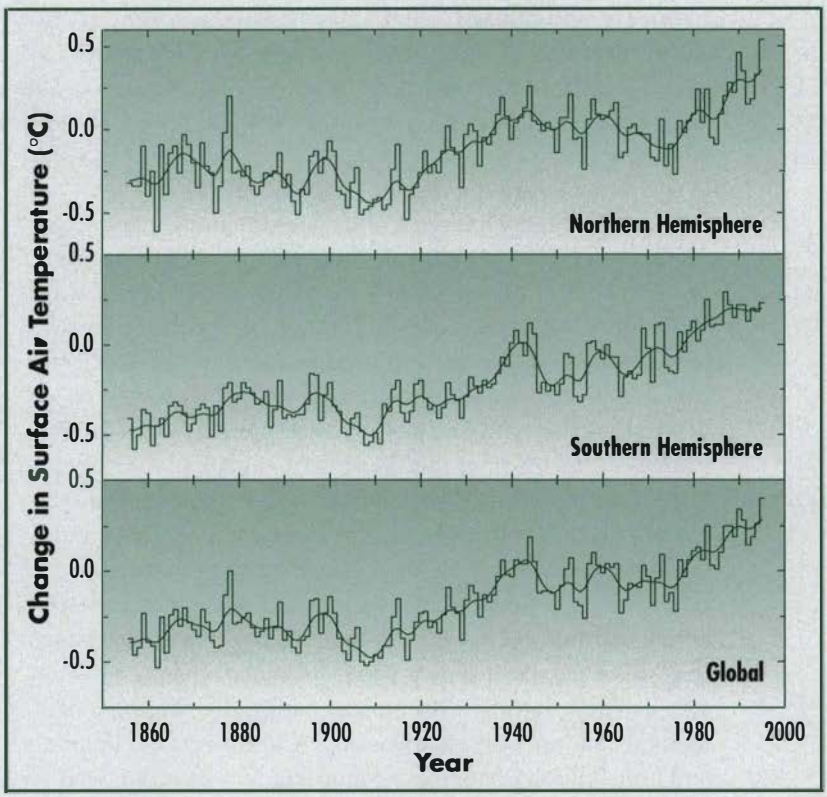
To provide more specific information requested by international decisionmakers, the broadly based IPCC Second Assessment Report will be followed up with Technical Papers and Special Reports providing more focused information. In addition to research on the six objectives indicated above, the USGCRP will continue actively to participate in international assessments of climate change through the IPCC and will explore the opportunities for enhancing the resource base on the national implications of climate change. In addition, research results will be provided to national and State-level planners and decisionmakers so that regional vulnerability can be evaluated.

Agency Contributions

To conduct and support the interdisciplinary research needed for more accurate predictions of climate change and to provide a better understanding of its potential consequences and implications for the environment and society, the USGCRP agencies are committed to a coordinated, long-term research effort on climate change over decades to centuries. Because of the issue's complexity, research contributions are needed by

multiple agencies. NASA, DOE, NOAA, and NSF play major roles in improving the projections of climate change, while USDA, DOI, EPA, and other agencies contribute to evaluating the potential consequences of climate change for society, ecosystems, and natural resources:

- NASA's research efforts involve space-based studies of the Earth as an integrated system. NASA's Mission to Planet



Changes in near-surface temperature (in °C, multiply by 1.8 for °F) from about 1860 through 1995 for the Northern Hemisphere, the Southern Hemisphere, and the globe. The values shown are departures from the average temperature for the period 1961 to 1990—the global average temperature being about 15°C (about 59°F). The figure shows annual departures and a 10-year filter designed to suppress short-term variations. Observations making up this record are drawn from land stations and ship records. For the Northern Hemisphere and for the globe, 1995 was the warmest year of the record, and proxy indicators such as tree rings suggest this century is the warmest since at least 1400 AD. The figure is courtesy of P. Jones, University of East Anglia in Norwich, UK.

Earth has a comprehensive program of satellite observations, as described in the observations and monitoring section, and process and modeling studies that contribute to national and international efforts to understand climate change over decades to centuries. Using data from satellite sensors, MTPE programs examine the role of clouds in the global radiation balance; the atmospheric water cycle; the concentrations, chemistry, and radiative effects of gases and aerosols; ocean circulation; air/sea fluxes; mean sea level change; sea ice dynamics; the mass balance of ice sheets; and other processes and features of the Earth. General circulation and Earth system modeling programs bring together remotely sensed and *in situ* data to examine climate change dynamics.

- DOE global change research addresses the impact of energy production and use on the global Earth system, primarily through studies of climate response to increases in radiatively active trace gases and aerosols. The research focuses on climate change prediction, including research to develop faster running and more accurate climate prediction models; to describe more accurately key physical processes that are the sources of the uncertainties in present climate predictions (e.g., cloud-radiation-water vapor interactions); quantify the sources and sinks of CO_2 and other greenhouse gases; and evaluate the effects of changes on ecological systems and resources. Additional efforts include studies of the atmospheric transport, dispersion, and fate of energy-related emissions (e.g., aerosols); critical data needs for global change research and for early detection of climate change; development of methods and models for integrated assessments of climatic and atmospheric changes; and funding for education and training of scientists and researchers in global change.
- NOAA carries out a balanced program of observational, experimental, and modeling studies that contribute to the understanding and prediction of natural climate variability and the consequences of human activities on climate. NOAA research includes characterizing the factors that are forcing climate change, with emphasis on narrowing the uncertainties in the global carbon cycle and elucidating the trends and forcing of the greenhouse gases and aerosols; understanding the role of the oceans in climate change, with emphasis on examining the role of the deep ocean circulation in climate; ensuring a long-term climate record through improvements in

instrumentation and data records; elucidating the impact of changes in the ozone layer on the Earth's radiation balance; understanding and documenting the causes of rapid climate fluctuations in the paleoclimatic record and the response of marine ecosystems to changes in climate; and furnishing prediction, assessment, and human-impacts information on global climate change.

- NSF supports research to improve the description and fundamental understanding of the physical, chemical, biological, and social and economic processes that affect and are affected by natural and human-induced climate variability and change. Research includes development, evaluation, and application of a global climate system model; observations of atmospheric and oceanic behavior and processes; the extension of records of climate variability and change through the assembly and analysis of paleoclimatic and instrumental data sets, and analyses of these data to distinguish natural climate variability from human-induced climate change; and understanding the connections among climate change, natural and managed ecosystems, and society and its activities. The ultimate goal of the integrated research efforts is to develop the capacity to predict the magnitude and rate of global and regional climate changes that would result from human-induced factors, such as enhanced atmospheric concentrations of greenhouse gases. As a contribution to the scientific community in this area, NSF sponsors the Climate Simulation Laboratory at the National Center for Atmospheric Research (NCAR), a supercomputing resource that is used by scientists funded by many different agencies.
- DOI conducts studies to understand the natural history of climate change, including the natural causes, rates, and ranges of climate change; and the interaction of changing climate with environmental systems on the Earth's land surfaces. Research emphasizes high-latitude cold regions and arid to semi-arid regions of the United States, which are particularly sensitive to climate, as well as biogeographic areas throughout the Nation where DOI requires information about the potential consequences of climate change on the management of U.S. land, freshwater, and biological resources. DOI research emphasizing the natural history, land-air-water interactions, and causes of climate change helps in testing and improving analytical models, distinguishing human influence

from natural variation, and estimating the potential extremes and consequences of future climate change.

- EPA conducts process-level research to improve understanding of the sources, sinks, and transformation of greenhouse gases; freshwater ecosystem response; coastal zone ecosystem response; long-term effects of global climate change on vegetation; and integration of terrestrial greenhouse gas emissions in Earth system models. Research is being conducted toward predicting effects of runoff on freshwater habitats and biota. Coastal zone sensitivity and coastal ecosystem response to interannual to decadal scale climate changes are being investigated in the Mid-Atlantic region of the U.S., where warmwater species have replaced former colder water dominants in the region over the last 20 years. Single tree, forest stand, and global vegetation models are being used to predict the long-term effects of global climate change and increased atmospheric CO_2 on the distribution of global forests, rangelands, croplands, and deserts.
- The Smithsonian Institution conducts collection-based research at its National Museum of Natural History that utilizes millions of specimens as well as field studies to look at both the natural causes of climate change and the human response. Such objects provide cultural records of human reaction to changing climates in a variety of ecological zones, ranging from the Arctic to the tropics. Studies of delta regions and coastal changes in tropical areas are used to determine long- and short-term effects of sea level on coastal ecosystems.
- USDA has no focused programs within the climate change issue area. USDA does, however, conduct a wide range of studies for other primary purposes that provide significant information about how forests, grasslands, and agriculture will be affected by long-term changes in the climate. In addition, through its continuing efforts to develop new seed strains and to enhance soil nutrient quality, USDA research contributes to the understanding of how intensively and less-intensively managed ecosystems can adapt to rapid climate change.

To assemble and assess the emerging information, the USGCRP agencies together support and participate in scientific assessments and in the development of enhanced integrated assessment capabilities.

Changes in Ozone, UV Radiation, and Atmospheric Chemistry

Understanding Atmospheric Chemistry and its Links to Human Well-Being

The recognition that many Earth System components—including the oceans, geosphere, terrestrial and marine biospheres, and cryosphere—are linked via the atmosphere is central to understanding global change. Geological records show that past climate change closely parallelled changes in the atmospheric abundance of the greenhouse gases carbon dioxide and methane, illustrating that changes to the atmosphere have the potential to perturb other major parts of the Earth system and *vice versa.* Because of this linkage, observations of atmospheric change may be early harbingers of climate change, and comprehending the reasons for atmospheric change is fundamental to understanding the potential for climate change.

As the global population nears 6 billion, human activities are inducing significant atmospheric change. This impact is clear, for example, in the firmly established linkage between emissions of CFCs—substances entirely of human manufacture—and the depletion of stratospheric ozone. Indeed, the awarding of the 1995 Nobel Prize in Chemistry to Professor Paul Crutzen, Professor Mario Molina, and Professor F. Sherwood Rowland for the demonstration of this linkage underscores the significance of this basic concept—that human activities can and do influence the global atmosphere and environment. As a consequence, an understanding of changes in atmospheric chemical composition and the implications of these changes is required if decisionmakers (e.g., the parties to the Montreal Protocol on Substances that Deplete the Ozone Layer and subsequent amendments and adjustments) are to choose among scientifically sound options.

The 1995 Nobel Prize in Chemistry also acknowledged the identification of the relationship between emissions at ground level and the chemistry of ozone formation and destruction in the stratosphere. This conceptual breakthrough, identifying the close coupling of Earth system components and phenomena, demonstrated that many environmental issues previously treated as unrelated are, in fact, interdependent. During the course of their studies on stratospheric ozone and atmospheric chemistry, all three scientists have been supported in part by funding from the agencies that support USGCRP research.

Research has demonstrated that stratospheric ozone depletion not only causes increased exposure to ultraviolet light, but exerts a

1995 Nobel Prize in Chemistry

For their work in atmospheric chemistry, particularly concerning the formation and decomposition of ozone, the Royal Swedish Academy of Sciences awarded the 1995 Nobel Prize in Chemistry to:

- Professor Paul Crutzen of the Max Planck Institute for Chemistry in Mainz, Germany. Dr. Crutzen was born in The Netherlands and is a Dutch citizen.
- Professor Mario Molina of the Department of Earth, Atmospheric, and Planetary Sciences and Department of Chemistry at the Massachusetts Institute of Technology in Cambridge, Massachusetts. Dr. Molina was born in Mexico City and is now a U.S. citizen. He is a member of the National Academy of Sciences.
- Professor F. Sherwood Rowland of the Department of Chemistry at the University of California, Irvine, California. Dr. Rowland was born in Ohio. He is a member of the National Academy of Sciences, and is currently its Foreign Secretary.

The announcement by the Royal Swedish Academy of Sciences stated that these three scientists "...have all made pioneering contributions in explaining how ozone is formed and decomposes through chemical processes in the atmosphere. Most importantly, they have in this way showed how sensitive the ozone layer is to the influence of anthropogenic emissions of certain compounds. The thin ozone layer has proved to be an Achilles heel that may be seriously injured by apparently moderate changes in the composition of the atmosphere."

In 1970, Dr. Paul Crutzen "...showed that the nitrogen oxides NO and NO_2 react catalytically (without themselves being consumed) with ozone, thus accelerating the rate of reduction of the ozone content....These nitrogen oxides are formed in the atmosphere through the decay of the chemically stable nitrous oxide (N_2O), which originates from microbiological transformations at the ground. The connection demonstrated by Crutzen between microorganisms in the soil and the thickness of the ozone layer is one of the motives for the recent rapid development of research on global biogeochemical cycles....This was also the start of intensive research into the chemistry of the atmosphere which has made great progress during the past several years."

1995 Nobel Prize in Chemistry (Cont.)

"The next leap in our knowledge of ozone chemistry was in 1974, when Mario Molina and Sherwood Rowland published their widely noted *Nature* article on the threat to the ozone layer from CFC gases—'freons'—used in spray bottles, as the cooling medium in refrigerators and elsewhere, and plastic foams....Molina and Rowland realized that the chemically inert CFC could gradually be transported up to the ozone layer, there to be met by such intensive ultraviolet light that they would be separated into their constituents, notably chlorine atoms. They calculated that, if human use of CFC gases was to continue at an unaltered rate, the ozone layer would be depleted by many percent after some decades....Many were critical of Molina and Rowland's calculations but yet more were seriously concerned by the possibility of a depleted ozone layer. Today, we know that they were right in all essentials. It was to turn out that they had even underestimated the risk."

Thanks to the good scientific understanding of the ozone problem achieved by Crutzen, Molina, and Rowland, as well as others who have made crucial contributions, it has been possible to make far-reaching decisions on regulating the release of gases that destroy ozone. A protocol on the protection of the ozone layer was negotiated under the auspices of the United Nations and signed in Montreal, Canada, in 1987. "Since it takes some time for the ozone-destroying gases to reach the ozone layer, we must expect the depletion, not only over Antarctica but also over parts of the Northern Hemisphere, to worsen for some years to come. Given compliance with the [Montreal Protocol], the ozone layer should gradually begin to heal after the turn of the century. Yet it will take at least 100 years before it has fully recovered."

cooling influence on the global climate. Conversely, formation of tropospheric (lower atmospheric) ozone, a primary component of smog, not only pollutes the air, but induces a warming influence on the climate. Further, emissions of sulfur dioxide from fossil fuel combustion not only lead to the formation of acid rain, but contribute to aerosol haze, which exerts a cooling influence. Similarly, increases in surface-UV radiation exposure and its consequences are associated with depletion of the stratospheric ozone layer, but are also influenced by many

non-chemical variables, such as cloudiness. And more subtly, changes in ozone levels in the troposphere influence the survival of certain ozone-depleting substances in their transit from the ground to the stratosphere.

The atmosphere does not segregate these chemical phenomena by scientific discipline, nor can the atmosphere be segregated from its interactions with the Earth system. Rather, there is one atmosphere, whose chemical changes can be properly understood only within the framework of a comprehensive and integrated Earth system research effort such as that of the USGCRP.

Atmospheric Chemistry Goal

The goal of the atmospheric chemistry element of the USGCRP is to understand and characterize the chemical changes in the global atmosphere and their consequences for human health and well-being.

Progress toward this goal will provide information to assist policymakers in protecting human health, in preserving the cleansing and protective qualities of the atmosphere, and in ensuring that new compounds do not lead to inadvertent environmental consequences.

Research to achieve this goal involves the following:

- Global observations of atmospheric change (through ground-, airborne-, and space-based measurements)
- Elucidation of the processes that cause those changes (through laboratory studies, site-specific research, and field campaigns)
- Incorporation of that understanding into a predictive capability (through development of models that test the scientific theories, reveal deficiencies in understanding, and predict future atmospheric responses to various emissions scenarios)
- Linkages of atmospheric chemical changes to other environmental changes such as ecological and human health
- Evaluation and assessment of the findings and their integration for use by decisionmakers.

Together, these studies will provide an improved set of predictive tools and capabilities that can continue to provide information for use by policymakers as they consider various options for mitigating or adapting to global change. Successful examples of such output from the research of USGCRP abound: Human emissions of CFCs and halons have been unambiguously identified as the cause of the Antarctic ozone hole; projections that large increases in CFC emissions would lead to

large losses of ozone underlie amendments to the Montreal Protocol to phase out CFC use; and observations of declining CFC growth rates and increasing abundances of CFC substitutes demonstrate the efficacy of the policies adopted to protect the ozone layer.

Improved understanding of the chemical processes associated with ozone depletion is being used to assess the ozone-depleting potential of proposed CFC substitutes. One substitute used in air conditioning (HFC-134a) was recently shown to be benign to the ozone layer despite hypotheses to the contrary, thus avoiding an erroneous and costly recall by the U.S. automobile industry. This is a prime example of immediate economic payoff from understanding fundamental atmospheric processes.

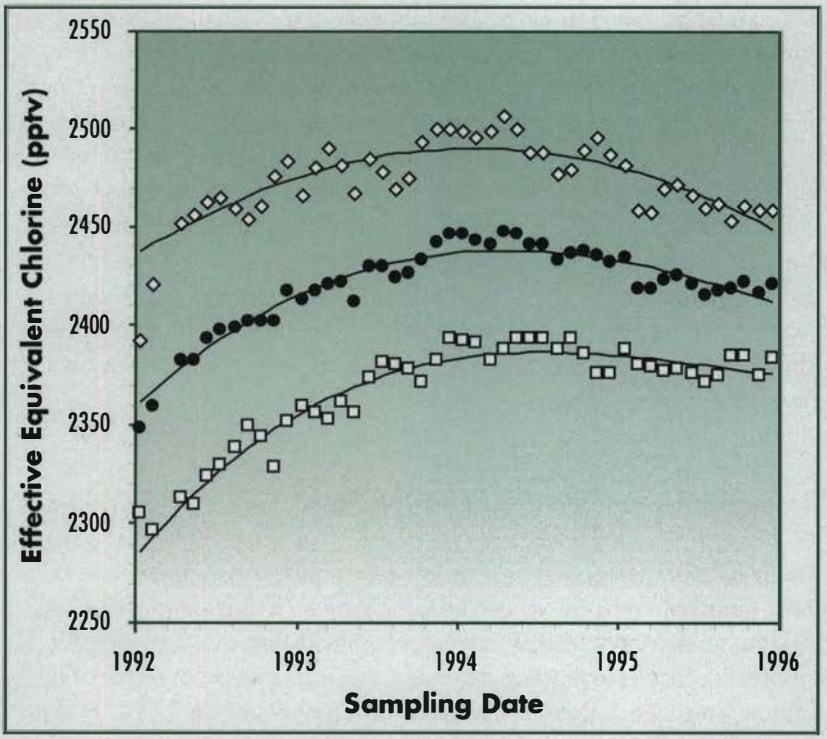
Atmospheric Chemistry Research Objectives

The USGCRP atmospheric chemistry program focuses on meeting near-term information needs by establishing global chemical trends; characterizing atmospheric chemical processes, including ozone depletion, and their consequences; and assessing this information in terms of decisionmaking. The objectives and near-term payoffs of the USGCRP's atmospheric chemistry research are as follows.

Objective 1—Monitor Atmospheric Chemical Composition Trends and the Human-Influenced Emissions that Cause Them

"What is changing in the atmosphere and why?" The answer to this basic question is often the clearest sign of a changed relationship between humankind and the environment. For example, the slowdown in the growth rate of CFC concentrations demonstrates the impact of international decisions to phase out the production of these compounds (see the figure on page 56). To meet the need for ongoing monitoring, a combination of ground-, airborne-, and satellite-based studies are focusing on defining and explaining the trends in ozone, ozone-depleting substances and their substitutes, and greenhouse gases.

Updated information on long-term atmospheric trends can aid in monitoring global compliance with decisions, thereby offering accountability in science and policy. Also, they provide an "early warning system" for new issues, (e.g., unexpected chemical species and surprises in the growth rates of substitutes for the CFCs and halons).



This figure shows the amount of chlorine and bromine (expressed as the effective equivalent chlorine, or EECl) in the lower atmosphere. This quantity is a good indicator of the amount that is predicted to be released a few years hence in an inorganic form in the lower mid-latitude stratosphere, where it can contribute to ozone depletion. Estimates are made on a monthly basis for the Northern Hemisphere (open diamonds), Southern Hemisphere (open squares), and global mean (closed circles). The EECl is derived by considering the changing concentrations of about a dozen gases that can affect the stratospheric ozone concentration and developing an index based on their ability to catalyze the destruction of ozone relative to the ability of chlorine (the units of EECl are in parts per trillion by volume). As a result of controls instituted under the Montreal Protocol on Substances that Deplete the Ozone Layer and subsequent agreements and amendments, the stratospheric chlorine concentration is expected to start decreasing in the near future, allowing the stratospheric ozone concentration to begin what will be a multi-decadal recovery period. The figure is courtesy of S. Montzka of the NOAA Climate Monitoring and Diagnostics Laboratory in Boulder, CO, and appeared in Science, **272**, *pp. 1318-1322 (1996).*

Objective 2—Understand the Stratospheric Ozone Variations during the Coming Most-Vulnerable Decade

Nations are committed to eliminating CFCs and halons, but development of practical, "ozone-friendly" substitutes requires a detailed understanding of the chemical processes responsible for ozone depletion. Further, despite such commitments, the ozone layer will be at its most vulnerable over the next decade, when peak halogen abundances will occur, and during which time a cold, protracted Arctic winter or a large volcanic eruption could accelerate ozone depletion resulting from human activities. In fact, the causes of the observed global downward trends are not yet fully understood, nor are the full impacts of newly recognized threats to the ozone layer, such as methyl bromide and aircraft emissions. Therefore, investigations are including airborne field campaigns to elucidate atmospheric processes, coupled with laboratory and modeling studies to analyze the impacts of proposed substitutes and their potential for enhanced ozone depletion.

This understanding will help avoid costly missteps in the search for and development of appropriate CFC and halon substitutes, provide better forecasts and attributions of ozone changes over the next decade, and keep the decisions associated with "rehabilitation" of the ozone layer on a sound scientific basis.

