OUR CHANGING PLANET

THE FY 1999
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 1999 Budget

On the Front Cover

Full View of the Earth, centered on the Western Hemisphere. Taken by the NOAA GOES-8 (Geostationary Operational Environmental Satellite) on September 2, 1994, at 18:00 UT. The colors are adjusted and enhanced to provide improved contrasts by combining measurements of visible light with measurements of infrared radiation. Because the North and South Poles were not actually observed by GOES-8, observations from a GOES-7 image were used to fill in these regions. The image is available on the Internet via the NASA Goddard Space Flight Center (GSFC) Web site at <http://rsd.gsfc.nasa.gov/rsd/images/>.

Source: Image produced by M. Jentoft-Nilsen, F. Hasler, D. Chesters (NASA/GSFC) and T. Nielsen (University of Hawaii).

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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).

About the Committee on Environment and Natural Resources

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
NATIONAL SCIENCE AND TECHNOLOGY COUNCIL
WASHINGTON, D.C. 20502

March 1998

Members of Congress:

I am pleased to transmit to you a copy of *Our Changing Planet: The FY 1999 U.S. Global Change Research Program.* The purpose of this report, which was prepared under the auspices of the President's National Science and Technology Council (NSTC), is to provide highlights of the Program's recent research and to describe future plans and directions.

The USGCRP was established in 1989, and the first edition of *Our Changing Planet* was transmitted to the Congress as a supplement to the FY 1990 budget. In the nine years since, the U.S. Global Change Research Program (USGCRP) has brought about dramatic improvements in our knowledge of the Earth system. Consider, for example, the fact that our scientists were able to predict the occurrence of the 1997–98 El Niño event. This, in turn, allowed us to prepare for this event, thereby greatly mitigating the adversity of its impacts. The scientific results of USGCRP's work are being used to create vitally important and useful information for resource managers around the world.

Regional-scale modeling and investigations are the natural outgrowth of the continued progress in global-scale analysis. Over the next year, the USGCRP will complete the series of workshops begun last year that focus on identifying and analyzing regional vulnerabilities to climate variability and change. The results of these workshops will provide regional texture for a national assessment of the consequences of climate change.

As you know, the authorizing legislation of the USGCRP mandates a National Assessment of Climate Change Impacts. In January of this year, it was my pleasure to initiate this effort. The National Assessment process will involve a broad spectrum of stakeholders from state, local, tribal, and Federal governments, business, labor, academia, non-profit organizations, and the general public. It will link research by scientists to specific needs of the stakeholders and provide managers, planners, organizations, and the public with the information needed to increase our resilience to climate variability and to improve our ability to cope with climate change.

The USGCRP has been strongly backed by every Administration and Congress since its inception. The President and the Vice President believe that global change research is one of the foundations of a sustainable future, and the FY 1999 Budget Request demonstrates their ongoing commitment to the program. The Administration looks forward to working with you as we carry on this bipartisan tradition of support for sound science.

John H. Gibbons
Director

Committee on Environment and Natural Resources

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Executive Summary

The broad array of research supported through the U.S. Global Change Research Program (USGCRP) has substantially improved understanding of global change. For example:

- Computer models successfully predicted the onset of the 1997–98 El Niño event with sufficient lead-time so that actions could be taken to mimimize damage from predicted flooding rains.
- Studies of past variations in the climate indicate that global average temperatures by the end of the next century could be warmer than any that have occurred on the Earth for several million years.
- Research results have strengthened the evidence that the phaseout of chlorofluorocarbons and other ozone-depleting compounds will significantly reduce levels of chlorine in the stratosphere.
- Observation and monitoring from space of changing land cover are providing an important foundation for efforts to make land use more sustainable.

These and other findings about changes in the Earth system are leading to a deeper appreciation of how human activities influence and are influenced by global change.