Objective 3—Monitor Changes in Surface UV Radiation, and Quantify Exposure and Consequences to the Biosphere and Human Health

Extended monitoring data on ultraviolet radiation are not currently available. The technical complexities associated with this task are challenging. Yet, such records are the raw material for assessing the impacts of enhanced UV exposure on ecosystems, materials, and human health, and are vital to public awareness of the dangers of increased exposure. Therefore, research is focusing on development and deployment of a network of UV-monitoring instruments, detection of trends in ground-level UV associated with ozone depletion, and studies of the impacts of enhanced UV on human health and ecosystems. Findings from this research should lead to an enhanced ability to model the global climatology of UV radiation, to improved characterization of radiation in atmospheric chemistry models, and to improved tests of model predictions using observations from UV networks.

A UV radiation exposure prediction and warning network could assist individuals to avoid potential adverse health effects. An

understanding of how UV radiation initiates and promotes disease could lead to techniques to intervene before diseases such as skin cancer and cataracts are fully developed. The results of this research will constitute an improved scientific basis for policies to protect human health and the environment.

Objective 4—Develop a Predictive Understanding of the Chemistry of the Global Troposphere

The lowest portion of the Earth's atmosphere (i.e., the troposphere) is intimately involved in the chemistry of global change. Natural tropospheric processes cleanse the atmosphere of most pollutants, thereby interrupting the transport of many ozone-depleting substances to the stratosphere and limiting the persistence in the atmosphere of the most common greenhouse gases. Accordingly, gaining a predictive understanding of tropospheric chemistry is central to efforts to protect the stratospheric ozone layer and to determine the climatic impacts of the aerosols and greenhouse gases that arise from surface pollution. Therefore, research is focusing on field campaigns designed to elucidate the chemical and mixing processes that control trace substances in the lower atmosphere, on space-based observations to achieve global coverage, and on modeling studies to test and refine prognostic capabilities.

A better understanding of chemical removal and other processes in the troposphere will help quantify the global warming potentials of human-influenced emissions and any potential environmental roles of aircraft. Better understanding will also provide the research base for addressing effectively the currently unknown, but inevitable, future issues associated with this part of the atmosphere, which is in direct contact with human activities.

Objective 5—Characterize the Radiative Links between Atmospheric Chemistry and Climate Change

Stratospheric ozone depletion is now understood to introduce a cooling tendency in the climate system. In contrast, tropospheric ozone formation adds a warming tendency. In addition, chemically formed and other aerosols introduce a cooling influence, not only through their direct scattering of sunlight away from the Earth, but through their modification of the number and size of cloud droplets and their possible influence on cloud extent and persistence. Understanding these

components, which is the next step to augmented climate-prediction endeavors, will require a blend of ground- to space-based observational studies, coupled with improved radiative theories and atmospheric chemistry models.

Improved knowledge of the links between atmospheric chemistry and climate change will help improve the level of confidence in scientific assessments (e.g., the expected IPCC assessment in the year 2000) regarding the detection and attribution of the climate changes that have occurred over the past several decades.

Objective 6—Assess the Scientific Understanding of the Future of the Ozone Layer and of the Role of Human-Influenced Chemistry in the Radiative Forcing of Climate Change

In December 1995, in Vienna, Austria, the United Nations (UN) Montreal Protocol Parties called for an updated state-of-understanding assessment of the ozone layer to be prepared in 1998. The Conference of the Parties to the UN Framework Convention on Climate Change (UNFCCC) has requested an elaboration of specific issues covered in the IPCC Second Assessment Report, and is also expected to call for a full, comprehensive Third Assessment Report in the year 2000. Further, it is possible that the International Civil Aviation Organization will need similar scientific input regarding aircraft issues. Accordingly, the USGCRP will place an overall focus on near-term projects that will facilitate preparation of these assessments, including conducting special reviews of related atmospheric chemistry and physics, and communicating research findings to stakeholders, including Government policymakers, key private sector decisionmakers, and the public.

The result will be a continued and updated series of authoritative, community-wide, unbiased, and integrated assessments of the scientific, technical, and economic knowledge on which informed decisions can be based.

Links to Users of Information through Assessment

Information produced by the atmospheric chemistry research community is conveyed to decisionmakers and the public through a variety of channels, beginning with peer-reviewed scientific journals. Periodically, panels of leading scientists review and interpret this evolving literature in policy-relevant terms and publish consensus assessment documents

such as the roughly triennial series, *Scientific Assessment of Ozone Depletion*, prepared under the auspices of the World Meteorological Organization and the United Nations Environment Programme to serve as the scientific input to the Montreal Protocol process. Another example of the assessment process is the series of *Climate Change* assessments, prepared under the auspices of the Intergovernmental Panel on Climate Change, which serve as one of the key inputs to the Conference of the Parties to the UNFCCC. In addition, information on new findings and their implications are regularly provided to Government and private-sector decisionmakers.

Agency Contributions

Several agencies work in close cooperation to gain a better understanding of atmospheric chemistry and its related issues. For example, the long-standing partnership and close coordination between NASA, NOAA, and NSF was a major underpinning of the highly effective research program in the late 1980s that provided the rapid understanding of the newly discovered Antarctic ozone "hole." Atmospheric chemical research has been augmented by selected programs sponsored by DOE and DoD. Further, the study of the impacts of ozone depletion and of the mitigative options has yielded, in concert with these agency efforts, an integrated information base for addressing this issue, with the primary emphasis on human health by HHS/NIH, with additional input from EPA, and on agricultural impacts and strategies by USDA. The component agency emphases are summarized as follows:

- NASA provides the major USGCRP support for the development and implementation of satellite observations of global atmospheric chemistry properties, along with supporting airborne and balloon-borne measurements and field campaigns. These comprehensive global observing programs span many of the atmospheric chemistry research objectives. Particular focuses include development and deployment of global chemical space-based observing systems for the stratosphere and the troposphere; helping build a predictive understanding of stratospheric ozone depletion and tropospheric ozone formation, with a particular focus on the role of aircraft emissions; and development of computational methodologies including global three-dimensional chemistry/transport models and large-scale data assimilation techniques.

Highlights of Recent Research on Atmospheric Chemistry

USGCRP-sponsored research continues to advance understanding of the causes, magnitude, and consequences of changes in stratospheric ozone, UV radiation, and atmospheric chemistry. The FY96 edition of *Our Changing Planet* included a summary of recent key findings. Highlights of more recent findings follow:

- Atmospheric concentrations of ozone-depleting chemicals are starting to decrease. Over the past few decades, global atmospheric monitoring stations had reported the steady growth in the concentrations of CFCs and other ozone-depleting chemicals. Recent observations have not only shown a slowdown in growth, but also are revealing, for the first time, decreasing concentrations. These downward trends are the first observed atmospheric response to the international agreements to halt production of these ozone-depleting chemicals.
- Year-to-year changes in the stratospheric ozone layer have been explained. Superimposed on the observed overall downward decadal trends in the ozone layer are variations over periods of a few years. The long-term declines have been associated with the growth in the use of ozone-depleting chemicals, such as CFCs, but the shorter term changes have been unexplained. Recent theoretical modeling studies have shown that these shorter term variations can be explained by the augmented ozone depletion caused from the chemistry on surfaces of particles resulting from episodic volcanic eruptions, thereby providing a more complete picture of ozone layer changes.
- Soils may be a larger methyl bromide sink than previously thought. Because methyl bromide is involved in the destruction of ozone in the stratosphere, this finding suggests that management of soils may have implications for the stratospheric ozone budget and the amount of UV radiation that reaches the Earth's surface.
- Satellite data have confirmed, on global scales, the expected stratospheric abundances of ozone-depleting chemicals. Surface-level stations have long monitored the lower atmospheric growth of the ozone-depleting chemicals that

Highlights of Recent Research on Atmospheric Chemistry (Cont.)

are released into the atmosphere by human activities. Balloon and airborne measurements have tracked the resulting ozone-related chlorine and bromine compounds in the stratosphere in particular regions. However, recent satellite data have provided the first truly global look at these species and have confirmed the picture of the human contributions to the global budget of these ozone-related species.

- Carbon monoxide concentrations were measured from latitudes from Alaska to the Antarctic using an instrument mounted in the Space Shuttle on two flights in 1994. These measurements demonstrated a capability for providing global data sets and measuring seasonal variations. The measurements showed the expected higher levels near the source regions, mainly in the Northern Hemisphere and near areas of biomass burning in the tropics, but were also able to observe the much lower concentrations over the Southern Ocean areas that are seldom measured. Carbon monoxide affects the rate of tropospheric chemical removal of other pollutants that affect the concentration of tropospheric ozone, which is both a photochemical oxidant and a greenhouse gas.

- NOAA shares the focused atmospheric chemistry USGCRP leadership role with NASA, bringing a coordinated program of trace-gas monitoring and laboratory and field characterization of chemical processes, with the objective of providing better forecasts and predictions of global atmospheric chemical changes. Particular focuses include the characterization of the chemical processes involved in stratospheric ozone depletion and in tropospheric ozone formation; identification of the natural processes involved in altering ozone concentrations; identification and quantification of ozone-friendly alternatives for the ozone-depleting substances; elucidation of trends of trace greenhouse gases; and characterization of the role of

atmospheric chemical change in climate forcing. NOAA and NASA also lead the preparation and reporting of the international scientific assessments of ozone depletion.

- NSF leads the support for university-based, investigator-driven studies in atmospheric chemistry, with a focus on tropospheric chemistry. Particular focuses include field, laboratory, and model investigations of changes affecting the radiative properties and oxidizing capacity of the atmosphere. Major support has been provided for field measurements of the chemical processes associated with the formation of radiation-altering aerosols and UV radiation monitoring in polar regions.
- NIST supports atmospheric chemistry research, with emphases on chemical and radiation standards, laboratory measurements of chemical processes associated with ozone depletion, and the establishment of standards of reference for the physical properties of proposed substitutes for ozone-depleting substances.
- DoD's Naval Research Laboratory plans to continue to support the Polar Ozone Aerosol Monitor II (POAM II) sensor, launched on the Systeme pour l'Observation de la Terre-3 (SPOT-3) satellite in 1993, and the POAM III, to be launched on SPOT-4 in 1998. These operational space-based systems provide continuous, consistently calibrated, high-resolution vertical profiles of ozone, water vapor, aerosols, and nitrogen dioxide in the polar stratosphere. A third sensor, giving similar data at low and mid-latitudes, will be launched on an Air Force satellite in 1998. These data are essential in determining the effectiveness of the Montreal Protocol on Substances that Deplete the Ozone Layer and other measures to minimize ozone depletion during the period 1994-2003.
- DOE supports source-receptor sequence studies to examine the fate of energy-related emissions in the atmosphere. These studies include examination of the chemical formation of aerosol particles, the large-scale transport of chemicals associated with fossil fuel combustion, and the processes associated with the formation and destruction of ozone in mid-latitudes.
- USDA contributes programs focused on development and deployment of a ground-based network of instruments for the measurement of surface UV trends; development of alternatives to the use of methyl bromide in agricultural applications; and, as part of ecosystem studies, assessing the impacts of increased UV radiation on agriculture.

- HHS/NIH contributes programs focused on characterizing the impacts of increased UV radiation on human health and well-being; determining how UV radiation initiates and promotes disease; and exploring the potential health-related impacts of the degradation of CFC substitutes.
- EPA contributes programs focusing on development and deployment of a monitoring network. EPA provides leadership for the international assessments of the technical and economic feasibility of developing and deploying new technologies to protect the ozone layer.

Changes in Land Cover and in Terrestrial and Marine Ecosystems

Global Ecosystems and the Dynamics of Sustainability

Changes in land cover and land use are occurring around the world at an increasingly rapid rate, as is the nature and configuration of our coastlines. Fisheries and marine ecosystems shift with changes in temperature and with human harvesting. Such changes are coupled in complex ways with the physical climate system, Earth system biogeochemistry, the vitality of ecosystems and sustainability of natural resources, and the societal activities associated with economic development and human migration.

The increasingly rapid rates of land-cover and land-use change and coastal alteration are driven largely by human activities. These activities are already beginning to threaten the continued provision of marketable goods and services produced in ecological systems through cultivation or harvesting (e.g., marine fisheries) and the effectiveness of ecosystem-level processes of importance to human activities (e.g., purification of water by forests and wetlands, regulation of water flow by forested watersheds, preservation of soil fertility).

The sustainability of these "ecological goods and services" depends on the recognition that (i) processes that control biogeochemical and hydrologic cycles are closely tied to and result in ecological goods and services; (ii) human influences that transform land cover and coastal areas from one type to another, or that change or intensify land- and coastal-management regimes, clearly affect the provision of ecological goods and services on regional scales and have the potential to affect their global availability and the chemical composition of the atmosphere on regional and global scales; and (iii) understanding the human influences on these processes is necessary in order to determine the potential for continuing provision of ecological goods and services to meet the needs of the expanding human population.

Ecosystems Program Goal

The goal of the land cover and terrestrial and marine ecosystems element of the USGCRP is to provide a stronger scientific basis for understanding, predicting, assessing, and responding to the causes and consequences of changes in terrestrial and marine ecosystems resulting from human-induced and natural influences.

Progress toward this goal will provide a stronger scientific basis for developing environmental and natural resource practices that are environmentally sound and practical, and that will ensure ecosystems yield sustainable benefits to humankind.

The effort to achieve this goal requires a wide range of activities. For example, observations are needed to document changes in land cover, coastal alterations, and ecological systems, including both natural changes and changes that result from human activity. Simultaneous *in situ* research is needed to quantify process rates and provide information for predictions of future ecological changes based on these processes. Combined information on patterns of change and processes causing these changes is needed to provide the foundation for evaluating landscape, coastal margin, and ecological changes due to global forcings (e.g., greenhouse gases, climate) as well as due to local and regional influences (e.g., watershed alterations, air pollution).

To take advantage of existing investments, new research efforts in land-use, land-cover, and coastal habitat change will be coupled to existing research programs and to data-gathering platforms and instruments that are already in place. To meet future research needs, new technologies and measurement capabilities will also be developed as necessary. Linkages will also be made to operational land-cover and coastal habitat classification and mapping efforts, both in the U.S. and abroad. The additional information to be derived from new and continuing observations will assist in the design of more sustainable management practices.

While some of the necessary measurements can be made from space, achieving the scientific understanding necessary to interpret and evaluate these observations cannot be done simply with data from remote sensing; other monitoring data are also necessary. An effective research program will require the cooperation of research communities and agencies with space-based, ground-based, ocean-based, and *in situ* research capabilities. Accounting accurately for land-use, land-cover, land-management, and coastal habitat change with fine spatial and temporal resolution, and carrying out the research needed for interpreting the findings, will necessarily require a partnership of many scientific and natural-resource management institutions around the world.

Ecosystems Research Objectives

Achieving the ecosystem research goal of improved understanding of land-cover and land-use change and changes in terrestrial and marine ecosystems will require achievement of several key objectives.

Objective 1—Document the Current Patterns and Past Changes in Global Land Cover

During FY97, the USGCRP will continue to monitor and inventory the current land cover of the Earth at 1-km spatial resolution. USGCRP agencies are producing a series of data products documenting regional land cover and its relationship to underlying land use with data from the Advanced Very High-Resolution Radiometer (AVHRR) satellite instrument. This inventory establishes for the first time a systematically produced, replicable global database from which changes can be measured. This database will continue to be used in assessing regional temperature variability associated with coastal ecosystem stress.

Additional efforts will be made to classify and inventory the changes in land cover in North America and humid tropical forests at finer spatial resolutions. Several Federal agencies are cooperating to analyze Landsat satellite data (with a resolution of less than 100 m) and to classify and inventory the changes in land cover that have occurred in North America and the entire equatorial tropics since 1970. This effort will document changes that affect the functioning of ecological systems and provide the global change research community and policymakers with valuable and accurate estimates of changes such as shifts from forest cover to grass cover.

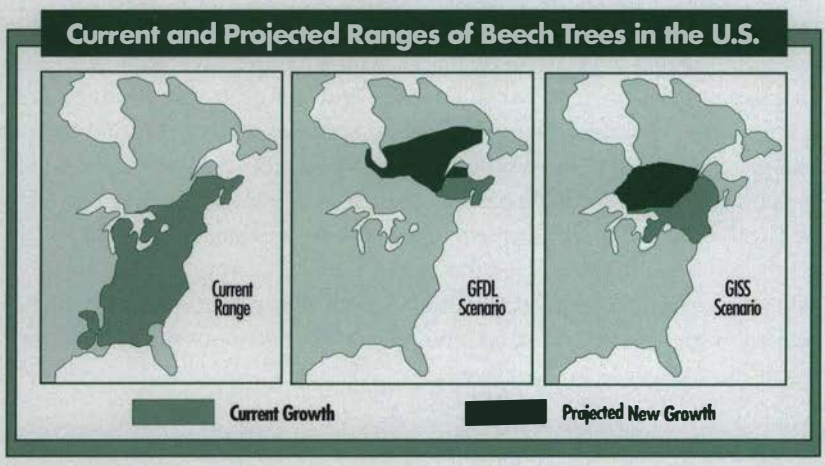
Objective 2—Understand Natural and Human-Induced Influences that Lead to Changes in Land Cover, Land Use, Coastal Alterations, and Ecosystems

Distinguishing the causes of changes that are occurring and developing the ability to predict future changes requires improved understanding of the causes and mechanisms of change. The USGCRP agencies are working within the United States and with international partners in a number of regions around the world to understand the factors leading to and controlling land-cover, land-use, and land-management changes. In support of these efforts, ecological and biogeochemical research on the functional consequences of land-cover, land-use, and land-management changes and climatic variability is being conducted, and new efforts will be initiated in the vitally important Amazon River basin as the first stage of a multi-year, multi-partner international campaign known as the Large-Scale Biosphere-Atmosphere Experiment in Amazonia (LBA).

USGCRP-sponsored research will also examine how ecosystems react to change and influence global phenomena. For example, the

accompanying figure provides an estimate of how future climate change may affect the distribution of an important tree species in the eastern United States. Research to examine ecosystem responses is being coordinated under the interagency programs on Terrestrial Ecology and Global Change (TECO) and Land-Margin Ecosystems Research (LMER). Program emphases follow:

- Focus on improving the understanding of how species, ecological characteristics and processes, and ecosystems are related to land-cover and watershed attributes and changes



Beech trees are currently found throughout much of the eastern United States (left panel). This distribution is determined largely by the climate. Changes in climate as a result of the increasing concentrations of carbon dioxide and other greenhouse gases are expected to change the optimum growing range for beech trees, thereby changing their distribution. Predictions of future climate conditions from the climate models of the NOAA Geophysical Fluid Dynamics Laboratory (GFDL) and the NASA Goddard Institute for Space Studies (GISS) have been used to estimate the types of shifts in optimum growing range that could occur a century hence as a result of changes in the concentrations of greenhouse gases alone (thus representing an extreme condition). While this warming will likely be delayed somewhat as a result of sulfate aerosol injections, the results suggest that the optimum growing ranges may shift roughly 300 miles to the north, changing the character of forests. The figure is adapted from M.B. Davis and C. Zabinsky, Changes in geographical range resulting from greenhouse warming: Effects on biodiversity in forests. In: Global Warming and Biological Diversity *[R.L. Peters and T.E. Lovejoy (eds.)]. Yale University Press, New Haven, CT (1992).*

- Enhance capabilities to predict the influences on ecosystems of multiple factors (e.g., when the physical environment and ecological parameters change simultaneously).

In addition to process-based studies, continental-scale models of terrestrial ecosystems are being developed. In coordination with the International Geosphere-Biosphere Programme (IGBP) Global Analysis, Interpretation, and Modeling (GAIM) task force, scientists are analyzing current models and data, evaluating the capability of current models and experimental programs to meet the needs of decisionmakers and of those modeling the global climate and biogeochemical system, and advancing understanding of the links between global biogeochemical cycles and the hydrologic cycle.

Objective 3—Predict the Extent and Consequences of Changes in Land Cover, Land Use, and Ecosystem Processes, especially as They Relate to the Sustainability of Natural Resources and Economic Development

The USGCRP will participate in the international Land-Use/Cover Change (LUCC) Core Project. 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 will use as a reference a combination of global coverage of land cover at 1-km spatial resolution, with selected areas represented at higher resolutions. LUCC will identify and examine the major human influences contributing to land-cover change in different geographical and historical contexts, and project changes that may occur over the next few decades—a focus that will require development of an understanding of the relationships between past changes in land cover and in the structure and function of ecosystems. This will include study of the societal and economic factors that also appear to be driving ecosystem changes.

As part of the USGCRP and the IGBP, the Land-Ocean Interactions in the Coastal Zone Program (LOICZ) will focus on the ecological systems at the interface of the coastal lands and seas. New and continuing studies will assess the linkages to terrestrial and shelf ecosystems and the influences of land cover, land use, and material inputs to the primary and secondary productivity of our coastal waters and estuaries, including the production of fish populations.

Objective 4—Quantify Exchanges of Trace Gases between the Atmosphere and the Terrestrial Biosphere, with Particular Emphasis on the Processes Controlling Carbon Sources and Sinks

A network of stations measuring the uptake and release of CO_2 will be expanded to include a representative set of native ecosystems and a variety of land-use and land-cover types. The network of measurements will be coordinated with research on processes (often conducted by measuring the isotopic composition of CO_2) and with studies of climatic and human factors that influence terrestrial systems. Contemporary measurements and results from field and laboratory exposures of plants to elevated concentrations of CO_2 will be used to refine scientific understanding of processes determining net carbon uptake by plants and soils. Estimates of carbon sources and sinks derived from atmospheric concentrations of CO_2 will be used to improve the accuracy of predictions of future atmospheric CO_2 concentrations. Results from field studies will also be related to observations of changes in land cover, historic records of changes in vegetation types, and measurements of carbon storage to address scientific issues related to the atmospheric sources and sinks of CO_2. The information is needed to provide the scientific basis for consideration of response and mitigation options for stabilizing atmospheric CO_2 concentrations.

Objective 5—Observe and Document the Current Patterns and Past Changes in Chemical, Physical, and Biological Activity in the Oceans, especially Those that are Relevant in Understanding the Exchange of Carbon Dioxide with the Atmosphere

As part of the USGCRP and the IGBP, interagency participation in the U.S. Joint Global Ocean Flux Study (JGOFS) will continue. Efforts are focused on characterizing the global geographic distribution of key biogeochemical properties and rate processes pertinent to the oceanic carbon system, as a necessary prerequisite to predicting change in the ocean system and its interactions with atmospheric carbon pools. The focus of JGOFS in FY97 will be the Southern Ocean around Antarctica:

- The biogeochemical mechanisms that control the forms in which carbon moves with and through the water via ocean currents, mixing, diffusion, and particle sinking, and the rates of processes transforming carbon among dissolved and particulate, living and non-living, and organic and inorganic forms

- The response of the ocean carbon system to physical and chemical forcing from subseasonal events to decadal changes.

In addition, scientists will gather information on ocean color data in order to address coastal issues:

- Distinguishing and tracking harmful algal blooms
- Tracking coastal and estuarine sediments to determine the fate of suspended sediments and land runoff into coastal oceans
- Tracking coastal dynamic processes (e.g., ocean circulation pattern) to determine dispersal patterns of pollutants and red tides.

Results are needed to document how the oceans exchange CO_2 with the atmosphere as a basis for understanding the role that marine ecosystems play in carbon transports, as well as to investigate the effects of natural and human-induced climate change on marine ecosystems and to assist in applications to coastal fisheries and ecosystem management.

Objective 6—Understand and Analyze the Chemical, Physical, and Biological Processes that Regulate Ocean Uptake and Release of Atmospheric Carbon Dioxide and that Control Biological Productivity in the Oceans, and Develop the Predictive Capabilities Needed to Ensure the Sustainability of Marine Resources

Understanding what has happened and predicting what may happen requires research to understand chemical, physical, and biological processes:

- The effects of inputs to the coastal ocean of nutrients from land, the atmosphere, and the ocean interior via upwelling
- The effects of temperature changes that can alter the physiological states of marine ecosystems
- The effects of changes in incoming UV radiation and the potential for changes in UV radiation to affect primary productivity or to damage cells
- The effects of changes in circulation patterns and other oceanic processes that can affect ecosystem structure and function.

The development of models will be encouraged in order to simulate the interactions of marine biological communities with their chemical and physical environment. Creating coupled physical and biogeochemical models of the ocean for the purposes of testing our understanding and improving our ability to predict future climate-related change will be pursued as part of the JGOFS program. When validated, these models will be used to predict the consequences of physical and

biological changes for the exchange of CO_2 with the atmosphere. Different models will be used to evaluate the effects of changes in marine phytoplankton and zooplankton on fish populations.

Scientists will begin using basin-wide circulation models and climate-scale changes in the investigation of how changing physics in the ocean will likely affect the distribution, abundance, and productivity of marine animals. Under the auspices of the USGCRP and IGBP, Global Oceans Ecosystems Dynamics Program (GLOBEC) research will continue to link climate variables with plankton productivity, and ultimately fish production, on wide time and space scales in order to better interpret past changes in animal abundance, as well as predict potential future changes in response to global climate change. Sorting out natural variability in the physical and biological system from that caused by progressive and human-induced changes is vital to the assessment:

- Developing long-term climatologies of the key ocean regions for both physical and biological variables
- Developing coupled predictive models for ecosystem dynamics
- Conducting process research at sites to provide some understanding of high-frequency variability in ocean physics and ocean animal populations.

The LOICZ program will include research on organic carbon dynamics in coastal zones.

Links to Users of Information

Because ecosystems provide such valuable goods and services for society, there is widespread interest in understanding how ecosystems are changing and what is causing these changes. Within the United States, intense attention is being devoted to this issue by the land management agencies as they seek to improve capabilities for sustainable management of our Nation's land resources. Findings on research on these aspects of ecosystems are made available in many ways, including through agency planning reports on land-management practices.

In addition, because changes in carbon storage on land can lead to changes in the atmospheric concentrations of CO_2, it is essential to have the information and understanding needed to understand the relative roles of fossil fuels and biomass conversion, and the potential for sequestering carbon in ecosystems. Reporting of results relating to the carbon cycle is carried out through studies that become the basis for IPCC findings.

Agency Contributions

Research on changes in land cover and in terrestrial and marine ecosystems is shared among a number of agencies, each of which brings its own particular history and strengths to bear. NSF-supported basic research on ecosystems and ecological processes has provided the scientific foundation on which other agencies' programs have been built. Because of its coupled strengths in remote sensing and in organizing and contributing to field programs, NASA plays a major role in the study of terrestrial and marine ecosystems. NASA emphasizes the use of remote-sensing data in landscape, regional, and global ecosystem models. New remote-sensing capabilities have been especially useful in collaborative studies within the United States and with other nations, particularly those working to understand and preserve their vulnerable ecosystems. DOE has emphasized the interplay of rising atmospheric CO_2 and physiological processes in ecosystems. USDA, DOI, NOAA, and EPA have focused on the implications of global change for their direct land-management responsibilities (in the case of USDA and DOI), and more broadly on their responsibilities to protect the environment. Within the United States, USDA and DOI manage public forest and rangelands and have major responsibilities for policies affecting privately owned agricultural lands, forests, and grasslands. Agency emphases follow:

- USDA's research program in global change has a primary focus on the development of knowledge and understanding about the effects of agriculture and forestry on the emissions and sinks of greenhouse gases, and how climate change is likely to affect agriculture and forestry in terms of production, resource sustainability, and trade. USDA supports research on the effects of changes in land use and management intensity on agricultural, range, and forest growth, structure, and carbon dynamics, in order to understand alternative ways we might manage these systems to sequester more carbon, increase productivity, and offset high levels of CO_2 emissions to the atmosphere from fossil fuel use and land-use changes. Researchers have developed an integrated model of global change effects on forests that will make projections of changes in forest productivity and health in response to global change, harvesting, disturbance, and succession. Studies explore scales ranging from the ecosystem to the organism to, ultimately, the molecular.
- DOI is responsible for managing large areas of land. To fulfill this responsibility, DOI develops, manages, and distributes data

Highlights of Recent Research on Land and Ocean Ecosystems

USGCRP-sponsored research continues to advance understanding of the causes, magnitude, and consequences of changes in land cover and in terrestrial and marine ecosystems. The FY96 edition of *Our Changing Planet* included a summary of recent key findings. Highlights of more recent findings follow:

- New understanding has been gained of the contemporary global carbon cycle through the measurement and analysis of changes in the atmospheric concentration of oxygen and the ratio of ^{13}C to ^{12}C in atmospheric carbon dioxide. These measurements and analyses support the hypothesis that terrestrial ecosystems of the mid-latitudes of the Northern Hemisphere have functioned as a significant carbon sink (up to about a third of the fossil fuel emissions) in the first half of the 1990s. Without this sink, the causes of which are not yet understood, the rate of carbon dioxide accumulation in the atmosphere would have been even faster.
- Large-scale ecosystem modeling efforts are making important progress. The models being developed are prognostic and can be used to simulate a range of ecological responses to changes in climate and the chemical composition of the atmosphere. Among the responses that can start to be considered are time-dependent changes in the distribution of terrestrial plant communities across the globe as climate changes.
- Long-term ecosystem-level experiments are now providing evidence that biodiversity plays a critical role in the carbon and nutrient cycles of terrestrial ecosystems. In addition, regular measurements are now being taken that will lead to improved estimates of the effects of interannual climate variability on carbon exchange between land ecosystems and the atmosphere. This information can be used to develop and test process-based ecosystem models that are important components of the larger Earth system models. These models are critical research tools in global change science and assessment, and will benefit greatly from improved representation of ecosystem processes.

Highlights of Recent Research on Land and Ocean Ecosystems (Cont.)

- New land-cover data for South America, Southeast Asia, and the conterminous United States have been released on the World Wide Web (http://amazon.unh.edu/pathfinder/ and http://edcwww.cr.usgs.gov/landdaac/). The data were developed from Landsat products. The new information for South America and Southeast Asia will facilitate better estimates of rates of deforestation and of the flux of carbon to the atmosphere associated with forest clearing. The land-cover data for the conterminous United States, which have a 1-km resolution, are an important information base for resource managers working on regional-scale planning.
- Recent modeling studies have shown that unusual physical conditions along the break in the Georges Bank's shelf during the late 1950s and 1960s can be traced to changes in the strength of the cold Labrador Current. The dynamics of planktonic animal populations on the Bank are thought to be strongly influenced by biological and physical events in the surrounding deep basins in the Gulf of Maine, the offshore slope water, and upstream waters on the Scotian Shelf. Changes in planktonic populations in turn influence the marine resource populations of these ecosystems. Scientists are evaluating the impact of such decadal-scale climate-related events on the seasonal cycle of heating and cooling that controls water column structure, local circulation, and plankton dynamics.
- Recent studies in the tropical Pacific Ocean indicate that iron, which is relatively abundant in waters near land, may be the limiting nutrient in determining primary production of marine life in the blue waters of the central ocean basins. In a series of field experiments involving controlled additions of iron salts to surface waters, scientists documented dramatic plankton blooms and concomitant drawdown of other excess nutrients. These results are encouraging studies of factors controlling primary production, carbon cycling, and ocean-climate impacts elsewhere in the world ocean.

needed by the scientific and land- and resource-management communities to characterize and map the Earth's land surface, model land surface processes, and detect changes in the land surface, land use, and land cover. DOI has statutory responsibility for archiving, managing, and distributing Landsat satellite data. DOI also employs space- and ground-based data in studies that provide land and resource managers with a scientific basis for addressing a wide variety of land-use and land-cover issues (e.g., desertification, wildland fires, and spread of noxious weeds in America's rangelands and national preserves).

- NASA's research promotes the analysis of existing and anticipated patterns of land cover and use throughout the world. The program develops observational tools and methods, process models, and data products that can be used to increase understanding and provide the basis for enhancing the production of food, fiber, and other renewable resources from a landscape while maintaining an adequate area for biodiversity, environmental quality, and climate protection. NASA's research also focuses on understanding the processes that regulate oceanic uptake of atmospheric CO_2 and changes in the structure of phytoplankton communities. Current efforts include:
  - Regional studies of the distribution of major land-cover types, and the rate of conversion and loss of these cover types due to both human activities and climate drivers
  - Process studies that assess the consequences of land-cover and land-use changes and losses for the biogeochemical, hydrologic, and biophysical characteristics of a landscape
  - Global observations of land cover/use that can be assimilated into Earth system models to assist in developing a comprehensive understanding of the cumulative impacts of human activities on the Earth
  - Development and validation of regional and global models of ecosystem processes and their interactions with hydrological and atmospheric systems
  - Development of models and algorithms that use ocean color information to characterize the ocean's biological productivity.

  NASA also develops land-imaging technology and provides unique data sets—such as Synthetic Aperture Radar images from the Shuttle-borne Space Radar Laboratory (SRL)—that are needed by researchers and land managers. NASA is developing Landsat-7 for launch in 1998, as well as the EOS-AM1 platform with the Moderate-Resolution Imaging

Spectroradiometer (MODIS) onboard to measure characteristics of both the land and ocean surface.

- DOE programs in terrestrial carbon processes, ecological research, and ocean margins research provide scientific knowledge of terrestrial and oceanic components of the global carbon cycle. Coupled with observations of atmospheric CO_2, these activities provide fundamental understanding of biophysical processes needed for predicting future atmospheric CO_2 changes, and the quantification of terrestrial and oceanic sources and sinks for excess CO_2 produced from energy emissions. Experiments with crop and natural ecosystems provide the empirical foundation for evaluating consequences and for assessing the effectiveness of natural and/or engineered controls on the rate of future atmospheric CO_2 increase. Effects on ecosystems from the simultaneous influence of climate variables, CO_2, nutrient status, and air pollutants are also evaluated in field experiments. The research contributes to the scientific understanding and prediction of consequences related to global environmental change.
- EPA contributes research that addresses landscape characterization and regional-scale vulnerabilities in the United States to global climate change, and will initially examine issues of regional hydrologic vulnerability and the impacts of climate change. EPA supports ecological effects research to evaluate the response of terrestrial systems (primarily forests) and freshwater and marine aquatic ecosystems to climate variability and change. Research is also focused on development of indicator methods, such as ecosystem boundary changes, to hasten detection of the ecological effects of climate change.
- NOAA supports research on coastal regions and marine ecosystems, mainly through GLOBEC and JGOFS. GLOBEC is an international effort to gain understanding of the factors that influence fisheries and the overall biological productivity of the oceans; JGOFS is part of an international effort to understand the uptake of carbon by the ocean.
- NSF supports research to improve the description and understanding of the physical, biological, chemical, and human processes that result from changes in land use, land cover, global economic productivity, and resource sustainability. The focus of the research extends from polar regions to the tropics and in ecological systems from the deep oceans to terrestrial environments:
  - Measurement of changes in land use and cover
  - The magnitude of resource harvesting and changes therein

- The effects of land use on the biological and ecological diversity of managed and unmanaged ecological systems, and the resulting effects of altered diversity on ecosystem function
- The influence of social and political institutions on land-use practices
- Examination of the relationships among population growth, consumption, technological change, and land-use change
- Use of remote-sensing intrumentation to link data on human activities and regional environmental dynamics.

The ultimate goal of the integrated research effort is to understand the relationships between changes in land use and cover and systemic environmental changes such as climate change or altered ecosystem productivity and their influences on the sustainability of natural and economic resources in marine and terrestrial environments.

- Smithsonian Institution research using the Nation's biological and physical collections provides the basis for determining natural and human-induced changes in the world's ecosystems. The Evolution of Terrestrial Ecosystems program at the National Museum of Natural History uses both collections and field research to determine changes in North American biomes. At the National Air and Space Museum, researchers use a variety of satellite data and ground monitoring to determine natural changes in drylands and variations in plant cover in response to those changes. At the Smithsonian's Ecological Research Station in Kenya, the linkages between land surface and biological activity are studied using geographic information systems to determine feedback effects of biologic and physical forces of change. Marine ecosystems are studied in Panama and in the southern Caribbean, where researchers are using rates and processes of coral reef growth to determine the response of these fragile ecosystems to increased human activities. In addition, tropical terrestrial ecosystems are studied by the Smithsonian Tropical Research Institute in Panama, and by a joint program with Guyana. This work concentrates on the effects of forest fragmentation, and on social forces that lead to ecosystem modification.

3. Integrating Research Themes, Scientific Information, and Outreach Responsibilities

Enhancing the Development of Integrative Activities and Perspectives

The USGCRP also includes a set of integrating activities and perspectives, which contribute in varying degrees to all of the priority environmental science issues discussed in Chapter 2:

1) **Observing and Monitoring Global Change**, with the goal of ensuring the availability of a long-term, high-quality observational record of the state of the Earth system, its natural variability, and changes that are occurring over extended time scales
2) **Global Change Data, Products, and Information Services**, with the goal of providing all users ready and affordable access in useful forms to the full spectrum of global change data, products, and information
3) **Earth System Science**, with the goal of supporting the long-term, integrated and exploratory research needed to gain a predictive understanding of the interactions among the physical, chemical, geological, ecological, and solar processes that determine the functioning of the Earth system and its trends and fluctuations on global and regional scales
4) **Human Contributions and Responses to Global Change**, with the goal of identifying, understanding, and analyzing how human activities contribute to changes in natural systems, how the consequences of natural and human-induced change affect the health and well-being of humans and their institutions, and how humans could potentially respond to problems associated with environmental change
5) **International Research Cooperation**, with the goal of supporting and assisting the program and its participating scientists and agencies in their interactions with related international research, observing, and assessment activities and in the full and open international sharing of data and research findings
6) **Global Change Education and Communication**, with the goal of increasing public awareness of the Earth system and how it is changing and to promote global change education.

Chapter 3 provides an overview of research and program activities and directions for each of these integrative activities and perspectives. For additional information on recent progress in several of these areas, the FY96 edition of *Our Changing Planet* reported on recent research accomplishments. Additional detail on planning in each of these areas for the next 5 to 10 years will be included in the full National Global Change Research Plan, which is being prepared by interagency teams for review by the National Research Council before submission to Congress pursuant to the Global Change Research Act of 1990.

Observing and Monitoring Global Change

Moving Toward an Integrated Global Observing and Monitoring System

Observations of the global environment are critical for documenting global change and for providing the basis for understanding how and why changes are occurring. For many centuries, humans had information only about what was happening in their immediate vicinity. Starting in the 19th century, accumulated historical records and the advance of communications technology permitted the assembly of information about surface conditions around the world. These capabilities have expanded greatly during the 20th century.

During World War II, aircraft and weather balloons began to provide data on the state of the atmosphere, and ships and buoys started providing regular observations of parts of the ocean. Only now, with the development of satellites over the past few decades and sophisticated instruments over the past several years, do we have the potential to broadly observe and monitor the atmosphere, the oceans, and the land surface on a global scale.

Advancing understanding of the Earth system and our ability to predict how it will change in the future requires detailed knowledge of the behavior and state of the atmosphere, the land and its vegetative cover, the oceans, and the polar regions. Systematic monitoring and observation on scales from regional to global are required to document climate fluctuations from season to season and year to year; to detect changes in climate and the environment over years to decades to centuries; to monitor changes in the composition and chemical make-up of the atmosphere; and to document changes that are occurring in land cover and the state of global ecosystems. This will require not only satellite-based observations, but also a wealth of diverse, detailed observations from *in situ* measurements. Only with information from this full range of observational efforts will a capability be developed to document and understand global change, to determine and understand its consequences for humans and ecosystems, and to plan and evaluate measures to aid in adaptation to and mitigation of change.

Observing and Monitoring Program Goal

The goal of the USGCRP observation and monitoring program is to ensure the availability of a long-term, high-quality observational record of the state of the Earth system, its natural variability, and changes that are occurring over extended time scales.

This record of the conditions of the atmosphere, oceans, and land surface, and their interactions, will provide the basis for understanding and monitoring changes in the Earth system. Accomplishing this will require a cooperative international effort to strengthen and augment the existing observational systems in a manner that will provide for the long-term, systematic, global- to regional-scale observation and monitoring of the Earth's environment and natural resources. To be comprehensive and global, such an integrated observing system must combine remotely and directly sensed information from satellites, surface stations, and *in situ* observing platforms such as aircraft, ocean buoys, and balloon soundings, and must be coupled to a data management system that provides ready access to the information gathered and provides analyzed information for use in research and applications (see the data management section).

We are the first generation capable of implementing such an integrated global observing system, observations from which would provide future generations with a stronger basis for sustaining development in a manner that ensures a healthy environment. Once missed, the opportunity for direct observations is lost forever. Delays in deploying instruments or temporary cessation of observations would present significant obstacles to advances in understanding, delaying the gathering of data needed to identify the trends and mechanisms causing and influencing environmental change. As such, maintenance and enhancement of this observing capability is critically important to the international assessments of global change that help guide international policymaking.

For example, monitoring of the ozone hole, global ozone depletion, and atmospheric levels of ozone-depleting substances is central to the periodic assessments of ozone depletion prepared under the auspices of the World Meteorological Organization and the United Nations Environment Programme. Similarly, observations of surface temperature, sea level rise, and other phenomena form the underpinnings of the assessments of climate change carried out under the auspices of the Intergovernmental Panel on Climate Change. Indeed, the significant U.S. contributions to observing the global environment and the conditions affecting our Nation must continue if we are to avoid being surprised by changes and fluctuations, and if we are to be prepared to adapt effectively to the changes and fluctuations that occur.

Observing and Monitoring Program Objectives

Many observational programs are currently underway that provide information on various aspects of the Earth's environment. Among these

are the operational and mission-focused systems maintained to support weather forecasting [mainly by NOAA, DoD, and the Federal Aviation Administration (FAA)] and to support resource management (e.g., USDA and DOI for land and water resources, and EPA and States for air quality). While the observations from these systems are very important, many gaps exist in the sets of measurements taken related to observing and monitoring global environmental change. Systematic global observations of key variables are urgently needed to enable the following:

- Detection and quantification of climate change
- Documentation of natural climate variability and extreme climate events
- Understanding, modeling, and prediction of climate variations and change
- Elucidation of the causes, magnitude, and impacts of stratospheric ozone depletion
- Estimation of the potential impacts of environmental change on ecosystems and socioeconomic resources and systems
- Development and evaluation of possible strategies to diminish potentially harmful effects
- Provision of seasonal forecasts and assistance to climate-sensitive sectors.

The identification and assembly of data needs are important aspects in determining the specific observations required of an integrated global observing system.

Specific objectives that will be addressed to meet the USGCRP needs for observations and monitoring follow.

Objective 1—Contribute to the Development of a Strategy that will Lead to an Integrated International System for Observing and Monitoring the Earth's Environment and Natural Resources

During FY96, the Task Force on Observations and Data Management (TFODM) of CENR is leading the Administration initiative to move toward a cooperative effort to design and implement an international strategy in pursuit of an integrated global observing system. The USGCRP, along with the operational agencies, is closely involved with the development of the U.S. contribution to this strategy.

Over the past few years, the scientific community has been considering what the needed measurements are and how best to make the observations. The major scientific programs, both national and international, have been important sources of information. The planning

efforts undertaken by the international scientific committees for the Global Climate Observing System (GCOS), the Global Ocean Observing System (GOOS), the Global Terrestrial Observing System (GTOS), and other organizations, and the Committee on Earth Observation Satellites (CEOS), have been identifying the requirements for a global observing system. An international strategy for global observing must facilitate a cohesive integration and augmentation of surface, space, and *in situ* measurement capabilities in a way that serves multiple needs.

The participation of agencies that fund observations for operational weather forecasting and research, working with the scientific community, is important in the design of a cost-effective and efficient means to acquire the needed data. Working in coordination with other agencies, NASA and NOAA are leading the U.S. effort to gain international agreement on an approach to developing such an integrated strategy. During FY96, two international workshops have been organized by CEOS and GCOS to discuss alternative approaches to establishing institutional mechanisms for coordinating the space-based and *in situ* components of this strategy. During FY97, we will work with our international partners to take steps to establish a process for consultation and coordination that will work toward an integrated global observing strategy.

Objective 2—Coordinate and Implement the U.S. Satellite Component of the International Integrated Global Observing System

The U.S. contribution to the satellite component of the integrated global observing system will draw upon the satellite resources of NASA, NOAA, and DoD. The NASA component will be carried out through the Earth Observing System series of satellites, which is the centerpiece of NASA's Mission to Planet Earth. MTPE is NASA's contribution to the USGCRP and is included within the USGCRP budget. The NOAA and DoD contributions to the satellite observing system are made through their operational weather satellite programs, a future component of which is being coordinated through the National Polar-Orbiting Environmental Satellite System (NPOESS) program; because their principal justification is for operational applications, these efforts are not included within the USGCRP budget.

EOS was recognized as the major component of MTPE and received its authorization from Congress in 1990. Its fundamental goal and objectives are to meet the needs of the USGCRP through the gathering and interpretation of observations of the Earth system from the unique vantage point of space. EOS is intended to be part of a long-term observation

program, with systematic, accurately calibrated measurement of various Earth system properties over a period of at least 15 years.