Much of the research supported by the USGCRP has emphasized global phenomena, and this research will continue to be extended and deepened. The USGCRP also has been actively building links between research and society's application of new knowledge in particular regions and sectors. For example, an important USGCRP priority is to improve capabilities to project climate change and other aspects of global change on a regional basis, as well as initiating a National Assessment of the ecological, economic, and social consequences of climate change in the context of other stresses.

Research supported by the USGCRP has been central to the development of the international scientific assessments that underlie the United Nations Framework Convention on Climate Change (FCCC) and the Montreal Protocol on Substances that Deplete the Ozone Layer. Continued research will be needed to meet the challenges posed by international negotiations and agreements.

Four Key Global Change Issues

To help forge a sustainable relationship between human society and the global environment, the USGCRP has focused on four areas of particular scientific and practical importance:

1) **Seasonal to Interannual Climate Variability**—The USGCRP seeks to obtain the understanding and skills needed to forecast short-term climate fluctuations and to use these predictions in social and economic planning and development in the United States and abroad.
2) **Climate Change Over Decades to Centuries**—The USGCRP seeks to understand, predict, and assess changes in the climate that will result from the influences of projected changes in population, energy use, land cover, and other natural and human-induced factors; to understand, predict, and assess the consequences of climate change for society and the environment; and to provide the scientific information society needs to address these changes.
3) **Changes in Ozone, Ultraviolet Radiation, and Atmospheric Chemistry**—The USGCRP seeks to understand and characterize chemical changes in the global atmosphere and their consequences for human well-being.
4) **Changes in Land Cover and in Terrestrial and Aquatic Ecosystems**—The USGCRP seeks to understand, predict, and assess the causes, magnitude, and consequences of changes in land cover and in terrestrial and aquatic ecosystems, and to strengthen the scientific basis for sustainable environmental and natural resource practices.

In pursuing these goals, the USGCRP is seeking to observe and document changes in the Earth system, understand why changes are occurring, improve predictions of future changes, analyze the environmental, economic, and social implications of change, and support scientifically based assessments of global environmental change issues.

Integrative Activities

The USGCRP also supports a number of integrative and cooperative efforts that contribute to its scientific goals. These efforts are directed toward six overarching objectives:

- To ensure a long-term, high-quality record of the state of the Earth system, its natural variability, and changes that are occurring.

- To provide all users ready and affordable access to the full spectrum of global change data, products, and information in useful forms.
- To gain an understanding of the interactions among the physical, chemical, geological, biological, and solar processes that determine the functioning of the Earth system and its trends and fluctuations on global and regional scales.
- 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 respond to problems associated with environmental change.
- To support and assist the program and its participating scientists and their interactions with related international research, observing, and assessment activities.
- To increase public awareness of the Earth system and how it is changing and to promote education on a wide range of global change issues.

National Assessment of the Consequences of Climate Change

The Global Change Research Act of 1990 mandates the preparation of scientific assessments of global change. The Subcommittee on Global Change Research, which coordinates the USGCRP, has initiated a national, scientifically based assessment of the consequences of climate change and climate variability for the people, environment, and economy of the United States. The goal of the National Assessment is to determine the regional and national implications of climate change and variability within the United States in the context of other environmental, economic, and social stresses.

A series of 20 workshops is being held to identify the distinctive regional characteristics and potential consequences of climate change and variability. The next phase will include a set of regional assessments, a set of sectoral assessments, and a national synthesis that draws together the regional and sectoral assessments in a summary for policymakers. A National Assessment report will be issued in 1999.