MTPE implementation consists of three phases, the first two of which are described here and the third under objective 5. During Phase I (1990-1997), NASA established the Pathfinder Program in collaboration with NOAA, DoD, and EPA to obtain, calibrate, process, and make available Earth observations acquired by NASA research satellites such as the Upper Atmosphere Research Satellite (UARS) and TOPEX/Poseidon, and NOAA and DoD operational environmental monitoring satellites. In addition, NASA and NOAA established joint projects with the space agencies of Canada, Europe, Japan, and Russia to acquire, process, and make available to U.S. scientists the satellite environmental data collected by these agencies. Notable successes have been observations of stratospheric ozone depletion obtained jointly with Russia and Japan; the observations of sea ice, ocean currents, and terrestrial ecosystems using Synthetic Aperture Radar by Canada, Japan, and Europe; and the observations of terrestrial and oceanic ecosystems with Japan. These programs will continue intensively over the next year, and are already making extensive data sets available for analysis of trends and conditions.

In Phase II (1997-2002), NASA will launch a series of missions, including the initial EOS satellites that will, for the first time, obtain a comprehensive range of space-based observations of the interactions between the atmosphere and the continents and oceans, especially the coastal regions. International partners will also play a major role during this phase, through their contribution of instruments that will be launched on U.S. satellites (Canada and Japan), accommodation of U.S. instruments on their satellites (Canada, Japan, and Russia), and/or development of joint satellites (France, Argentina, and South Africa). The MTPE satellites and instruments flown on satellites of our international partners over the next few years include the following:

- TRMM (planned launch in 1997) will provide the first observations of precipitation using active remote sensing from space over much of the world, especially over the oceans, helping to improve predictions of the global hydrological cycle.
- The Landsat-7 mission (planned launch in 1998) will provide high-spatial resolution visible and infrared observations of the land surface.
- The EOS-AM1 and -PM1 missions (planned launches in 1998 and 2000, respectively) will provide crucial new measurements or improvements of existing measurements to characterize the atmosphere (including clouds, aerosols, and the radiation balance), the land surface (including ecosystems,

land cover, and soils), and the oceans (including ocean color and sea ice extent).

- The EOS-CHEM1 mission (planned launch in 2002) will provide detailed measurements of the chemical composition of the stratosphere and troposphere.

The table accompanying this section shows how the planned series of measurements from MTPE/EOS satellites will contribute to the research needs of the USGCRP's four key environmental science issue areas.

With respect to the operational weather satellite programs, an important step toward an integrated global observing system is the ongoing convergence of the NOAA and DoD satellite programs that gather information for use in initializing weather forecast models and other applications. The NPOESS program is setting as its objective the deployment of observing instruments that will meet civilian and defense weather forecast requirements. These data will go a long way in meeting the needs of scientists seeking to document, understand, and project global environmental change. Such a coordinated effort will result in substantial long-term savings while also providing a greatly increased set of observations of a quality suitable for studies of long-term environmental change.

These satellite missions, together with coordinated and complementary missions of our international space partners, will ensure the diverse and necessary array of Earth observations needed to document and improve predictions of weather, to identify seasonal to interannual climate fluctuations, and to document long-term climate variability and change.

Objective 3—Strengthen the Commitment to and Implementation of an Integrated Surface Observing System for Addressing Global Change Needs

Measurements in and near the surface are critical to understanding the environment that people experience and for identifying changes that cannot be observed remotely. Such measurements require a strong program of airborne, surface, and deep ocean observations to provide critical measurements of quantities that cannot be measured with sufficient accuracy from space, and to help calibrate satellite measurements, which are based on indirect rather than direct measures of many of the quantities. Also, because satellites cannot measure below the surface of the land or the oceans, it is vital to have *in situ* measurements from buoys and ground probes.

Earth Observing System Contributions to USGCRP Research Goals

Measurements	Seasonal to Interannual Climate Variability	Climate Change Over Decades to Centuries	Changes in Ozone, UV Radiation, and Atmospheric Chemistry	Changes in Land Cover and in Terrestrial and Marine Ecosystems
	Global Change Environmental Science Issues			
Atmosphere Set				
Aerosol Properties (naturol and human-induced)	✘	✘	✘	
Atmospheric Humidity	✘	✘	✘	✘
Atmospheric Temperoture	✘	✘	✘	✘
Cloud Amounts, Types, and Properties	✘	✘	✔	
Lightning	✔	✔	✔	
Precipitation	✘	✘	✔	✘
Radiative Energy Fluxes	✘	✘	✔	✔
Stratospheric Chemistry	✔	✔	✘	
Tropospheric Chemistry	✔	✘	✘	✔
Solar Radiation Set				
Total Solar Irrodiance	✔	✘		
Ultraviolet Spectral Irrodionce	✔	✔	✘	✔
Land Set				
Fire Occurrence	✔	✔	✔	✘
Land Cover and Land Use Change	✔	✔	✔	✘
Surface Temperoture	✘	✘	✔	✘
Surface Wetness	✘	✔		✘
Vegetation Dynamics	✔	✔		✘
Volcanic Effects (on surface)	✘	✔	✘	✔
Ocean Set				
Ocean Surface Topography	✘	✘		✔
Phytoplankton and Dissolved Organic Motter	✔	✔	✔	✘
Surface Temperoture	✘	✘		✔
Surface Wind Field	✘	✔		
Cryosphere Set				
Land Ice	✔	✘		✔
Sea Ice	✘	✘		
Snow Cover	✘	✘		✔

KEY

✘ Essential Contribution

✔ Supporting Contribution

Increased coordination of the Nation's environmental monitoring and related research networks and programs is being proposed under the auspices of the CENR and its National Environmental Monitoring and Research Initiative, with which the USGCRP is cooperating. We anticipate that this initiative, which is proceeding with both national- and regional-level planning activities, will begin a process in FY97 that will, when fully developed, provide the needed baseline information for documenting how ecosystems in the United States are being affected by environmental fluctuations and changes over periods from seasons to decades and longer.

In support of the needs for weather forecasting, air quality and ecosystem monitoring, and natural disaster mitigation, the United States has deployed a number of station networks, only very limited aspects of which are funded by USGCRP:

- The network of surface and upper-air meteorological observation stations implemented by the United States and other nations under the aegis of the international World Weather Watch provides measurements of the dynamics and thermodynamics of the lower atmosphere. The North American Atmospheric Observing System study provides the basis for making sound decisions on a "best mix" of observing systems for operational weather forecasting; the needs for observations in support of climate research will also be considered.
- The NOAA, NASA, and EPA networks of observing stations and similar facilities implemented by other nations under the aegis of the international Global Atmosphere Watch provides observations of the concentrations of greenhouse gases and ozone-depleting substances. Stratospheric ozone and key ozone-related compounds and parameters are measured through remote sounding by the international Network for the Detection of Stratospheric Change, sponsored in the United States by NASA, NOAA, and NSF. DOE and other agencies are supporting an effort to develop a network of stations that measure the land-atmosphere fluxes of carbon dioxide, and its variation over seasons and interannually, seeking to improve the information base on carbon feedback processes. In addition, a succession of extensive field campaigns designed to elucidate the mechanisms of global change provide a mosaic of observations on the key chemical compounds and processes involved in causing change. Augmentation of capabilities for observing aerosols and adding stations for monitoring over land areas are the most important current needs.

- An internationally sponsored array of moored and drifting buoys that monitor surface and below-surface temperatures in the tropical Pacific Ocean help detect the onset of El Niño events. The scientific community is considering how best this USGCRP-funded network of buoys might be extended in the Pacific and in other oceans to augment operationally funded ocean measurements in order to further improve the predictive capability of the seasonal to interannual climate fluctuations that so affect agriculture and water resources in the tropics and higher latitudes.
- Extensive USDA, DOI, and EPA networks monitor the conditions of forests and other ecosystems, biota (the plants and animals of a region), soils, runoff, and water resources. The monitoring stations of these and other agencies provide data to fulfill their statutory responsibilities while also providing information for research on environmental change. NSF, DOI, USDA, and DOE also support a number of ecological research sites that are gathering long records for use in detection of trends and for understanding the causes of environmental change. The improved coordination of these networks is being considered as part of the National Environmental Monitoring Initiative organized by the CENR.
- The Surface Radiation Budget Network (SURFRAD) is operated by NOAA to provide continuous measurements of the upward and downward component of visible and infrared radiation. The network consists of stations in Illinois, Montana, Mississippi, and Colorado that provide information needed for evaluating satellite-based estimates of surface radiation and estimates of solar irradiance at the surface. NOAA and NASA are contributing to the baseline surface radiation network of the World Climate Research Programme, which is extending these types of measurements globally.
- The UV radiation network of stations maintained by USDA, EPA, and NSF provide reference measurements for the United States and the polar regions that are starting to indicate the effects of ozone depletion. Sustaining this new capability is an essential resource for assessment of ecological consequences.

Objective 4—Obtain Observational and Proxy Data to Provide a Retrospective of Weather and Climatic Conditions in the Past

In addition to strengthening the system for observing the current climate, understanding climatic behavior requires that there be a detailed historical

record of the climate, both over the past few decades and further back into the past. While the actual state of the atmosphere and oceans will have changed, there are many indications of past conditions that can be combined with observations that do exist to provide a retrospective picture of the previous climatic states. This effort, which is closely tied to the data analysis and climate system history efforts of the USGCRP, includes efforts to derive measurements for periods ranging from the very distant past (e.g., through the drilling of ice cores where ancient air is trapped) to the more recent decades (e.g., by measuring temperatures in boreholes drilled into the ground and in the ocean depths).

These records of past conditions are essential in providing the information needed to determine trends in conditions, to identify geographic patterns that can indicate the global consistency of changes seen in one or a few regions, and to improve understanding of the mechanisms leading to changes.

Objective 5—Develop and Demonstrate New and More Cost-Effective Instruments for Providing Critical Information in the Future

While providing very significant information of high societal value, observing the full Earth system on a continuing basis is a challenging and expensive process. There are many quantities to keep track of, in the atmosphere and oceans and over and below the land surface. To ensure that the observations are being taken in the most cost-effective manner, while still maintaining the quality and continuity of measurements needed for scientific purposes, continuing efforts are underway to improve and reduce the cost of observation systems. Much of this effort is occurring under the auspices of NOAA and DoD's operational programs and in cooperation with FAA. For example, a number of systems have been in development to provide moisture and temperature measurement on a large scale, including new sensors for automated aircraft measurements during ascent and descent and improved use of existing satellite-based systems.

With regard to development of new satellite measurements—which are the most costly, the most comprehensive, and essential for observations at the global scale—several new initiatives are underway:

- The Global Positioning System/Meteorology (GPS/Met) is a very small satellite instrument developed and recently launched with funding from the FAA, NSF, NOAA, and NASA, and substantial contributions from industry. GPS/Met, which weighs only 10 kg (about 22 lb), receives signals from 24

GPS satellites operated by DoD. Data already obtained from this proof-of-concept experiment are demonstrating that atmospheric effects on the transmission of signals from the GPS satellites can be used to derive three-dimensional distributions of a combined measure of atmospheric temperature and water vapor, which could be useful in both climate research and weather forecasting.

- To support improvements in Phase III of the MTPE program (2002-2015), NASA intends to extend the set of space-based observations by incorporating new and emerging technologies and taking advantage of small satellite technologies; activities that start this process will begin in FY97. For example, NASA's New Millennium Program of small satellites is a step to provide opportunities for demonstrating new, more cost-effective instrument technologies. NASA's Earth System Science Pathfinder (ESSP) program, initiated in FY96, will acquire new experimental types of scientific measurements over the next few decades.

Regarding *in situ* data gathering, the Office of Naval Research is proposing to continue interagency support for a basin-scale ocean measurement program capitalizing on the FY92-96 investments by DoD in the Acoustic Thermometry of Ocean Climate (ATOC) research program. The ATOC studies of acoustic travel-time variability along fixed ocean paths were designed to accurately characterize seasonal and long-term trends in ocean temperature. It is expected that a system of acoustic arrays may provide data that could revolutionize understanding of the ocean's interior just as GPS/Met could revolutionize understanding of the atmosphere upward from the mid-troposphere.

Efforts are also underway among USGCRP agencies to improve measurements of various chemicals in the environment and of other quantities, generally as part of the field programs that are focusing on how Earth system processes are working.

Agency Contributions

Consistent with their respective roles and missions, the Federal agencies are supporting a wide array of observing systems that record the state of the environment. Many of these systems are provided as part of the operational and mission responsibilities of various agencies (including, for example, the weather satellites of NOAA and DoD, and the surface measuring sites of NOAA, DoD, USDA, DOI, and

other agencies). Data from these systems, which are maintained primarily for other purposes, are provided to the USGCRP for research on longer term trends and conditions. In addition, in support of their research responsibilities, several of the USGCRP agencies support special efforts to gather the wider set of information needed to study and monitor seasonal to interannual fluctuations, climate change detection and response, terrestrial and marine ecosystems, and atmospheric chemistry:

- NOAA's contributions to the USGCRP observational program are focused through its Office of Global Programs, which supports an extensive set of oceanic and atmospheric observations. Oceanic observations include an array of moored and floating buoys in the Pacific Ocean and an associated real-time communication system that provides the essential information underlying successful forecasts of El Niño and seasonal to interannual climate fluctuations. Atmospheric observations include the worldwide *in situ* and flask-sampling network for greenhouse and ozone-depleting gases operated by NOAA's Environmental Research Laboratories, as well as ground-based and airborne measurements of stratospheric and tropospheric ozone and of key chemically reactive species (gases and aerosols) responsible for ozone change. Through its operational programs and in coordination with other countries, NOAA also supports the Nation's civilian observing, data assembly and processing, and data archival and information systems. While not formally part of the USGCRP, these systems provide essential observations and information for USGCRP programs by drawing upon the information gathered at a wide number of surface stations, through measurements from commercial aircraft, and from a wide array of instruments on polar-orbiting and geostationary satellites.
- NASA's Mission to Planet Earth is the largest of the agency contributions to the USGCRP observing and monitoring program. For this effort, MTPE includes space-, ground-, and aircraft-based measurement systems to provide the information needed to enhance the scientific basis for understanding the Earth system, climate, and its variations. NASA's contributions to MTPE include ongoing and near-term satellite missions (e.g., UARS, Earth Radiation Budget), approved new missions (e.g., TRMM, EOS), and future missions yet to be developed (e.g., via ESSP).

- DoD provides an extensive set of measurements through its satellite and weather observation systems, many in cooperation with other agencies. To further expand the set of available measurements taken by defense systems, the MEDEA project has been reviewing DoD data sets that may prove valuable in improving understanding of the oceans, the land surface, changes in vegetation, and atmospheric conditions. DoD also sponsors the ATOC program to measure ocean temperatures.
- NSF depends on high-quality, well-documented and calibrated, long-term, and uninterrupted time series of environmental data for the scientific research activities that it sponsors. NSF supports three activities that relate to this need: (i) Collections of special observations required for funded research projects, some of which may be long term (NSF, however, does not support the collection or processing of long-term observations required by mission agencies for their operational needs); (ii) innovative observing techniques and instrument development (such support is generally provided for "proof-of-concept" projects of limited duration); and (iii) construction of very long time series of past environmental conditions and indicators.
- DOI sponsors programs addressing the collection, maintenance, analysis, and interpretation of short- and long-term land, water, biological, and other natural resource data and information, including monitoring of hydrologic, biologic, and geologic processes and resources through nationwide observation networks; research, production, and dissemination of land-use and land-cover information, including creation of maps and digital data products; and inventories and monitoring of biological habitats, resources, and diversity. A series of Water, Energy, and Biogeochemical Budget (WEBB) sites are measuring changes in CO_2, climate, and biogeochemistry relating to the terrestrial carbon cycle, nutrient cycles, the hydrologic cycle, and the surface energy budget. Volcano-monitoring studies are improving baseline estimates of emissions of greenhouse gases, sulfurous gases, aerosols, and particles to the atmosphere. Monitoring of glacier mass balance provides information for sea level and climate impact studies. DOI's monitoring activities contribute not only to global change studies, but also to many other activities relating to resource management and use.
- USDA is taking the lead in providing information on the climatology and geographical distribution of UV-B radiation as

well as long-term trends. This information supports USDA-sponsored research on UV-B radiation effects on crops and forests (including research on effects on plants and animals sponsored by other agencies as well as human health effects) and provides a basis for the development of mitigation strategies if effects research finds that UV radiation is increasing to potentially damaging levels. The USDA effort involves the establishment of a national climatological network of UV-B monitoring sites, of which 10 are in place and an additional 20 will be installed during the next 18 months. Because the UV-B measurement is extremely difficult, international efforts are underway to improve instrumentation and measurement accuracy. USDA is taking the lead in the U.S. to develop highly accurate spectral instruments of high resolution to support research on factors controlling surface UV-B radiation levels, which will serve as standards for the larger networks of less sophisticated instrumentation. In addition, USDA has led the effort to establish an instrument calibration facility at NOAA.

USDA also maintains a soil climatic data network with 21 sites throughout the United States and Puerto Rico. The system is tied through the SNOTEL system, which uses meteor-burst radio communication technology and phone links to collect remote site information. Data monitored includes above-ground climate data and soil temperatures, soil moisture, and other below-ground parameters.

- DOE supports a number of observation and data management activities relating to its cloud-radiation and carbon flux studies. In addition, DOE supports the collation, analysis, and quality assurance of carbon dioxide emissions data.
- EPA is an active participant in programs to monitor the state of the Nation's ecosystems and air and water quality. EPA also supports the monitoring of UV radiation at urban sites within the United States.
- HHS, because of its broader responsibilities for human health, collects a significant amount of information on the extent of diseases and the vectors (e.g., mosquitoes, rodents) that transmit them. HHS is working with NASA on new studies that are increasing understanding of how changes in seasonal weather that alter the domain and population of these vectors affect the occurrence of various diseases.

Global Change Data, Products, and Information Services

Meeting User Needs for Full and Open Access to Useful Products and Services

Data and information on the global environment and how it may be varying and changing are needed by a wide range of users for a wide range of purposes, including, but not limited to, the following:

- Understanding and predicting seasonal and interannual fluctuations of the climate and of long-term trends in ozone concentration and climate
- Monitoring and documenting changes in climate, atmospheric chemistry, and ecosystems
- Investigating Earth system processes
- Providing information on global changes to policymakers
- Supporting commercial applications by the private sector
- Teaching about our home planet by educators
- Informing the communications media and the public about the scientific progress and accomplishments of global change research.

Basic data and derived data products of importance include everything from temperature and pressure in the atmosphere, to currents and salinity in the oceans, to vegetation and population over land. Data needs cover the physical, chemical, biological, economic, and social sciences, and can span domains from the center of the Earth to the Sun. Time and space scales needed include everything from local observations to globally integrated patterns and from instantaneous measurements to multi-century trends. The spectrum of data sources includes observations taken by satellites, aircraft, ships, and surface stations; simulations by models; and measurements taken in research studies. The data are generated by any of a number of sources, including Federal agencies, international organizations, individual scientists, State and local governments, public institutions, and private organizations. The types of user needs range from single measurements to specifically designed products that can be immediately applied in ways that will reduce impacts and improve the human condition.

Given this great diversity, the challenge is to provide a flexible and adaptable system that builds from both existing agency capabilities and an underlying set of agreed-upon principles. As one example of such principles, the U.S. Government has established a set of data policy statements that govern how the USGCRP approaches data management.

Fundamentally, the intent is to ensure that data are readily available at minimal cost, and are documented and archived so that they may benefit not only current users but also future generations.

Data Management for Global Change Research Policy Statements

- The U.S. Global Change Research Program requires an early and continuing commitment to the establishment, maintenance, validation, description, accessibility, and distribution of high-quality, long-term data sets.
- Full and open sharing of the full suite of global data sets for all global change researchers is a fundamental objective.
- Preservation of all data needed for long-term global change research is required. For each and every global change data parameter, there should be at least one explicitly designated archive. Procedures and criteria for setting priorities for data acquisition, retention, and purging should be developed by participating agencies, both nationally and internationally. A clearing-house process should be established to prevent the purging and loss of important data sets.
- Data archives must include easily accessible information about the data holdings, including quality assessments, supporting ancillary information, and guidance and aids for locating and obtaining the data.
- National and international standards should be used to the greatest extent possible for media and for processing and communication of global data sets.
- Data should be provided at the lowest possible cost to global change researchers in the interest of full and open access to data. This cost should, as a first principle, be no more than the marginal cost of filling a specific user request. Agencies should act to streamline administrative arrangements for exchanging data among researchers.
- For those programs in which selected principal investigators have initial periods of exclusive data use, data should be made openly available as soon as they become widely useful. In each case, the funding agency should explicitly define the duration of any exclusive-use period.

Global Change Data, Products, and Information Services Program Goal

The goal of the data, products, and information services element of the USGCRP is to provide all users ready and affordable access in useful forms to the full spectrum of global change data, products, and information.

Achieving this goal will accelerate scientific progress while also greatly enhancing public and private sector access to data that can make the economy more resilient to changes and fluctuations, help education at all levels, allow adaptation to changes, and aid resource managers in management and planning.

There are two fundamental components of the data, products, and information services efforts that are being implemented. The first component involves making the data readily accessible, both now and in the future. This responsibility is being met through the interagency Global Change Data and Information System (GCDIS), which is explained more fully later in this section. The second component involves providing useful products (for scientists, for the broader user community, and for other Government activities) and is being fulfilled through GCDIS-participating data centers and through the efforts of thousands of scientists who gather, develop, and assemble new information and transform it into useful data products.

Global Change Data, Products, and Information Services Program Objectives

To meet the goal of providing all users ready and affordable access in useful forms to the full spectrum of global change data, products, and information, the USGCRP agencies are pursuing a number of implementation objectives.

Objective 1—Provide a Coordinated Means by which Users can Readily Find the Global Change Data, Products, and Information They Need

There are thousands of possible sources and massive numbers of potential individual data and information products. It is critical to a user to be able to find the data, products, and information that they need. Over the past few years, significant progress has been made in addressing

this need for information and much of the data, products, and information holdings of the Federal agencies can be found through the GCDIS Home Page on Internet. The USGCRP, as directed by the Global Change Research Act of 1990, has also established the Global Change Research Information Office (GCRIO) as the point of contact for all users who need help in finding data held by the U.S. Government relating to global environmental change. During FY97, it is planned that GCDIS will pursue the following:

- Expand coverage of model data outputs, socioeconomic and biological data, and non-Federal sources
- Apply developing standards and technology to make possible more efficient user searches for data, products, and information
- Provide access capabilities tailored to meet the needs of the individual program elements of the USGCRP.

Objective 2—Ensure that the Data, Products, and Information are Quickly Available and Affordable

It does no good for a user to find that information exists if it cannot be obtained in time to meet the user's needs or if it is more expensive than can be afforded. Because of the fundamental value of data to advancing science and society, the U.S. Government has instituted a policy that its global change data should be fully available to all at only the cost of distribution. The United States has also been very active in encouraging that this approach be taken by international organizations, thereby making available data from many nations around the world. Since the issues being studied are global in scope, access to these data sets is essential.

To make sure that data are quickly available, the USGCRP agencies have moved rapidly to make their data available over the Internet. At present, global change-related data, products, and information from seven agencies can be located using Internet access to more than 70 of their data centers, libraries, and information service nodes. Included are links to the U.S. World Data Centers, which in turn are linked to similar World Data Centers around the world. Each of these data centers not only archive data from many nations, but also provide for its full and open access through the policies established for this international cooperative system.

During FY97 it is planned that policies for how to provide interfaces with private sector and other non-governmental data, products, and information will be developed.

Objective 3—Ensure that Data, Products, and Information are Documented and Archived

The U.S. Government has established responsibilities for long-term archiving of global change-related data, products, and information by giving specific responsibilities to the National Archives and Records Administration and to agencies such as DOC and DOI. Agreements for some interagency transfers to meet these policies are in effect, such as DoD sending relevant data to DOC for archiving and use, but others still need to be completed.

Without adequate attention to documenting and archiving data, it is lost or rendered unusable to future users—wasting the investments of both funding and intellectual effort made for the data to be obtained. Further, without documentation of its fundamental properties such as data quality, location, and time, the data from diverse sources cannot be used together with confidence, a critical need for study of long-term change. Failing to take actions to document and archive is tantamount to forgetting the past.

During FY97, it is planned that standardized documentation format policies will be identified for the USGCRP.

Objective 4—Meet the Specific Data, Products, and Information Needs of the Scientific Community to Conduct USGCRP-Related Research, Monitoring, and Assessment Activities

As an integrated and coordinated program, the USGCRP depends upon the data, products, and information services component to provide data sets and derived products needed to monitor the environment, to understand its functioning, to enable predictions, to evaluate the consequences of changes, and to estimate the socioeconomic impacts of change. Each of the USGCRP's focused programs has its own user community that needs data products tailored to meet respective requirements.

An important example of such a derived data product is the reanalysis of past information. While new measurements of the weather of past years cannot be taken, it is possible to use computer models of the atmosphere to process all of the available observations, thereby reconstructing a best estimate of past weather. This process, called reanalysis, first requires the assembly and careful checking of all available data from past measurements taken at the surface, by balloon and aircraft, and from satellites and ships. With such data assembled, the

best models currently available for the interpolation and initialization of weather observations for operational forecast purposes can be used to adjust for consistency and to interpolate observed parameters to regions where observations were not available. That this process works quite well can be readily checked by leaving out some of the available observations and checking how well they are estimated by the reanalysis process. Such efforts are underway in both NOAA and NASA, as well as cooperatively with the European Centre for Medium-Range Weather Forecasts, to cover different periods and different regions of the atmosphere. The data provide a very high-quality information base for testing all types of models and for use in determining the character and causes of past climatic fluctuations.

During FY97, it is planned that the data management program will work with the focused program elements of the USGCRP to define and begin to produce the specific derived data products they most need.

Objective 5—Be Responsive to the Data, Products and Information Needs Identified by the User Community and its Representatives, Including Educators

Data are needed by a wide variety of users in addition to the scientific research community. In addition to simply providing information on what is happening, commercial users of the data provide special products for users ranging from the insurance industry to agriculture, and from shipping companies to water resource managers. Ready access to information is what makes the Nation's economy more efficient, allows the optimization of economic activities related to the climate, and indicates the degree of resilience that must be provided. In addition, given that the information plays such an important economic role, the education community needs the data, products, and information to train students for jobs of the future—that the information is also very interesting, and even inspiring, is an additional important benefit.

For several years, GCDIS has worked closely with the National Academy of Sciences as a representative of the user community. In addition, a pilot evaluation of GCDIS for Internet-coupled schools in Virginia is now being completed. These schools spanned the K-12 to university education levels.

During FY97, it is planned that GCDIS will expand its on-line user evaluation capability and secure critiques by the focused elements of the USGCRP, including global change education, as representatives of their user communities.

Objective 6—Coordinate Global Change Data Management Activities with Related Activities being Carried Out by Other Parts of the Federal Government and Internationally

The data and information collected for understanding global change are part of the much larger amount of data and information being collected, accessed, and used for other purposes. The needs of the USGCRP cannot be met without working with these other entities to share data, products, information, and capabilities. Moreover, many other Federal programs could be enhanced by having access to USGCRP data, products, and information. GCDIS is actively coordinating its activities with those of the Federal Geographic Data Committee, the Government Information Locator Service, and the National Environmental Data Index. Internationally, global change-related data systems are being planned by global observational coordinating mechanisms such as CEOS, GCOS, GOOS, and GTOS.

During FY97, it is planned that cooperative links to these international global observation programs data systems will be expanded. Similarly, it is planned to continue and to expand the close working relationships with the National Environmental Monitoring Initiative in order to improve access to data on the United States.

Global Change Data and Information System

The key to meeting all of these objectives has been the establishment of the Global Change Data and Information System. As a system, GCDIS embraces the full range of people, infrastructure (e.g., hardware, software, networks, telephones, mail), and procedures necessary for identifying, assembling, documenting, archiving, and disseminating global change data and information. This system builds on the mission resources and responsibilities of each agency, and links the data and information services of the agencies to each other and to an open set of users.

Interagency GCDIS implementation is founded on strong coordination and cooperation among the participating Federal agencies, yet recognizes the differences in the types and levels of support they provide to the USGCRP. This has led to the design of GCDIS as a "virtual" system—that is, one that provides a view of the diverse Federal global change-related data and information holdings, with a minimum of cross-cutting new infrastructure to link individual agency data and information systems. This computerized system is made interoperable (i.e., with the various components capable of being used in a reciprocal, complementary

manner) through the use of standards, common approaches, technology sharing, and data policy coordination. GCDIS will emerge through coordinated interagency participation, with portions of each agency's own data and information system serving as that agency's component of the GCDIS. Users can initially enter the data and information system from a single point of contact via the Internet, through the GCDIS World Wide Web Home Page, using the uniform resource locator http://www.gcdis.usgcrp.gov.

While the initial phase of GCDIS implementation focuses on the Federal agency systems, the system will be broadened to provide increased access to relevant international and State and local holdings. Access to international data and information is now provided through existing agency participation in the World Data Center system. This system, conceived and fostered by the International Council of Scientific Unions (ICSU), is responsible for archiving and exchanging important environmental data and information among almost all nations.

To support widespread access to GCDIS, GCRIO provides information resource services to applications users and others outside the research community, both nationally and internationally.

Agency Contributions

Each of the participating agencies plays a role appropriate to its agency mission, and implements GCDIS consistent with its mission and with available funds:

- USDA depends on data relating to climate and hydrology, biogeochemical dynamics, ecological systems, Earth system history, and human interactions in fulfilling its responsibilities to support agriculture, forestry, and ranching programs that ensure a continued and healthy food supply for the Nation and our trading partners throughout the world, and protection of private and public lands for future generations. USDA is identifying data and information among its holdings that are of value to the USGCRP and is taking steps to make them available.
- DOC, particularly NOAA, gathers data from satellites, ships, aircraft, and surface stations on the state of the atmosphere and oceans in support of its responsibilities for operational forecasting, detecting and mitigating environmental problems, managing natural resources, sustaining the environment, and conducting research. NOAA provides user access to global

NOAA and DoD environmental data and information of value to the USGCRP through the interoperable NOAA National Data Centers and World Data Centers. DOC also will provide access to census data and information.

- DoD routinely makes unclassified data and information available to the appropriate U.S. National Data Centers; agencies receiving DoD data products assume the responsibility for GCDIS functions. In June 1995, the Navy released all data collected by the Geodetic Satellite (GEOSAT-A) into the public domain. Precise geodesy mission data from 72°S to 72°N is being distributed by the National Oceanographic Data Center operated by NOAA. Further, in 1995, the Navy commissioned a subset of MEDEA scientists to determine the potential for unique environmental research arising from the use of existing classified databases and to identify opportunities for collaboration between the civil and Navy science communities. Recommendations from the report *Scientific Utility of Naval Environmental Data* are currently under review. In addition, the President signed an Executive Order on February 24, 1995, directing declassification of imagery obtained by the first generation of photo-reconnaissance satellites. More than 800,000 satellite images collected between 1960 and 1972 will be declassified. The public will be able to access these records through the National Archives facility at College Park, Maryland.
- DOE's mission includes developing efficiency in energy use, diversity in energy sources, a more productive and competitive economy, and improved environmental quality, making their data critical to the study of global environmental change. DOE is working to provide access to data and information from its programs through a set of individual data and information systems focused on specific databases to which interoperable functionality will be added. DOE, through the Carbon Dioxide Information Analysis Center (CDIAC), which is a World Data Center for atmospheric trace gases, will provide access to a variety of archived data and information including, for example, atmospheric trace gases, ocean and soil carbon, atmospheric ozone, and climatic data.
- DOI Bureaus collect, maintain, analyze, and interpret short- and long-term land, water, air, biological, geological, and other natural resource data and information in support of DOI's USGCRP and mission responsibilities. DOI is working

to provide access to data and information from its programs and other sources for which the DOI is custodian. GCDIS interoperability initially will be provided at the U.S. Geological Survey (USGS) Earth Resources Observation System (EROS) Data Center, which is one of the key U.S. Government data archives.

- EPA has data gathered both for USGCRP and related programs and for its regulatory responsibilities, much of which may contribute to the understanding of global change. EPA is developing the means to access its public data through a series of public access servers and the Envirofacts Database. Global change-relevant data will be made available to GCDIS users through these servers and Envirofacts.
- NASA is responsible for remotely sensed data gathered as part of its satellite and *in situ* measurement programs. NASA is making all of the data and information from its Mission to Planet Earth available through EOSDIS, and will seek funding to ensure the functional interoperability required for implementation by all participating agencies. NASA will also provide for the data and information archiving and management, where needed, of socioeconomic data and information through its Socioeconomic Data and Applications Center.
- NSF sponsors a wide array of research activities. Data from these activities is made available through a number of publicly accessible archives, including the National Center for Atmospheric Research, the Long-Term Ecological Research (LTER) program, and the Inter-University Consortium for Political and Social Research. These entities provide access to archived data and information through an existing data system to which interoperability will be added. An electronic data system for data and information from the LTER sites will also be developed. NSF's goal is to have sponsored researchers identify and make available their relevant data and information to a publicly accessible archive for use by global change researchers.

In addition to these agencies, the Department of State and the National Institute of Environmental Health Sciences participate in GCDIS planning. The Department of State will maintain and coordinate links with intergovernmental organizations and UN technical agencies that have programs relevant to GCDIS. A high-priority objective is to promote wide adoption of a policy of full and open sharing of global change data in multilateral forums, as well as in bilateral agreements.

Program Documentation

The data management issues, policies, and plans of GCDIS have been presented in the *Data Management for Global Change Policy Statements*, issued in 1991 by the Executive Office of the President, and in a series of three documents published in 1992 by the Committee on Earth and Environmental Sciences, in 1994 by the Committee on Environment and Natural Resources, and in 1995 by the Subcommittee on Global Change Research. Each of these reports has benefitted significantly from a continuing series of reports by the National Academy of Sciences Committee on Geophysical and Environmental Data and from core working relationships with its members. These policy statements have been widely used internationally, particularly as applying to full and open data access.

Earth System Science

Toward a Predictive Understanding of Variations and Changes in the Earth System

Within the USGCRP, the study of the global aggregate of interactive linkages among the major systems that affect the environment is defined as Earth system science. Developing a holistic view of the Earth system is essential to the development of the comprehensive understanding needed to address fundamentally important questions about global environmental change and its impacts and consequences. Improving overall understanding and building the capability to address new questions as they arise in the future depends on continued progress in the traditional disciplines of the geophysical and environmental sciences and in the integration-oriented focus provided by the development and use of predictive Earth system models. The research from these studies contributes both to the objectives of the four key interrelated USGCRP environmental science issues—seasonal to interannual climate fluctuations, climate change over decades to centuries, changes in atmospheric chemistry and ozone depletion, and changes in land cover and in terrestrial and marine ecosystems—and to the overall effort to understand the Earth as an integrated system. Earth system science is a program-wide integration of scientific activities.

Earth System Science Program Goal

The goal of the Earth system science component of the USGCRP is to support the long-term, integrated and exploratory research needed to gain a predictive understanding of the interactions among the physical, chemical, geological, ecological, and solar processes that determine the functioning of the Earth system and its trends and fluctuations on global and regional scales.

Pursuing this goal provides the basis for continuing advances in fundamental understanding of the world around us and helps to identify emerging issues and potential changes of low probability but high impact (often referred to as surprises). It will contribute to understanding and improving predictive capabilities on each of the four environmental science issues.

To make progress toward this goal, the USGCRP is supporting programs of ongoing fundamental research by individual and groups

of scientists within the disciplinary sciences as a means of strengthening the foundation of understanding of the Earth system. The broad range of studies being undertaken involves observations, analysis, theory, modeling, and assessment. The scope of these studies ranges from regional to global, and encompasses phenomena and processes within the atmosphere, land, oceans, and biosphere. It includes research on both the current climate and past climates, even of the distant past, to provide context for understanding the significance of human-induced effects on the climate.

Earth System Science Program Objectives

To provide greater focus to the research and to better match research needs to the strengths and disciplines of the scientific community, research is organized around the following broad objectives.

Objective 1—Gain a Predictive Understanding of the Dynamic, Thermodynamic, and Hydrological Processes that Determine Temperature, Precipitation, and Other Physical Characteristics of the Earth System and their Variability, especially their Extreme Values

The USGCRP sponsors a number of national and cooperative international programs that seek to advance understanding of the physical and dynamic aspects of the Earth system. Under the auspices of the WCRP, the United States participates in GEWEX, the CLIVAR program, the World Ocean Circulation Experiment (WOCE), Arctic System Science (ACSYS), and international observing programs. A number of these programs have important sub-elements, including the GOALS program, which seeks to extend seasonal to interannual predictive capabilities, and ISLSCP, which aims to improve representation of land surface processes and interactions. U.S. agencies in a number of cases sponsor programs that have expanded or been incorporated into these international programs because of their special focus; these include the Atmospheric Radiation Measurement (ARM) program, which seeks to understand cloud-radiation interactions, and the Atlantic Climate Change Program (ACCP), which focuses on the variations in the North Atlantic that strongly affect European and North American climate. In addition, the United States is active in the overall climate modeling program, including the Atmospheric Model Intercomparison Project (AMIP) and the Climate Dynamics and Experimental Prediction (CDEP) program.

Objective 2—Gain a Predictive Understanding of the Chemical and Biogeochemical Processes that Determine Atmospheric Composition and the Chemical Characteristics of the Earth System

The USGCRP sponsors a number of programs nationally and under international auspices that focus on understanding changes in the chemical cycles of the atmosphere and oceans and interactions with the land surface. Internationally, most programs are under the auspices of the IGBP. JGOFS focuses on measuring the exchange of carbon between the atmosphere and oceans, and is done in coordination with the WOCE program. The International Global Atmospheric Chemistry (IGAC) program focuses on understanding the chemistry contributing to the formation of tropospheric ozone and aerosols. Significant studies also are conducted to improve predictions of changes in stratospheric chemistry; these studies focus on the homogeneous and heterogeneous chemical reactions that affect stratospheric ozone concentrations and the Antarctic springtime ozone hole. The Global Change Terrestrial Ecosystem (GCTE) program includes research on biogeochemical cycling of carbon and nutrients within ecosystems and IGBP's GAIM project, together with the ecosystem and hydrologic modeling, focuses on evaluating the capabilities of current models to simulate terrestrial components of the Earth's biogeochemical cycles. The USGCRP also sponsors a number of modeling activities to explore and enhance predictive understanding.

Objective 3—Gain a Predictive Understanding of the Biological and Ecological Processes that Determine the Distribution, Character, Influence, Interactions, and Trends of the Flora and Fauna of the Land and Oceans

Ecological systems both are affected by their physical and chemical environment and affect this environment through their characteristics and their uptake and release of chemicals. Internationally, ecological programs that study these issues are under the auspices of the IGBP. Studies include GLOBEC, which focuses on the marine environment, and GCTE, which focuses on the terrestrial environment. Within the U.S., TECO, a new interagency program, is focusing on exchanges of carbon and other trace gases as well as other cause and effect interactions between terrestrial ecosystems and other natural systems associated with global change. Programs have also been established to look at the polar regions and their particular ecosystems.

Objective 4—Gain a Quantitative Understanding of the History of the Earth's Environmental and Biological Systems, and Determine the Full Range and Character of Natural Environmental Variability

Understanding the past provides context for the future. Internationally, research in this area is coordinated under the IGBP-sponsored program on Past Global Changes (PAGES). USGCRP-sponsored research is underway to contribute to these efforts by determining past rates of climate change, the ecological and biogeochemical characteristics of past warm and cold periods, and regional climate patterns when the world's climate was different than at present. Model simulations are conducted [e.g., under the Paleoclimatic Model Intercomparison Project (PMIP)] in order to test both the models and scientific understanding.

Objective 5—Gain a Quantitative Understanding of the Geophysical, Geochemical, Geological, and Cryospheric Processes that Determine Global Sea Level, Volcanic Activity and Intensity, the Dynamics of Ice Sheets and Glaciers, and Related Interactions with the Earth's Surface Features and the Effects of these Processes upon the Global Environment

While the USGCRP sponsors some programs relating to the natural geological and geochemical aspects of the Earth, the USGCRP relies in many ways on the continuation of significant complementary research being carried out for many other purposes (e.g., hazard assessment, resource identification, seismology). USGCRP research generally focuses on natural factors (e.g., volcanic emissions) that accelerate or diminish human-induced effects on the global environment (e.g., volcanic aerosols can accelerate the ozone destruction caused by CFCs). A major responsibility is to ensure an integrated consideration of the human-induced and natural factors affecting the climate.

Objective 6—Gain a Predictive Understanding of the Solar and Upper Atmosphere Processes that Determine the External Forcing Factors Influencing the Biosphere and Climate System

The Sun is the major heat source for the Earth. Small changes in its output can alter the Earth's climate and affect the biosphere. Solar changes can be either direct or indirect: Direct changes are those that change the solar irradiance itself, while indirect changes are induced as a result of

changes in the upper atmosphere that result from changes in the solar output. The USGCRP augments the extensive research on the Sun through its ongoing basic research programs into solar behavior, which seek to understand how solar changes may be amplifying or masking changes resulting from human activities.

Earth System Intercouplings and Modeling

The knowledge gained from disciplinary studies in these six areas is being applied to the development of predictive capabilities for the USGCRP's four key interrelated environmental science issues:

- Seasonal to interannual climate variability
- Climate change over decades to centuries
- Changes in ozone, UV radiation, and atmospheric chemistry
- Changes in land cover and in terrestrial and marine ecosystems.

While each serves as a distinct focus, these areas also are intercoupled, and advances in understanding in any area will benefit each of the others. Changes in land cover (e.g., deforestation) and terrestrial and marine ecosystems influence climate change. Climate change, in turn, will likely alter the frequency and intensity of short-term climate fluctuations and their associated extreme events (such as severe storms, hurricanes, droughts, and floods). Changes in land cover also will alter soil moisture patterns, which strongly affect seasonal (summertime) continental climates. Stratospheric ozone depletion increases the amount of UV radiation reaching the Earth's surface, which in turn may alter terrestrial and marine ecosystems. Earth system science thus provides the paradigm for integrating diverse sets of knowledge developed within the elements of the USGCRP to derive a comprehensive natural science view of the Earth's environment as a whole.

The integration, testing, and application of existing and new knowledge produced by the full suite of USGCRP programs proceeds by means of developing, testing, and applying fully coupled and interactive Earth system models. We have progressed from relatively simple to highly sophisticated coupled atmosphere-ocean models that include plausibly realistic representations of land-surface and sea ice processes. These models are now being used to make simulations lasting centuries and longer, an order of magnitude longer than was possible with the simpler models of several years ago. While the results of these climate simulations still include significant simplifications and shortcomings, the newest models do

provide quite realistic representations of many atmospheric, oceanic, and land-surface processes and features of the observed Earth system. Work is in progress to include direct human-induced changes in land cover, dynamic ecological succession, and tropospheric chemistry, and representation of biogeochemical cycling, into Earth system models. The USGCRP is committed to creating an Earth system modeling structure that will provide for a suite of cutting-edge models capable of making increasingly credible predictions of environmental changes.

Agency Contributions

Earth system science provides a context for physical, chemical, biological, and geological research relating to the atmosphere, oceans, land surface, and the overall environment. The research of all participating agencies contributes to Earth system science, both through programs formally within the USGCRP and those carried out by the agencies in related fields that contribute less directly to the USGCRP. Primary emphases of the agencies follow:

- NSF sponsors research on all aspects of the Earth system, focusing particularly on the atmosphere, the oceans, the land surface, the polar regions, solid Earth, and solar physics. Many of the scientists supported by NSF participate in the international programs of WCRP and IGBP, while others explore the many questions that remain about atmospheric and oceanic dynamics, terrestrial and marine ecosystems, atmospheric chemistry, Earth system history, and the factors contributing to environmental change. NSF sponsors a major Climate System Modeling program that is intercoupling the atmosphere, ocean, and land-surface domains.
- NASA sponsors research on the atmosphere, oceans, polar ice, and land surface relating to processes that can be sensed remotely from space and from aircraft. Research focuses particularly on processes that are tied to specific instruments and missions, including stratospheric and tropospheric chemistry, precipitation, solar and terrestrial radiation, clouds, and the land surface. Earth system models are used to test the consistency of the data sets that are gathered and to explore the climatic effects of various changes in radiative forcing.
- NOAA research focuses on the atmosphere and oceans, most intensely on those aspects that would lead to near-term

improvements in the ability to predict seasonal to interannual fluctuations in the climate and the mechanisms controlling longer term change. NOAA modeling research focuses on the coupled atmosphere-ocean system.