Summary of Key USGCRP Accomplishments in 1997

- **National Assessment**—A national assessment of the consequences of climate change for the United States was begun during 1997. Eight regional workshops and the U.S. Climate Forum, a major national workshop with more than 400 participants, examined the likely consequences of climate change for U.S. regions and ecological and economic sectors.
- **El Niño Southern Oscillation**—There was continued improvement in the accuracy and lead times of predictions of seasonal climate fluctuations associated with the El Niño Southern Oscillation. Several forecasting activities successfully predicted the onset of the 1997–98 El Niño event early enough to support flood mitigation actions.
- **Climate Change**—A new 300-site survey of borehole temperatures on four continents produced a detailed record of the climate of the last 5 centuries, confirming that the Earth is warming and that the rate of warming has been accelerating since 1900.
- **Global Temperature Record**—Based on observations of global average surface temperature, scientists from the NOAA National Climatic Data Center found that 1997 was the warmest year on record since measurements began, continuing the recent pattern in which the 1980s and 1990s have produced 12 of the 13 warmest years on record.
- **20th Century U.S. Rainfall**—Another NOAA analysis showed an average 5 to 10 percent increase in the overall amount of U.S. rainfall in the last 100 years. The frequency of heavy downpours, in which more than 2 inches of rain falls in a day, has increased by about 20 percent. Such events can lead to flooding, soil erosion, and even loss of life.
- **Global CO_2 Emissions**—The DOE Carbon Dioxide Information and Analysis Center (CDIAC) released data showing that global emissions of CO_2 grew by about 5 percent between 1992 and 1995, and have reached the highest level ever recorded.
- **Stratospheric Ozone**—Observations in the stratosphere show a flattening out of the growth curve of hydrogen fluoride, which at that altitude is a very good indicator of the total amount of industrially produced halogens (especially fluorine and chlorine) in the atmosphere. In concert with previous findings of decreasing halogen levels in the troposphere, these results prove that regulation under the Montreal Protocol on Substances that Deplete the Ozone Layer is affecting stratospheric composition.

- **Arctic Ozone Depletion**—Unusually low values of total ozone observed over the Arctic in the spring of 1997 demonstrate that, for appropriate meteorological conditions, appreciable chemically induced ozone depletion resulting from human activities can occur in the Arctic as well as the Antarctic.
- **Mapping Global Land Cover**—Development of the first global synthesis of information on land cover at a spatial resolution of 1 km (about 0.6 miles) was completed. These data are helping improve understanding of land cover, ocean productivity, and the cycling of carbon through the Earth system, thus contributing to better predictions of climate change on national and global scales.
- **Tropical Rainfall Measuring Mission (TRMM)**—The TRMM satellite, a joint NASA-Japanese project, was successfully launched in November 1997, and is providing rainfall observations that are improving our understanding of the global hydrological cycle and its role in climate change and variability.
- **SeaWiFS**—Ocean productivity images from the SeaWiFS instrument aboard the SeaStar satellite, launched in 1997 as part of an innovative public-private partnership, are playing a major role in understanding the behavior and consequences of the ongoing El Niño and in other global change research.
- **Total Ozone Mapping Spectrometer (TOMS)**—Following the failure of the Japanese ADEOS spacecraft in mid-1997, NASA successfully changed the orbit of another satellite to allow resumption of near-global daily mapping of ozone by TOMS, as well as concentrations of stratospheric sulfur dioxide produced from large volcanic eruptions.
- **Atmospheric Radiation Measurements (ARM)**—The third ARM site, on the North Slope of Alaska, began operation in 1997. The ARM program focuses on the effects of clouds on the Earth's radiative energy balance, a major source of uncertainty in climate models.
- **Intergovernmental Panel on Climate Change (IPCC)**—USGCRP research continued to play a leading role in the IPCC during 1997, and provided important contributions to the IPCC Special Report on *Regional Impacts of Climate Change: An Assessment of Vulnerability* and to several IPCC Technical Papers on other key issues. A U.S. citizen, Robert T. Watson, was elected overall Chair of the IPCC, replacing Bert Bolin of Sweden, and James McCarthy of Harvard University was elected Co-Chair of IPCC Working Group II, which will assess impacts and adaptation options.

Summary of USGCRP Goals and Expected Performance for FY99

National Climate Change Assessment

- The first U.S. national assessment of the consequences and implications of climate change and variability for the United States will near completion. Reports describing regional and sectoral analyses will emerge from the review phase by late FY99 and the review draft of the national synthesis report will be near completion.