- DOE research focuses on specific processes that are creating significant uncertainties in predicting the climatic impacts of emissions from energy generation and use. Thus, DOE sponsors the ARM program—to examine cloud-radiation interactions—and research on the carbon cycle and terrestrial ecosystems, including the effects of an increased CO_2 concentration on plant growth. DOE modeling research focuses on understanding the differences among models and in exploring the uncertainties that exist in model simulations. DOE's Program on Ecology and the Terrestrial Carbon Processes focuses on biogeochemical and ecological responses related to global change.
- USDA research focuses most on managed ecosystems, including agricultural lands, range, and forests. The USGCRP component of this research examines the additional effects of global environmental changes on such ecosystems' productivity in the context of the many other stresses that affect renewal and sustainability.
- DOI research focuses on the effects of global environmental change on natural ecosystems and watersheds. In addition, DOI studies of past climates, based on the evidence drawn from the geological record, provide essential insights into past changes in climate and terrestrial ecosystems.
- Smithsonian Institution research focuses primarily on ecosystem behavior, particularly aspects relating to the rich mix of species. The Smithsonian Institution also, on behalf of the USGCRP, monitors solar radiation and conducts research to understand variations in solar irradiance.
- DoD basic research is keyed to Defense requirements, with a modest USGCRP component focused primarily on mechanisms that drive seasonal to interannual fluctuations of the global ocean and atmosphere.

Human Contributions and Responses to Global Change

Toward an Understanding of the Human Dimensions

Humans are an important component of the global environment—their lives and activities are not only affected by it, they are also reshaping it. Humans depend on the environment for their food, fiber, forest products, water, and habitat. Human activities alter local, and even the global, environment through the long-term cumulative effects of individual and collective actions, which are influenced by social and economic institutions throughout the world. Understanding the relationships between human activities and environmental systems is essential in coming to terms with the meaning of global environmental change for society, as well as for gaining insight into the potential effectiveness of measures to mitigate or adapt to change.

To gain more knowledge about the human contributions to global change, as well as about possible human consequences and responses, the USGCRP undertakes research on the human contributions and responses to global change. This research is being conducted by leading researchers in universities, research institutions, and Government laboratories all over the United States, in both basic and applied settings. It will enhance our ability to understand the implications of global change, and the advantages and risks of different strategies for responding to it. Research on the human dimensions of global change will accomplish the following:

- Improve our understanding of the factors affecting future trends in population growth, economic development, technological change, and other forces influencing the use of natural resources. This information will assist in improving projections of the demands that are likely to be placed on the environment and human systems that extract resources from it. These globally important driving forces include emissions of greenhouse gases and aerosols, changes in land use and cover, intensification of resource use, and other patterns in both developed and developing countries.
- Lead to a better understanding of potential impacts, both positive and negative, in food production, water resources, infrastructure (especially in coastal zones, deltas, and other highly sensitive locations), financial services, economic activities dependent on natural resources (e.g., forestry, tourism),

and human health. Understanding the potential importance of global change for U.S. communities requires not only looking at the local and regional scales in the United States, but also at global trends and flows of resources (such as international trading patterns) which have an ever-increasing effect on the well-being of U.S. communities. This information will assist in improving bottom-line estimates of the potential effects of global change on economic productivity and growth.

- Enable us to improve estimates of the potential economic effects of options for anticipating and responding to global changes. Economic estimates for reducing the impact of human activities on the environment (e.g., by reducing greenhouse gas and aerosol emissions through improvements in energy efficiency or development of alternative sources of energy) range from large costs to large benefits. This research will contribute to making these estimates more precise by improving our understanding of technology change and barriers to diffusion of new technologies, factors that affect adaptation and resource management, and paths for economic development in developing countries that can have a low impact on the environment, enhance their economic and social prospects, and provide improved commercial opportunities for U.S. firms.

Success in this area of research requires the talents and contributions of the full range of agencies involved in the USGCRP. It requires fundamental advances in the social and economic sciences (e.g., to improve our understanding of the factors that affect the demographic transition from high to low birthrates), in interdisciplinary research linking ecological and physical sciences with economics and other social science disciplines (e.g., to better account for the value of goods and services provided by ecosystems that are not traded in the marketplace), and in modeling to better integrate the diverse dimensions of global change and to improve our estimates of the sensitivity of global environmental systems to changes in human management and behavior.

Research on these issues of human contributions and responses is a small, but critical and growing, research component of the USGCRP. As described below, the USGCRP agencies are developing an interesting and diverse range of research programs to contribute to improved understanding of the human dimensions of global change.

Human Contributions and Responses Program Goal

The goal of this USGCRP activity is to identify, understand, and analyze how human activities contribute to changes in natural systems, how the consequences of natural and human-induced change affect the health and well-being of humans and their institutions, and how humans could potentially respond to problems associated with environmental change.

Progress toward this goal will provide an improved scientific basis for decisionmakers considering how society should respond to global-scale environmental change. USGCRP priorities for research on the human dimensions of climate change follow:

- Observe, analyze, and predict the processes through which population growth, migration, and technological, social, and economic change affect natural and managed systems at all scales in ways that influence the global environment
- Observe, analyze, and predict the impacts of changing environmental conditions on the health and well-being of individuals, institutions, and societies
- Identify the processes through which individuals and institutions anticipate, adapt, mitigate, and respond in other ways to global change, including the development and adoption of industrial, energy, and environmental technologies
- Develop improved methods for monitoring, modeling, and predicting critical interactions between human and natural systems, including the refinement of integrated assessment models and the enhancement of methods to study varied strategies for responding to long-term environmental change
- Improve the scientific infrastructure supporting research and management capabilities.

U.S. research in these areas is coordinated with related efforts in other nations through such mechanisms as the International Human Dimensions of Global Environmental Change Programme (IHDP), thus providing a broader capability for considering the complexity of the global social and economic structure.

Human Contributions and Responses Program Objectives

In order to develop an enhanced capability to address certain fundamental issues, research on human contributions and responses to global change will address the following objectives.

Objective 1—Understand How Human Activities Interact with Natural Ecological Systems and Managed Natural Resource Systems in Ways Related to Global Environmental Change

In the coming century, activities aimed at maintaining and raising living standards for a growing human population will contribute to global environmental change. Currently, in some locations, resource degradation and shortages interact with increased demands, thereby seriously straining local and regional environmental systems and human institutions. Developing an improved understanding of the dynamics that contribute to these trends is important both for projecting future change and ultimately for understanding how best to reconcile attainment of human needs and wants with protection of the long-term ability of environmental systems to renew themselves. Research focuses on the following:

- *Processes through which Humans Affect Natural Systems*: An important line of research on human-environmental interaction is the identification and analysis of the dynamics of human systems that affect natural systems. Human impacts on natural systems are manifest in many ways, including land-use change, industrial metabolism (production processes from extraction and use of resources through to emissions and waste products), agricultural and forest management system change, and the emission of air and water pollutants. Research focuses on assessing the socioeconomic factors that influence both the emissions of greenhouse gases, aerosols, and other species, and changes in land cover and use.
- *Impacts of Changing Environmental Conditions on the Health and Well-Being of Individuals, Institutions, and Societies*: Important lines of research on the consequences of global change on the health and well-being of individuals and institutions, thus on society, include effects of global change on different economic sectors and managed resources, such as water resources, agriculture, forestry, fisheries, energy, transportation, financial and insurance services, and coastal infrastructure; human health effects including the effects of UV radiation on disease and organs (especially the eyes and skin), the effects of UV radiation on photosensitivity of people using commonly prescribed medications, and the effects of changes in natural systems on the incidence of diseases; and analyses of vulnerability to environmental change, particularly of the interacting factors that increase or decrease societal vulnerability to environmental variability and change.

- *Fundamental Human Processes that Underlie the Complex Mix of Human-Environmental Interactions*: Important lines of research, conducted primarily by the NSF Human Dimensions of Global Change (HDGC) program, include studies that emphasize advancing basic understanding of the ways that human activities affect and respond to changes in natural systems, including economic processes affecting and affected by global change, resource impacts and adaptation, the value of information and decisionmaking under uncertainty, socioeconomic forces shaping technology and practice linked to global change, and comparative analysis of different types of policies and policy instruments.

Objective 2—Understand How Individuals and Institutions Anticipate, Adapt, Mitigate, and Respond in Other Ways to Global Change

Throughout history, people have shown the capacity to alter their behavior when they perceive their activities to be hazardous or detrimental to their own interests. An important facet of research on human contributions and responses to global change is the identification and analysis of current and proposed strategies for responding to environmental change.

A special form of human response is the development and implementation of environmental policies by governments and other institutions. As part of NSF's ongoing leadership of an interagency-initiated human dimensions research thrust, NSF includes a special Policy Sciences program component within its HDGC program. This activity emphasizes studies to enhance methods and knowledge used in environmental policy analysis.

The broader set of USGCRP agencies focus their programs on specialized response frameworks and strategies closely related to their missions:

- Analysis of feasibility, costs, benefits, and efficacy of response strategies
- Research on social values, including examination of valuation, intergenerational issues, and environmental justice
- Research on technological innovation and diffusion
- Research on how changes in social and economic conditions influence adjustment options
- The role of information in decisionmaking.

Objective 3—Understand How Methods for Monitoring, Modeling, and Predicting Critical Interactions between Human and Natural Systems can be Improved

The advancement of knowledge about human contributions and responses to global change requires significant progress in essential research capabilities and methods, especially data assembly and methods for comprehensive analysis.

Identification, collection, and archiving of critical human systems data needed for research on the human contributions and responses to global change and on interactions among human and natural systems is carried out by the Consortium for International Earth Science Information Network (CIESIN) and major NSF-sponsored data-collection efforts, as well as through the efforts of many individual researchers.

Research on integrated modeling and assessment of human-environment interactions includes a range of approaches for examining the complex interactions among Earth's physical, biological, and human systems. The integrated assessment approach uses quantitative models and other methods to understand individual component systems and their interactions, with particular emphasis on how changes in one or more component systems will affect other systems. Research is supported on a variety of proposed approaches, ranging from quite general to regionally and sectorally specific.

Objective 4—Understand How the Infrastructure Supporting Research and Management Capabilities Related to Human Contributions and Responses to Global Change can be Strengthened

In addition to conducting and sponsoring research, agencies participating in the USGCRP work together to support an infrastructure that encourages the active exchange of ideas and the development of research agendas that deal with human contributions and responses to global change:

- National efforts to stimulate research on the human contributions and responses to global change, including work of the National Academy of Sciences/National Research Council Subcommittee on the Human Dimensions of Global Change
- Efforts to strengthen international research collaborations, such as the International Human Dimensions Programme and the Global Change System for Analysis, Research, and Training

- Activities linking fundamental research and users of research results
- Activities to build research capabilities in different research communities.

Agency Contributions

Several USGCRP agencies support research on issues of human contributions and responses to global change:

- NSF's major contribution to research in this area is its Human Dimensions of Global Change program, which is the largest component of the NSF programs in environmental social science. HDGC supports fundamental research that emphasizes basic understanding of the ways that human activities affect and respond to changes in natural systems. HDGC grant awards are primarily for research on economic processes affecting and affected by global change; resource impacts and adaptation; the value of information and decisionmaking under uncertainty; socioeconomic forces shaping technology and practice linked to global change; and comparative analysis of different types of policies and policy instruments. In addition to the support of individual investigators, NSF has established the National Center for Environmental Decisionmaking Research and a consortium of centers and teams on HDGC research. As part of its policy sciences activities, NSF collaborates with EPA to support research on valuation and environmental policy. Methods and Models for Integrated Assessment (MMIA), a separate focused area of the NSF Global Change program, supports research that advances the development of tools and models for the framing and conduct of integrated assessments.
- DOE supports research on integrated assessments, involving the use of quantitative models and other methods to understand the interrelated components of human-environmental interaction, including the cost-benefit tradeoffs of climate change response strategies. DOE's National Institute for Global Environmental Change supports focused applications of these methods and models.
- NASA funds the Socioeconomic Data and Applications Center as one of its nine EOSDIS Distributed Active Archive Centers, which provide EOS standard data products. The Socioeconomic

Data and Applications Center is managed by CIESIN, the designated data center for the human contributions and responses component of GCDIS. NASA's Land-Cover and Land-Use Change program addresses the processes through which humans affect the state of the land surface, while the Resource Vulnerability Assessment program supports research that uses remote-sensing and other data to analyze societal and natural-resource vulnerability to global change impacts, and to develop response strategies.

- HHS/NIH research focuses on human health effects and exposure to UV radiation, including the effects of UV radiation on disease and organs (especially eyes and skin), and the effects of natural system change on the incidence of diseases.
- EPA's programs on constituencies at risk and economic impacts address the vulnerability of societies to global change, including potential human health effects of climate change, and the potential costs and benefits to society of global change and of alternative response strategies. EPA also supports research on integrated assessment of global change.
- NOAA's Economics and Human Dimensions program supports research to improve understanding of societal vulnerability to the impacts of short-term climate fluctuations.
- USDA supports research on the sensitivity of agricultural and other managed systems to climate change, and the impacts of societal changes on agricultural and other managed systems, through its Global Environmental Change and Resource Adjustment program and Environmental Change and Global Sustainability program.
- The DOI/USGS Land Characterization Research program focuses on the study of landscape changes resulting from natural causes and human activities.

International Research Cooperation

U.S. Commitment to Leadership and Coordination

The USGCRP seeks to improve understanding of global change and to improve capabilities for predicting and dealing with such change in response to new trends and challenges. This objective, common to many nations, can best be achieved through cooperative international programs that aggregate and coordinate the capabilities and resources of various nations. In support of this cooperative effort, the USGCRP participates in and supports the three major international global change research programs that have been initiated within the scientific community: The World Climate Research Programme; the International Geosphere-Biosphere Programme; and the International Human Dimensions of Global Environmental Change Programme. Coordination of funding for these programs is provided through the informal International Group of Funding Agencies, which matches available funding to the set of proposed activities.

Cooperation depends on open communication. Improved communications systems enable U.S. scientists to interact directly with foreign colleagues on a daily or even an hourly basis. Progress is greatest when there is an ability to exchange data and results of studies openly and rapidly. Recently, however, some countries have subordinated the interests of long-term basic research to shorter term objectives relating to recovery of data-collection costs through sale of data and products. U.S. scientists and agencies are thus finding it necessary to undertake new efforts to maintain the long-standing policy of full and open international exchange of data.

The USGCRP has also developed a range of global, regional, and bilateral mechanisms to provide a framework within which U.S. scientists and colleagues in other countries cooperate to address specific research issues and to study specific regions of mutual interest. The value of such cooperation is well illustrated by international contributions to NASA's Mission to Planet Earth program, which are estimated to exceed $3.5 billion between 1995 and 2002.

International Research Cooperation Goal

The goal of the international research cooperation element of the USGCRP is to support and assist the program and its participating scientists and agencies in their interactions with related international research, observing, and assessment activities and in the full and open international sharing of data and research findings.

Progress toward this goal will enhance the cooperative effort to improve understanding of global change, which can best be achieved by aggregating and coordinating the capabilities and resources of various nations.

Key Examples of International Cooperation

This section provides examples of significant international cooperative research activities in which the USGCRP and its participating agencies are currently active.

Example 1—Participate in the International Research Institute: A Global Concept with Regional Applications

The USGCRP, with NOAA leading this effort, is working with the scientific community, international research and development organizations, and governments to develop the International Research Institute, a critical component of the seasonal to interannual climate variability thrust of the USGCRP. The IRI will provide an integrating point for modeling, observations, process studies, and social science research conducted by many nations, including many activities sponsored by the USGCRP, with the following specific objectives:

- Continually develop dynamic and thermodynamically consistent coupled models of the global atmosphere, ocean, and land system to serve as a basis for improved climate prediction
- Systematically produce useful experimental climate forecasts on time scales of several months to several years
- Receive, analyze, and archive global atmospheric and oceanic data to improve the scope and accuracy of forecasts
- Shape and augment experimental forecasts by incorporating additional physical, agricultural, economic, and other appropriate data in order to provide explicit social and economic benefits to societies
- Explore systematically the predictability of climate anomalies on time scales of up to a few years.

At the widely attended "International Forum on Forecasting El Niño: Launching an International Research Institute," held in Washington, DC, in November 1995, the United States offered to provide a site for the core facility of the IRI. Regional applications activities will be developed through existing networks, such as the Inter-American Institute for Global Change Research (IAI), the European

Network for Research in Global Change (ENRICH), the Asia-Pacific Network (APN), and the Global Change System for Analysis, Research, and Training (START).

Example 2—Develop Scientific Input to the International Policymaking Process

Descriptions of two key assessment activities in which the USGCRP is intimately involved follow:

- *The Intergovernmental Panel on Climate Change*: The IPCC has recently completed its Second Assessment Report. U.S. scientists joined with colleagues from many other countries in developing and extensively reviewing this major comprehensive assessment. As amplified in the box on pages 30-33, the IPCC Second Assessment Report concludes that human activities are likely to have affected the climate over the past century; that climate change is likely to become more pronounced over the next several decades; and that many natural ecological systems and managed natural-resource systems are vulnerable to climate change. While the IPCC assessment identified some potential strategies to assist adaptation to climate change, it concluded that adverse ecological and socioeconomic impacts may result from not mitigating, or slowing, climate change.

  Internationally, consideration is being given to undertaking a Third Assessment Report for completion in the year 2000. In addition, the Subsidiary Body for Scientific and Technological Advice of the UNFCCC has recently asked the IPCC to prepare over the next 6 to 18 months a number of special assessments to clarify issues under negotiation in the UNFCCC or to further articulate and integrate the vulnerability assessments presented in the Second Assessment Report.

  The United States has served as co-chair of the IPCC Working Group II, and the USGCRP provided the resources to support Working Group II's Technical Support Unit.

  The U.S. Government coordinates its IPCC-related activities on an interagency basis. USGCRP research programs and USGCRP-supported scientists provide scientific and technical input to the assessments. A number of U.S. scientists served as lead authors for chapters of the Second Assessment Report and many U.S. scientists served as co-authors, contributors, and reviewers. The U.S. Government, in developing its comments

on this report and its individual chapters, invited input from a wide variety of sources, including many non-governmental organizations.

- *The International Ozone Assessment*: During 1994, the United States served as a leader in the preparation of the international *Scientific Assessment of Ozone Depletion*, continuing a series started in the 1970s. This assessment compiled information about emissions of ozone-depleting substances, observed and predicted changes in ozone concentrations, the effects on the ozone layer of recent volcanic eruptions, the development and character of the Antarctic ozone hole, the increases in UV radiation that result from ozone decreases, the effects on the radiation balance (and thereby on climate) of changes in ozone concentrations, and the build-up and expected effects of substitute compounds. The ozone assessments have provided crucial scientific information to those who negotiated the *Montreal Protocol on Substances that Deplete the Ozone Layer* and its subsequent amendments and adjustments.

  As a follow-up to the overall assessment, a special assessment on the effects of subsonic and supersonic aircraft is currently underway under the leadership of NASA. It is expected that the next assessment in this series will be completed in 1997.

Example 3—Bilateral Arrangements

The USGCRP agencies participate in a large number of bilateral arrangements for research collaboration:

- *TOPEX/Poseidon—Studying Ocean Circulation and Sea Level Trends with France*: TOPEX/Poseidon is a joint spaceflight mission between NASA and the Centre Nationale d'Etudes Spatiales (CNES) under the Mission to Planet Earth program. This joint mission observes ocean circulation to a high degree of precision; maps ocean currents and sea surface topography; and monitors mean sea level trends for evidence of global warming. The mission will include scientific studies of the interactions between the tropical ocean and interannual climate variability—especially the tropical Pacific Ocean anomaly known as the El Niño, which contributes to climatic anomalies on a planetary scale.
- *TRMM—The U.S.-Japan Tropical Rainfall Measuring Mission*: Under the 1995 agreement on TRMM between NASA and

Japan's National Space Development Agency (NASDA), NASA is building the TRMM spacecraft and four scientific flight instruments. These instruments will obtain data on tropical precipitation, thus improving understanding of global energy and water cycles. NASDA is building the primary scientific instrument, a Precipitation Radar, and will launch TRMM in 1997. The collected data will be shared with the world scientific community quickly and inexpensively.

- *Improving Models for Global Change Research with China*: U.S. scientists sponsored by DOE are initiating joint research efforts with their counterparts at the Chinese Meteorological Administration (CMA) and the Chinese Academy of Sciences, under the Science and Technology Agreement between the People's Republic of China and the United States. Research with the CMA will focus on regional climate models, meteorological observations to verify models, and impacts of climate change.
- *Research on Smoke, Clouds, and Radiation—A Joint Brazilian-U.S. Effort*: In 1995, NASA, the Brazilian Space Agency, and Brazil's National Institute of Space Research conducted the successful Smoke, Clouds, and Radiation–Brazil (SCAR-B) campaign. The campaign relied on both *in situ* and remote-sensing platforms to study physical and chemical properties of atmospheric aerosols to learn more about the impact of biomass burning on the tropics. SCAR-B also enabled the two countries to gain new insights into the global cooling/ heating effect of these aerosols.
- *U.S.-Japan Planning for Cooperative Research on Land-Use and Land-Cover Change*: The fourth bilateral workshop on global change research, held in early 1996, focused on this subject and resulted in a series of recommendations for future cooperative research in areas such as comparative analyses of land-management institutions; strategies for development of new databases; resolution of data management issues, such as standards and access; and improvement of models.
- *ADEOS—The Advanced Earth Observing Satellite*: As part of the international earth observing system, Japan is leading a cooperative mission to observe surface visible and near-infrared radiance/reflectance, scatterometry, and tropospheric and stratospheric chemistry. NASA is providing the scatterometer. ADEOS is scheduled for launch in the summer of 1996. France also participates in this mission.

- *U.S. Country Studies Program*: The U.S. Country Studies Program (USCSP) is an important example of how USGCRP research and related U.S. capabilities have been made available to other nations to enable them to improve their understanding of climate change, strengthen their participation in the IPCC process, and assist in the development of their national communications as called for under the UNFCCC. Developing from a commitment by President Bush in 1992, the USCSP has assisted 56 developing countries and countries with economies in transition around the world to estimate their greenhouse gas emissions, assess their vulnerability to climate change, evaluate adaptation and mitigation options, and develop climate change action plans. The program has prepared more than 20 peer-reviewed publications documenting preliminary results from the 56 countries, and will be releasing several major synthesis reports and databases in the near future. In addition, the USCSP has provided training and analytical support to more than 1,000 analysts from other countries.

Example 4—Observations and Data for Global Change Research

Examples of new efforts to enhance international cooperation and collaboration follow:

- *Exchanging Global Change Data with Japan—A Precedent for a Global Network*: In 1995, the United States and Japan announced a plan for a Global Observations and Information Network (GOIN) that will enable users on both sides of the Pacific to access data from the other side by computer. NOAA is leading this effort for the USGCRP. This network will make it easier and faster to share critical data for predicting, preparing for, and responding to natural disasters. GOIN is also expected to help provide the basis for a global information infrastructure.
- *Moving Toward a Global Observing System*: The United States is working with our international partners to develop a strategy for planning and moving toward a comprehensive global observing system. The United States has developed a white paper on how to improve coordination:
  - Recommendations of user groups for multi-purpose observing and data systems
  - National commitments to long-term implementation of the various components of a coherent global system

- Efforts of operating agencies involved in space-based and *in situ* observing systems and data management.

This strategy is intended to contribute to development of an international effort to organize systematic programs for global observation of atmospheric, oceanic, and terrestrial variables from the surface, space, and *in situ*.

Example 5—The Inter-American Institute for Global Change Research

Seventeen countries, including the United States, have signed an agreement to establish the Inter-American Institute 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, an IAI Director, and a site for the IAI Directorate (at the National Space Research Institute of Brazil). The Director officially assumed his position and the Directorate was inaugurated in March 1996.

The IAI has issued two calls for scientific proposals, and grants are currently being awarded. The results of these awarded proposals will serve as the first examples of IAI-fostered regional cooperation, which 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.

Example 6—Capacity-Building

START is a joint effort of the IGBP, IHDP, and WCRP. The United States continues to provide strong leadership and funding support for START, which reflects our international commitment to build capacities for global change research in the developing world. START regional research networks promote focused research and training on regional issues of global relevance, integrate and synthesize results, and provide input to decisionmakers at national and regional levels. START networks in Asia and Africa have initiated studies on land-use and -cover change; climate variability and agriculture; and regional modeling of climate and biospheric changes. START regional centers have been established in Beijing, Bangkok, New Delhi, and Accra. Scientific assessments on global change issues of relevance to regional decisionmakers have been initiated, and science policy forums are being conducted.

Global Change Education and Communication

Encouraging Global Change Science Literacy

Global environmental change is, increasingly, an essential part of the context in which social, economic, and technological development take place. From now on, choices about these activities will be influenced by environmental considerations and, in turn, will affect the global environment. Societal decisionmaking will need to be based on an informed understanding of the factors driving global change, how the changes may manifest themselves, and how society can most effectively adapt to or limit future changes.

Global change education and communication seeks to provide useful information on the results of scientific research. In addition, it is an effort to help lay the underlying foundation for the understanding that is needed in order to interpret and apply scientific findings appropriately. The application of knowledge from research and assessments to the challenges faced by society calls for a broad-based public understanding of global change.

In addition, society has a vital interest in the education of talented young scientists who can question, investigate, and develop the ability to carry forward the development of scientific understanding. For scientific ability to achieve its full potential, interests and skills must be developed early in life.

Thus, the education and communication component of the USGCRP is responsible for fostering public understanding and the development of the next generation of scientists.

Global Change Education and Communication Goal

The goal of the education and communication component of the USGCRP is to increase public awareness of the Earth system and how it is changing and to promote global change education.

Progress toward this goal will help ensure that societal decisionmaking is based on an informed understanding of global change, and will serve society's vital interest in the education of young scientists.

To achieve this goal, the USGCRP has a multi-pronged approach to reach a diverse set of information users. To train the next generation of scientists, USGCRP supports undergraduate, graduate, and post-doctoral participation in ongoing scientific research activities. To meet

the needs of formal educators, the USGCRP provides resources for statewide action planning, teacher enhancement, curriculum support, and select student support programs. Informal education is another approach to reach a broad community with the results of global change research. Multimedia communication resources provide a valuable mechanism for communicating the complex, interdisciplinary nature of global change science.

In global change education, the emphasis of the individual agencies has historically been aimed broadly at the university undergraduate and graduate level. Our current programs, while continuing the focus on higher level education, are working more comprehensively to make available educational resources at levels from kindergarten onward, not only to inspire students to undertake scientific careers but also to stimulate non-career scientific literacy.

Global Change Education and Communication Objectives

USGCRP leadership in global change education is working to promote coordination among participating Federal agencies and to enhance the effectiveness of available resources.

Objective 1—Promote the Dissemination and Use of Global Change Research and Information

The USGCRP has established infrastructure and capability for communication through the Global Change Research Information Office, which is mandated by the Global Change Research Act of 1990, "...to disseminate to foreign governments, businesses, and institutions, as well as to 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." In addition, the USGCRP has developed unique products and resources with specific target audiences in mind.

USGCRP agencies have produced a number of global change education and communication products, including the Global Change Education Resource Guide, videotapes, overhead transparencies, and a CD-ROM; the NOAA Monograph Series, Journalist Guide, and Internet Activities Using Scientific Data; NASA lithographs depicting remotely sensed and visualized images, and NASA global change education national video conferences; the USDA Global Change Information Packet; the DOI/USGS Global Change

Teaching Packet and Historical Landsat Data Comparisons monograph; and exhibits at national professional conferences such as the National Science Teachers Association.

These activities promote interagency coordination and leveraging of communication resources, and promote the accurate and timely transmission of relevant and age-appropriate information to public information users. For additional information, the USGCRP World Wide Web Home Page may be accessed at http://www.usgcrp.gov.

Objective 2—Promote the Development of the Next Generation of Scientists, and Ensure an Understanding of the Multidisciplinary Nature of Global Change Science for All through Real-World Experiential Learning Activities

Students today are both interested and concerned about the state of the environment. One way to encourage and empower them to participate in problem-solving and to become comfortable with science is to engage them in the process of authentic scientific investigation. Active participation in the ongoing investigation of Earth and the environment in a global context is applicable at differing levels of sophistication for children in elementary school through post-doctoral graduate research programs.

The Global Learning to Benefit the Environment (GLOBE) program has multi-agency support, and has established school and private sector partnerships to offer a long-term, hands-on environmental monitoring program on global change for students worldwide.

The International Science and Engineering Fair, offered a new category of projects on global change in 1995, supported by the USGCRP. Students in grades 9-12 in every school district in the United States and in countries around the world were encouraged to design experiments related to global change research. The USGCRP again provided support for this effort in 1996, while seeking to obtain private sector support for continuing this activity. Students from 20 countries and all 50 States participated in the 1996 Fair, culminating in Tucson, Arizona. The global change division of the Fair had 114 entrants (10% of all participants).

Graduate and post-doctoral fellowships continue to be a major budget allocation for agency education efforts. Graduate and post-doctoral fellows contribute to the research and knowledge base about global change and promote the development of a cadre of scientists who cooperate with educators to translate scientific information for diverse audiences.

Objective 3—Integrate Global Change Information into the Existing Formal and Informal Educational Systems

This effort builds on the USGCRP relationship with Global Change Education State Teams (initiated in 1994 at the National Educators Conference on Global Change), and action plans developed by each State at NASA-sponsored regional forums in 1995. The aim is to integrate global change content into statewide core curricula, professional and association meetings at regional and national levels, and programs conducted in museums, science centers, and community groups.

Objective 4—Support Professional Development Programs for Educators on Earth Eystem Science

Educating educators is a highly effective method for translating complex scientific research for use by non-technical audiences. Educators in both formal and informal programs identify training as a primary need for increasing the probability that materials will actually be used.

The USGCRP agencies have developed and supported complementary teacher training programs for in-service education. NOAA supported a 4-year national train-the-trainers effort for informal educators through the Sea Grant College Program. NASA funds teacher training programs through universities along with projects like Discover Earth and Classroom of the Future. DoD promoted education of minority teachers and teachers of minority students through Operation Pathfinder. NSF supports teacher training in global change education through grants for national and regional programs.

Pre-service education has been identified as an approach to train emerging teachers from schools of education. NASA's Project NOVA is an example of providing support to university teams (from Education and Science Departments) to develop courses and/or course modules for students seeking teacher certification.

APPENDIX A

THE PROPOSED USGCRP BUDGET FOR FY97

The proposed FY97 USGCRP budget totals $1.73 billion. After adjusting so that comparable programs are included in the compilation (see discussion of NOAA budget below), the FY97 request is down slightly (0.7%) from the FY96 budget request. The FY97 request is up slightly (0.5%) from the actual Congressionally approved funding level for FY95.

Since the FY96 Congressionally approved budget is estimated to result in a reduction of $110.3 million (6.3%) below the actual funding level for FY95, the FY97 request is, in effect, proposing a restoration to the approved FY95 spending level.

Of the $122.7 million (7.5%) proposed increase from the FY96 to the FY97 budget, $112.8 million is to restore the NASA Mission to Planet Earth program to approximately the FY95 funding level. The budget request also includes an $11.1 million increase from FY96 for DOC/NOAA.

As outlined in this edition of *Our Changing Planet*, the USGCRP budget supports scientific research on key global change environmental issues, including seasonal to interannual climate variability; climate change over decades to centuries; changes in ozone, UV radiation, and atmospheric chemistry; and changes in land cover and in terrestrial and marine ecosystems. The USGCRP budget supports global change research integrating activities, including observing and monitoring global change and global change data, products, and information services; research on Earth system science and on human contributions and responses to global change; and program responsibilities including international research cooperation and global change education and communication.

The figures in Appendix A indicate broadly, for each of the principal program thrusts and program integration activities in the USGCRP budget, which agencies make a "major" contribution in that area and which additional agencies also participate by making a more "focused" contribution. The tables show the USGCRP budgets for FY95-FY97 and also the budgets by Budget Function.

For comparison with budgets of earlier years, a few changes deserve attention:

- In the FY96 *Our Changing Planet*, DOC/NOAA included funding for the NOAA fleet of oceanographic vessels, the NOAA Corps, the NOAA laboratories, the National Undersea Research Program, and the VENTS program as part of the USGCRP budget. For FY97, DOC/NOAA has redesignated these activities out of the USGCRP. The DOC/NOAA FY95 and FY96 USGCRP budget figures in the current edition of *Our Changing Planet* have been adjusted accordingly, in order to focus on the NOAA global change research programs that have been a continuing part of the USGCRP budget.
- The Department of Transportation and the Tennessee Valley Authority, two USGCRP-participating agencies that have funded global change research in the past, are not requesting any funding for global change research in FY97. This reduces the number of USGCRP agencies that fund global change research from 12 to 10.

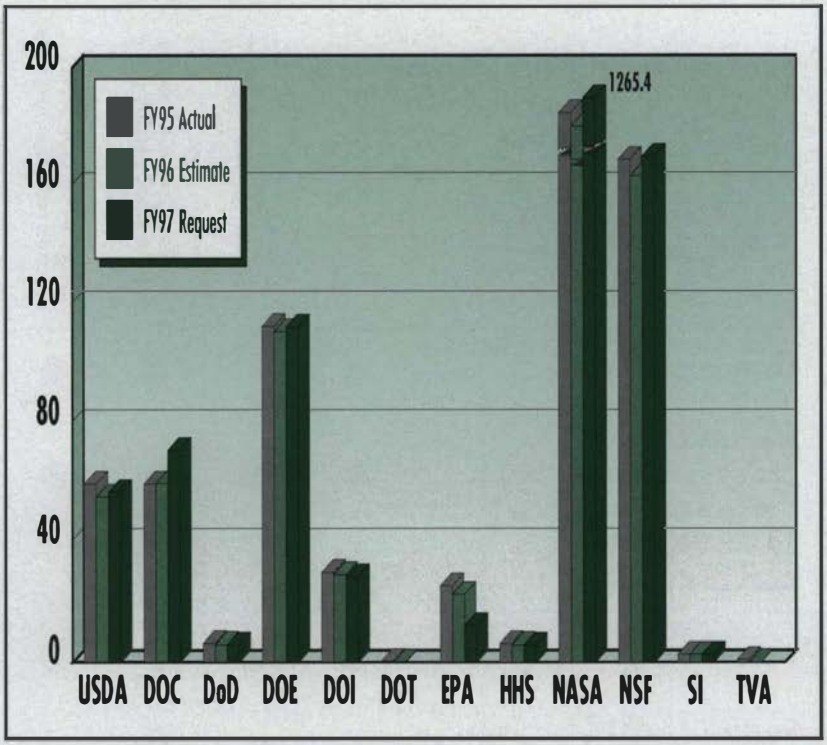
Of the 10 remaining agencies, in the FY97 request, NASA accounts for 72% of the total USGCRP budget. The global change research budgets of NASA, NSF, DOE, DOC, and USDA together account for just over 95% of the USGCRP total. The USGCRP budgets of NIH, DOI, EPA, DoD, and the Smithsonian Institution together account for the remaining portion.

It should be noted that the $1.852 billion FY97 request for global change research in the President's Budget[5] is not equivalent to the $1.73 billion USGCRP budget presented in *Our Changing Planet*. There are several reasons for this difference. Most of the difference is accounted for by the NASA budget; the USGCRP budget does not include launch services as global change research in *Our Changing Planet*, whereas the President's *Budget Supplement* does. *Our Changing Planet* includes global change research at DoD and DOC/NIST, as designated for the USGCRP by these agencies. The USGCRP budget also includes corrected or updated figures for DOT, EPA, Smithsonian, and TVA, as designated by these agencies. More detailed information is available from the Office of the USGCRP on request.

[5] *Budget Supplement: Budget of the United States Government, Fiscal Year 1997*, Table 10-2, p. 98.

FY95–FY97 USGCRP Budget by Agency

(dollars in millions)



Agency	FY95	FY96	FY97 Request
Department of Agriculture (USDA)	59.6	55.2	56.7
Department of Commerce (DOC/NOAA, DOC/NIST)	59.6	59.8	70.9
Department of Defense (DoD)	6.4	6.0	5.9
Department of Energy (DOE)	112.7	110.8	112.4
Department of the Interior (DOI)	29.9	28.2	28.3
Department of Transportation (DOT)	0.5	0.2	0.0
Environmental Protection Agency (EPA)	26.3	21.9	13.7
Department of Health and Human Services (HHS)	4.0	4.0	4.0
National Aeronautics and Space Administration (NASA)	1249.5	1152.6	1265.4
National Science Foundation (NSF)	169.0	163.3	170.0
Smithsonian Institution (SI)	2.8	2.8	2.8
Tennessee Valley Authority (TVA)	1.0	0.1	0.0
Total Budget	**1721.3**	**1604.9**	
President's Request	1769.0	1742.7	**1730.1**

Global Change Environmental Science Issues

USGCRP Program Thrusts

	Seasonal to Interannual Climate Variability	Climate Change over Decades to Centuries	Changes in Ozone, UV Radiation, and Atmospheric Chemistry	Changes in Land Cover and in Terrestrial and Marine Ecosystems
Department of Agriculture	●		●	●
Department of Commerce				
National Oceanic and Atmospheric Administration	●	●	●	◐
National Institute of Science and Technology			◐	
Department of Defense	◐		◐	
Department of Energy	◐	●	◐	◐
Department of Health and Human Services			●	
National Institutes of Health				
Department of the Interior	◐	●		●
Environmental Protection Agency		◐	◐	◐
National Aeronautics and Space Administration	●	●	●	●
National Science Foundation	◐	●	●	●
Smithsonian Institution		◐	◐	◐

KEY

● Major Contribution to Core Program

◐ Focused Contribution to Core Program

Issues Central to Program Integration

USGCRP Program Areas

	Integrated Global Observing and Monitoring System: Satellite	Integrated Global Observing and Monitoring System: Surface and *In Situ*	Global Change Data, Products, and Information Services	Predictive Understanding of the Earth System	Human Contributions and Responses to Global Change
Department of Agriculture		●	●		●
Department of Commerce					
National Oceanic and Atmospheric Administration	✱	●✱	●✱	●	●
National Institute of Science and Technology					
Department of Defense	✱	✱	✱	●	
Department of Energy		●	●	●	●
Department of Health and Human Services					
National Institutes of Health					●
Department of the Interior		●	●	●	●
Environmental Protection Agency		●	●		●
National Aeronautics and Space Administration	●	●	●	●	●
National Science Foundation	●	●	●	●	●
Smithsonian Institution				●	

KEY

● Major Contribution to Core Program

● Focused Contribution to Core Program

✱NOAA, DoD, and other agencies have substantial satellite and surface observing activities that are not included as part of the USGCRP budget, because their primary role is in support of other governmental responsibilities.

FY95–FY97 USGCRP Budget by Budget Function

(dollars in millions)

Budget Function	Budget Function #	FY95	FY96	FY97 Request
National Defense	50			
Department of Defense (DOD)		6.4	6.0	5.9
General Science, Space, and Technology	250			
National Aeronautics and Space Administration (NASA)		1249.5	1152.6	1265.4
National Science Foundation (NSF)		169.0	163.3	170.0
Energy	270			
Department of Energy (DOE)		112.7	110.8	112.4
Tennessee Valley Authority (TVA)		1.0	0.1	0.0
Natural Resources and Environment	300			
Department of Agriculture (USDA/FS and NRCS)		24.5	18.6	18.1
Department of Commerce (DOC/NOAA and NIST)		59.6	59.8	70.9
Department of the Interior (DOI)		29.9	28.2	28.3
Environmental Protection Agency (EPA)		26.3	21.9	13.7
Agriculture	350			
Department of Agriculture (USDA/ARS, ERS, and CSREES)		35.1	36.6	38.6
Transportation	400			
Department of Transportation (DOT)		0.5	0.2	0.0
Smithsonian Institution	503			
Smithsonian Institution (SI)		2.8	2.8	2.8
Health	550			
Department of Health and Human Services (HHS)		4.0	4.0	4.0
Total Budget		**1721.3**	**1604.9**	
President's Request		1769.0	1742.7	**1730.1**

APPENDIX B

FY95-FY97 USGCRP BUDGET BY PROGRAM

The allocations of resources by program within an agency that are reflected in these tables for FY96 and FY97 serve as an estimate only, and are subject to change based on decisions on scientific and programmatic priorities among USGCRP agencies, their advisory bodies, and the input of the national and international scientific communities.

These budgets are for programs designated by participating agencies for inclusion in the USGCRP. The budget pages for individual agencies that follow include a listing of these programs, as well as a general description of each agency's "Areas of Global Change Research." In addition, the agencies conduct a broad range of "Related Research," which is outlined on the budget pages but funding of which is not part of the USGCRP budget because the research is conducted primarily for other purposes.

Each agency budget page also includes a "Mapping of Budget Request to Appropriations Legislation." These entries point to the locations in the various Appropriations Bills (and, in some cases, Appropriations Committee Reports) of funding for USGCRP activities. Note that it is common for global change research to be funded within Appropriations accounts that also include funding for other activities, so that Appropriations Bills and Committee Reports do not necessarily designate funding specifically for global change research. Thus, the actual funding level for global change research activities must be determined, in part, by decisions within agencies about how to allocate appropriated funds. It should also be noted that USGCRP activities are funded by eight different Appropriations Bills, as well as by a varying number of Budget Authorization Bills. Thus, the relationship between the USGCRP budget and the Appropriations process is complex and not easily summarized.

It should be noted that the budget totals for individual agencies are in some cases not equivalent to the totals presented in the FY97 request for global change research in the President's Budget, as discussed in Appendix A.

Department of Agriculture

Areas of Global Change Research. 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	FY97 Request
ARS	Agriculture and Rangeland Global Change	11.3	11.7	10.5
ERS	Economics of Global Change and Agriculture	0.8	0.8	0.8
FS	Forest Global Change	23.0	17.1	16.6
CSREES	Improved Response Models	8.3	8.8	11.0
ARS	Methyl Bromide Research	13.1	13.7	14.7
NRCS	Soil Carbon Studies	1.5	1.5	1.5
CSREES	UV-B Monitoring Network	1.6	1.6	1.6
	Total	**59.6**	**55.2**	
	President's Request	58.4	61.5	**56.7**

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 the 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, and social sciences; implementation of ecosystem management on the national forests and grasslands; and human interaction with natural resources.

Mapping of Budget Request to Appropriations Legislation. In the Agriculture, Rural Development, Food and Drug Administration, and Related Agencies Appropriations Bill, USGCRP activities are funded in Title I–Agricultural Programs, within the Agricultural Research Service (ARS), Cooperative State Research, Education, and Extension Service (CSREES) Research and Education Activities, and Economic Research Service (ERS) accounts; and in Title II–Conservation Programs, within the Natural Resources Conservation Service (NRCS) Conservation Operations account. In the Interior and Related Agencies Appropriations Bill, USDA USGCRP activities are funded in the USDA Forest Service (FS) section of Title II–Related Agencies, within the FS Forest Research account.

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 on engineering system design of systems utilizing CFC alternatives.

DOC	Program Title	FY95	FY96	FY97 Request
NIST	Ozone and UV Radiation: Chemically Induced Changes	2.6	2.3	2.3
NOAA	Aerosols	0.0	1.1	1.1
NOAA	Atmospheric Chemistry Project	7.2	6.4	7.7
NOAA	Climate Change Data and Detection	4.0	3.9	5.2
NOAA	Climate Dynamics and Experimental Prediction	8.0	13.9	14.9
NOAA	Climate Observations	7.1	8.0	9.6
NOAA	Climate Variability	16.2	11.6	15.8
NOAA	Economics and Human Dimensions of Climate Fluctuations	1.1	1.3	1.4
NOAA	Global Energy and Water Cycle Experiment	5.5	4.6	5.9
NOAA	Marine Ecosystem Response	1.4	0.4	0.0
NOAA	Ocean-Atmosphere Carbon Exchange Study	2.6	2.4	2.9
NOAA	Paleoclimatology	3.9	3.9	4.1
	Total	**59.6**	**59.8**	
	President's Request*	86.3	89.6	**70.9**

** Our Changing Planet 1996* NOAA entry included funding for NOAA Labs, Fleet, and VENTS; these items have been redesignated out of the Global Change Research Program.

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 weather and 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.

Mapping of Budget Request to Appropriations Legislation. In the Departments of Commerce, Justice, and State, the Judiciary, and Related Agencies Appropriations Bill, NOAA and NIST USGCRP activities are funded in Title II—Department of Commerce and Related Agencies, within the NOAA Operations, Research, and Facilities and NIST Scientific and Technical Research and Services accounts. In Appropriations Committee reports, funding for NOAA's USGCRP activities is included as part of the Climate and Air Quality Research budget within Oceanic and Atmospheric Research.

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 (HLD), regional resolving models (RRS), boundary layer dynamics (BLD), and ocean ecological systems.

DOD	Program Title	FY95	FY96	FY97 Request
ONR	BLD/Marine Aerosols	1.0	1.0	1.0
ONR	HLD/Arctic Lead Ice Dynamics	2.0	2.0	2.0
ONR	HLD/Arctic Sediment History	0.3	0.3	0.3
CRREL	HD/Impact of Climate Change on Energy Fluxes	0.4	0.1	0.1
ONR	Ocean Ecological Dynamics/Marine Light Mixed Layer	1.0	1.0	1.0
CRREL	HD-RRS/Coupled Hydrologic and Thermal Models	0.3	0.2	0.1
ONR	RRS/Coupled Ocean-Atmosphere Models	1.4	1.4	1.4
	Total	**6.4**	**6.0**	
	President's Request	6.4	6.4	**5.9**

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.

Mapping of Budget Request to Appropriations Legislation. In the Department of Defense Appropriations Bill, research associated with the USGCRP is funded in Title IV–Research, Development, Test, and Evaluation, within the Navy account. In Appropriations Committee reports, nearly all funding is included within the budget for Defense Research Sciences.

Department of Energy

Areas of Global Change Research. Research by DOE's Office of Health and Environmental Research (OHER) 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. The DOE Policy Office supports studies that assist in interpretation of research results.

DOE	Program Title	FY95	FY96	FY97 Request
OHER	Atmospheric Chemistry and Carbon Cycle	27.3	29.0	28.1
OHER	Climate and Hydrology	63.4	61.0	63.4
OHER	Ecological Processes	12.3	11.8	11.4
OHER	Human Interactions	9.7	9.0	9.5
	Total	**112.7**	**110.8**	
	President's Request	126.1	122.8	**112.4**

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 to reduce 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.

Mapping of Budget Request to Appropriations Legislation. In the Energy and Water Development Appropriations Bill, DOE USGCRP activities are funded in Title III–Department of Energy, within the Energy Supply, Research, and Development Activities account. In Appropriations Committee reports, funding for almost all of DOE's USGCRP programs is included within the budget for Biological and Environmental Research.

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	FY97 Request
NIH*	Human Health Effects of Exposure to UV Radiation	4.0	4.0	4.0
	Total	**4.0**	**4.0**	
	President's Request	4.0	4.0	**4.0**

*The National Institutes of Health devote approximately $28M per year to the study of the effects of UV-radiation on health. This research is sponsored by the National Cancer Institute, the National Eye Institute, the National Institute of Arthritis and Musculoskeletal and Skin Diseases, and the National Institute of Environmental Health Sciences (NIEHS). While all of this research was included in the compilations for the USGCRP budget in the FY95 and FY96 editions of *Our Changing Planet*, for FY97 only the component within NIEHS is included, since it is done primarily as a result of concerns about global environmental change. For this reason, the HHS/NIH contribution to the USGCRP budget for FY97 is now given as $4M; the entries for previous years have been adjusted for comparability.

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; occupational exposure and health effects of materials used in alternative energy production; and infectious diseases, including encephalitis, malaria, dengue, lyme disease, and leishmaniasis, whose incidence would be affected by climate change.

Mapping of Budget Request to Appropriations Legislation. In the Departments of Labor, Health and Human Services, and Education and Related Agencies Appropriations Bill, USGCRP activities are funded in the NIH section of Title II–Department of Health and Human Services, within the National Institute of Environmental Health Sciences account.

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	FY97 Request
USGS	Biogeochemical Exchanges between Terrestrial Systems	2.6	2.6	4.3
USGS	Climates of Arid/Semi-Arid Regions	0.7	0.7	1.5
USGS	Cold Regions Research	1.2	1.2	1.5
NBS*	Global Change Impacts on Coastal Lands and Ecosystems	1.1	1.0	1.0
NBS	Global Change Impacts on Terrestrial Ecosystems	3.9	3.3	3.3
USGS	Interaction of Climate and Hydrologic Systems	4.2	4.2	2.3
USGS	Land Characterization and Data Management	7.4	7.4	7.3
NBS	Impacts of Global Change on Fish and Wildlife	1.5	1.0	1.0
USGS	Paleoclimate Research	6.8	6.8	6.1
BOR	Sensitivity of Water Resources	0.5	0.0	0.0
	Total	**29.9**	**28.2**	
	President's Request	31.0	30.0	**28.3**

*As of FY97, the National Biological Service will become part of the U.S. Geological Survey.

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.

Mapping of Budget Request to Appropriations Legislation. In the Interior and Related Agencies Appropriations Bill, DOI USGCRP activities are funded in Title I–Department of the Interior. Funding for U.S. Geological Survey (USGS) USGCRP programs is included within the USGS Survey, Investigations, and Research account. As of the FY95 enacted Appropriations Bill, funding for National Biological Service (NBS) USGCRP programs was included within the NBS Research, Inventories, and Surveys account.

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. FAA research is coordinated with efforts of national and international organizations and agencies.

DOT	Program Title	FY95	FY96	FY97 Request
FAA	Atmospheric Effects of Aviation	0.5	0.2	0.0
	Total	**0.5**	**0.2**	
	President's Request	0.5	0.5	**0.0**

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

Mapping of Budget Request to Appropriations Legislation. In the Department of Transportation and Related Agencies Appropriations Bill, DOT USGCRP activities are funded in Title I–Department of Transportation, within the FAA Operations account.

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	FY97 Request
ORD	Terrestrial Carbon Flux Tracking	9.8	1.9	0.0
ORD	Developing Predictive Models	2.7	1.9	1.8
ORD	Regional Vulnerabilities	6.4	12.5	8.2
ORD	Integrated Assessment Research	2.9	1.2	1.0
ORD	Stratospheric Ozone Depletion	3.5	3.5	1.3
OARM	Data Management, Access, and Integration	0.5	0.5	1.0
OPPE	Policy Assessment Research	0.5	0.4	0.4
	Total	**26.3**	**21.9**	
	President's Request	31.8	23.4	**13.7**

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.

Mapping of Budget Request to Appropriations Legislation. In the Departments of Veterans Affairs and Housing and Urban Development, and Independent Agencies Appropriations Bill, EPA USGCRP activities are funded in the EPA section of Title III–Independent Agencies. As of the enacted FY95 Appropriations Bill, the great majority of funding for EPA USGCRP programs was included within the Research and Development account.

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, archival, retrieval, dissemination, and use of global change data. The focus is Earth system science, which involves interdisciplinary research and coupled modeling. Development of algorithms for retrieval of the information content of space-based, remotely sensed observations is carried out as part of the flight mission.

NASA	Program Title	FY95	FY96	FY97 Request
MTPE	Airborne Science Program	26.0	27.3	17.8
MTPE	Applications Research	0.0	1.0	2.0
MTPE	Atmospheric Chemical Modeling	6.7	5.7	5.9
MTPE	Atmospheric Dynamics and Remote Sensing	7.9	5.5	5.5
MTPE	Biological Oceanography	7.7	3.7	4.3
MTPE	Consortium for Int'l Earth Science Information Network	6.0	0.0[1]	0.0[1]
MTPE	Data Purchase	0.0	0.0	50.0
MTPE	Earth Systems Science Pathfinder	0.0	1.0	20.0
MTPE	Ecological Processes	23.1	14.6	15.1
MTPE	EOS Data and Information System	220.6	241.2	261.1
MTPE	EOS Flight Development	415.0	384.8	445.1
MTPE	EOS Science	37.3	56.5	47.5
MTPE	EOS Special Spacecraft	81.7	71.7	66.7
MTPE	Geodynamics and Geopotential Fields	15.2	7.6	7.9
MTPE	Geology	4.4	3.9	3.9
MTPE	Global Data Integration and Validation	5.1	2.4	2.4
MTPE	Global Modeling and Analysis Program	5.1	4.4	4.4
MTPE	HPCC Earth Remote Sensing	20.5	26.1	28.3
MTPE	Information Systems	9.7	9.6	8.6
MTPE	Interdisciplinary Research and Analysis	13.1	35.2	27.0
MTPE	Land Cover and Use Change	0.0	3.0	5.0
MTPE	Land Surface Hydrology	2.2	2.7	2.9
MTPE	LANDSAT	77.4	78.8	73.9
MTPE	Mission Operations and Data Analysis	34.6	30.5	24.8
MTPE	NASA Scatterometer	15.4	10.1	13.0
MTPE	Natural Hazards Program	0.0	1.0	2.0
MTPE	Ocean Color Data Purchase/SeaWiFS	4.5	3.7	3.7
MTPE	Payloads and Instrument Development	19.5	4.6	3.6
MTPE	Physical Oceanography and Ocean Modeling	9.0	7.0	7.3
MTPE	Polar Programs	7.1	4.9	4.9
MTPE	Radiation Science Program	9.6	6.0	6.0
MTPE	Stratospheric Chemistry	19.5	16.3	17.0
MTPE	TOPEX/POSEIDON	31.2	17.3	18.7
MTPE	Total Ozone Mapping Spectrometer	18.6	11.8	5.1
MTPE	Tropical Rainfall Measuring Mission	57.8	30.1	31.8
MTPE	Tropospheric Chemistry	7.5	6.8	7.8
MTPE	Upper Atmosphere Research Satellite	30.5	16.0	14.4
	Total	**1249.5**	**1152.6**	
	President's Request	1235.8	1217.1	**1265.4**

NASA (CONT.)

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

Mapping of Budget Request to Appropriations Legislation. In the Departments of Veterans Affairs and Housing and Urban Development, and Independent Agencies Appropriations Bill, NASA USGCRP activities are funded in the NASA section of Title III–Independent Agencies, within the Science, Aeronautics, and Technology account. Within this account, Appropriations Committee reports specify funding for the Mission to Planet Earth (MTPE) program, which consists largely of the NASA USGCRP program. Note that some components of the total MTPE budget, including Launch Services and Construction of Facilities, are not included as part of the USGCRP budget.

Explanations

1) For FY96 and beyond, funding for social sciences data and research activities is awarded competitively, and not designated specifically for CIESIN.

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	FY97 Estimate
	Antarctic Ecosystems	1.5	1.0	1.0
	Arctic System Science	14.2	14.2	15.0
	Climate Modeling, Analysis, and Prediction	11.5	11.7	12.0
	Climate Variability and Predictability	12.2	11.5	11.4
	Earth System History	9.0	9.4	10.2
	Ecological Diversity	4.6	4.8	5.6
	Ecological Rates of Change	3.0	3.0	3.0
	Geodata	1.4	1.4	1.4
	Global Ocean Ecosystems Dynamics	6.7	7.4	8.8
	Global Tropospheric Chemistry Program	12.8	12.4	13.1
	Greenhouse Gas Dynamics	0.2	0.2	0.2
	Human Dimensions of Global Change	17.6	12.2	12.2
	Joint Global Ocean Flux Study	16.8	19.4	20.1
	Land-Margin Ecosystems Research	2.9	2.8	2.9
	Methods and Models for Integrated Assessment	3.4	3.4	3.7
	Polar Ozone Depletion/UV Radiation Effects	5.6	3.5	4.4
	Regional Research Institutes	3.1	3.2	3.2
	Ridge Interdisciplinary Global Experiments	4.0	3.7	3.3
	Sea Level Changes	5.8	5.8	5.8
	Solar Influences	6.1	6.0	6.4
	Water & Energy: Atmospheric-Vegetative-Earth Interactions	8.9	8.7	9.5
	World Ocean Circulation Experiment	17.9	17.8	16.7
	Total	**169.0**	**163.3**	
	President's Request	207.5	183.4	**170.0**

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.

Mapping of Budget Request to Appropriations Legislation. In the Departments of Veterans Affairs and Housing and Urban Development, and Independent Agencies Appropriations Bill, NSF USGCRP activities are funded in the NSF section of Title III–Independent Agencies, within the NSF Research and Related Activities account.

Smithsonian Institution

Areas of Global Change Research. Within the Smithsonian Institution (SI), 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	FY97 Request
NMNH/STRI	Long-Term Environmental Change	1.6	1.6	1.6
SAO/NASM/SERC	Monitoring Natural Environmental Change	1.2	1.2	1.2
	Total	**2.8**	**2.8**	
	President's Request*	7.3	2.8	**2.8**

*$4.5M of the SI request was redesignated out of the Global Change Research Program during FY95.

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 performed at the Smithsonian Tropical Research Institute (STRI) and the National Museum of Natural History. 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.

Mapping of Budget Request to Appropriations Legislation. In the Interior and Related Agencies Appropriations Bill, Smithsonian Institution USGCRP activities are funded in the SI section of Title II–Related Agencies, within the Salaries and Expenses account. Appropriations Committee reports specify funding for a Sciences line item component of this account, which includes USGCRP programs.

Tennessee Valley Authority

Areas of Global Change Research. Research by the Tennessee Valley Authority (TVA) focuses on the regional and local scale aspects of climatic and hydrologic systems, biogeochemical dynamics, climate change impacts assessment, and greenhouse gas sources and sinks.

TVA	Program Title	FY95	FY96	FY97 Request
ERC	Environmental Impacts of Bioenergy Plantations	0.4	0.1	0.0
ERC	Reduction of N_2O Emissions from Fertilizers	0.3	0.0	0.0
ERC	Regional Climate Change Impact Assessment	0.3	0.0	0.0
	Total	**1.0**	**0.1**	
	President's Request	1.0	1.0	**0.0**

Related Research. TVA also sponsors research emphasizing environmental and economic concerns, including programs for managing water resource systems and power operations, water quality, biological health of reservoirs and rivers, and wetlands.

Mapping of Budget Request to Appropriations Legislation. In the Energy and Water Development Appropriation Bill, TVA Environmental Research Center (ERC) USGCRP activities are funded within the TVA section of Title IV–Independent Agencies.

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 nine committees organized under the National Science and Technology Council (NSTC).

The SGCR 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 of 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 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, the World Climate Research Programme, the International Human Dimensions of Climate Change Programme, and the International Geosphere-Biosphere Programme. These efforts underpin U.S. 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 boards, 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 1995 review drew representatives from academic, institutional, and industrial groups conducting global change research; the results of this 1995 review are described on pages 15-17.

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 decisionmakers; (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) conformity 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 (i) essential, high priority national and international components of the USGCRP in each fiscal year; and (ii) 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 ensuring continued program quality.

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USGCRP	WWW—http://www.usgcrp.gov
IPCC Working Group II TSU	WWW—http://www.usgcrp.gov/ipcc

Appendix D

Acronym List

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**
BOR	Bureau of Reclamation
NBS	National Biological Service
USGS	U.S. Geological Survey
DOS	**Department of State**
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**
NIEHS	National Institute of Environmental Health Sciences
NIH	National Institutes of Health
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
SAO	Smithsonian Astrophysical Observatory
SERC	Smithsonian Environmental Research Center
STRI	Smithsonian Tropical Research Institute
TVA	**Tennessee Valley Authority**
ERC	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

ACCP	Atlantic Climate Change Program
ACSYS	Arctic System Science
ADEOS	Advanced Earth Observing Satellite
AMIP	Atmospheric Model Intercomparison Project
APN	Asia-Pacific Network
ARM	Atmospheric Radiation Measurement
ATOC	Acoustic Thermometry of Ocean Climate
AVHRR	Advanced Very High-Resolution Radiometer
CDEP	Climate Dynamics and Experimental Prediction
CDIAC	Carbon Dioxide Information Analysis Center
CEES	Committee on Earth and Environmental Sciences
CENR	Committee on Environment and Natural Resources
CEOS	Committee on Earth Observation Satellites
CFC	Chlorofluorocarbon
CIESIN	Consortium for International Earth Science Information Network
CLIVAR	Climate Variability and Predictability
CMA	Chinese Meteorological Administration
CNES	Centre Nationale d'Etudes Spatiales
EECl	Effective Equivalent Chlorine
ENRICH	European Network for Research in Global Change
ENSO	El Niño/Southern Oscillation

EOS	Earth Observing System
EOSDIS	EOS Data and Information System
EROS	Earth Resources Observation System
ESSP	Earth System Science Pathfinder
FAA	Federal Aviation Administration
FY	Fiscal Year
GAIM	Global Analysis, Interpretation, and Modeling
GCDIS	Global Change Data and Information System
GCIP	GEWEX Continental-Scale International Project
GCM	General Circulation Model
GCOS	Global Climate Observing System
GCRIO	Global Change Research Information Office
GCTE	Global Change Terrestrial Ecosystem
GEOSAT	Geodetic Satellite
GEWEX	Global Energy and Water Cycle Experiment
GFDL	Geophysical Fluid Dynamics Laboratory
GISS	Goddard Institute for Space Studies
GLOBE	Global Learning to Benefit the Environment
GLOBEC	Global Oceans Ecosystems Dynamics Program
GOALS	Global Ocean-Atmosphere-Land System
GOIN	Global Observations and Information Network
GOOS	Global Ocean Observing System
GPS/Met	Global Positioning System/Meteorology
GTOS	Global Terrestrial Observing System
HDGC	Human Dimensions of Global Change
IAI	Inter-American Institute for Global Change Research
ICSU	International Council of Scientific Unions
IGAC	International Global Atmospheric Chemistry
IGBP	International Geosphere-Biosphere Programme
IHDP	International Human Dimensions of Global Environmental Change Programme
IPCC	Intergovernmental Panel on Climate Change
IRI	International Research Institute
ISCCP	International Satellite Cloud Climatology Project
ISLSCP	International Satellite Land Surface Climatology Project
JGOFS	Joint Global Ocean Flux Study
LBA	Large-Scale Biosphere-Atmosphere Experiment in Amazonia
LMER	Land-Margin Ecosystems Research
LOICZ	Land-Ocean Interactions in the Coastal Zone Program
LTER	Long-Term Ecological Research
LUCC	Land-Use/Cover Change
MMIA	Methods and Models for Integrated Assessment
MODIS	Moderate-Resolution Imaging Spectroradiometer
MSU	Microwave Sounding Unit
NAS	National Academy of Sciences
NASDA	National Space Development Agency

NCAR	National Center for Atmospheric Research
NPOESS	National Polar-Orbiting Operational Environmental Satellite System
NRC	National Research Council
NSTC	National Science and Technology Council
OMB	Office of Management and Budget
OSTP	Office of Science and Technology Policy
PAGES	Past Global Changes
PMIP	Paleoclimatic Model Intercomparison Project
POAM	Polar Ozone Aerosol Monitor
ppmv	Parts Per Million by Volume
pptv	Parts Per Trillion by Volume
SAGE	Stratospheric Aerosol and Gas Experiment
SCAR-B	Smoke, Clouds, and Radiation–Brazil
SCPP	Seasonal-to-Interannual Climate Prediction Program
SGCR	Subcommittee on Global Change Research
SPOT	Systeme pour l'Observation de la Terre
SRL	Space Radar Laboratory
START	Global Change System for Analysis, Research, and Training
SURFRAD	Surface Radiation Budget Network
TECO	Terrestrial Ecology and Global Change
TFODM	Task Force on Observations and Data Management
TOGA	Tropical Oceans/Global Atmosphere
TOPEX	Ocean Topography Experiment
TRMM	Tropical Rainfall Measuring Mission
UARS	Upper Atmosphere Research Satellite
UN	United Nations
UNEP	United Nations Environment Programme
UNFCCC	UN Framework Convention on Climate Change
USCSP	U.S. Country Studies Program
USGCRP	U.S. Global Change Research Program
UV	Ultraviolet
WCRP	World Climate Research Programme
WEBB	Water, Energy, and Biogeochemical Budget
WMO	World Meteorological Organization
WOCE	World Ocean Circulation Experiment

APPENDIX E

SUBCOMMITTEE ON GLOBAL CHANGE RESEARCH

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Abstract

Our Changing Planet: The FY 1997 U.S. Global Change Research Program is a report to Congress supplementing the President's FY97 budget, pursuant to the Global Change Research Act of 1990. The report describes the structure of the program, its goals and objectives, the specific contributions of participating agencies, and the proposed budget for component elements of the program. The report also discusses current and planned research activities designed to address a number of key global change environmental science issues. Achieving the goals and objectives of the program will require continued strong support for the scientific research needed in order to improve understanding of how human activities are affecting the global environment, as well as how natural and human-induced global change is affecting society.

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On the Back Cover

The El Niño/Southern Oscillation (ENSO) phenomenon is the most pronounced climate variation on time scales of seasons to a few years. ENSO events occur irregularly every few years, and involve a warming of the equatorial Pacific Ocean east of the international dateline that causes nearly worldwide disruptions of atmospheric circulation and precipitation regimes. ENSO impacts include droughts in Australia, northeastern Brazil, and southern Africa; floods in Peru and Ecuador; increased tropical storms in regions of the Pacific (and reduced hurricanes in the Atlantic); and various temperature and precipitation fluctuations in key regions of North America and other continents.

Although aspects of ENSO were recognized in the early 1900s, it was the 1982-83 ENSO warm event, which was probably the largest of the century, that underscored the global impact of this phenomenon and the potential value of ENSO-related climate predictions. Intensified research since then, much sponsored by USGCRP agencies, has demonstrated that some aspects of the ENSO interaction are predictable using models of the coupled ocean-atmosphere system. These initial predictions of sea surface temperature in the tropical Pacific are an important starting point in achieving a full prediction capability because of this region's strong connections to regional climate fluctuations over much of the world. The figure on the back cover shows the observed sea surface temperatures for January 1992 and those that were predicted for that month using data up to January 1991. The forecast differs slightly in magnitude compared to reality, but is otherwise in good agreement. This forecast, made by the operational system at the Lamont Doherty Earth Observatory, demonstrates the level of prediction skill that has been achieved to date with several forecast systems. Such forecasts have already proven useful for certain applications in agriculture.

More sophisticated forecast systems being developed and tested can predict not only sea surface temperatures, but the expected precipitation and temperature anomalies in specific regions. Increasingly, such regionalized forecasts will be able to provide specific guidance to assist farmers and decisionmakers in water resources, utilities, fisheries, emergency management, public health, and a host of other disciplines.

Figure courtesy of Stephen E. Zebiak, Lamont-Doherty Earth Observatory, Palisades, NY.

The U.S. Global Change Research Program