Seasonal to Interannual Climate Variability

- Observations, analyses, and modeling studies of the El Niño Southern Oscillation (ENSO) will focus on understanding the cause-and-effect relationships between midlatitude and tropical variability on decadal time scales, which is expected to contribute to improving ENSO predictability.
- Observations, analyses, and modeling studies will focus on documenting and understanding decadal variability centered on the Atlantic Ocean, such as the North Atlantic Oscillation (NAO), which is a critical determinant of climate over much of Europe and the East Coast of North America, with the goal of eventually predicting variations in the NAO.
- Observations of climate variability will be expanded in the Atlantic Ocean, with a pilot system of networks designed to measure the key parameters of the ocean and atmosphere relevant to climate prediction.
- Experiences documented during the 1997–1998 ENSO event will be used to study how social and economic systems are influenced by short-term climate fluctuations and how human behavior can be (or may not be) affected by information about such fluctuations. Pilot applications projects will develop methodologies for society to utilize climate forecast information to reduce socioeconomic disruption.

Climate Change Over Decades to Centuries

- USGCRP scientists will actively participate in the preparation of the Third Assessment Report (TAR) of the Intergovernmental Panel on Climate Change (IPCC), which is scheduled for completion in late 2000 or early 2001. Several new and improved data sets, which will include model simulations, will be made available for the IPCC assessment and the U.S. National Assessment.
- Both the Joint Global Ocean Flux Study (JGOFS) and the World Ocean Circulation Experiment (WOCE) will be well into a phase of analysis, interpretation, modeling, and synthesis. Preliminary assessments of both the Pacific and Indian Oceans will be available, as will the first interdisciplinary analysis of seasonal carbon cycling and CO_2 drawdown in the Ross Sea and in the region of the Antarctic Polar Front.
- The first phase of a study of the climate of the 20th century and the climate of the future, as simulated by the community Climate System Model, will be completed. The simulations will include changes due to greenhouse gases, aerosols, and solar variability and will enable a critical evaluation of the predictive capability of climate models.
- Field experiments and focused model simulations will be initiated to study the effects of tropospheric and stratospheric aerosols on global and regional radiative balances and climate. The observational phase and initial analyses of the data will be completed in the Indian Ocean Experiment (INDOEX), which will examine and help quantify the influence of natural and human-produced aerosols on future climate change.
- Model simulations and observations needed to increase confidence in the detection and attribution of human-induced climate change will be prepared using updated and more comprehensive data and improved detection procedures. Simulation studies will be conducted of various greenhouse-gas atmospheric stabilization trajectories using improved coupled atmosphere-ocean climate models.

Changes in Ozone, UV Radiation, and Atmospheric Chemistry

- The IPCC Special Report on *Aviation and the Global Atmosphere* will be published, with USGCRP scientists having made important contributions. This will be the authoritative assessment by the international scientific and technical communities of the impacts of aviation on the atmosphere, including ozone layer depletion and climate change.
- The *Scientific Assessment of the Ozone Layer: 1998*, a periodic international scientific assessment prepared on behalf of the Conference of the Parties to the Montreal Protocol, will be published, with USGCRP scientists serving as co-chair and lead authors. The focus of the assessment will be on management of the recovery of the ozone layer over the coming decades and on the relationship of ozone depletion to other global environmental issues, such as climate change.
- The Pacific Exploratory Mission (PEM)–Tropics B, an airborne field campaign, will be conducted during February–April 1999, to document air quality baseline data over the tropical Pacific Ocean. These data will be essential to quantifying expected future impacts on the tropical Pacific atmosphere from biomass burning and emissions from rapid industrial development in Asia.
- A peer-reviewed report describing the integrated, multi-agency, national UV monitoring program will be published.

Changes in Land Cover and in Ecosystems

- The Landsat-7 satellite will provide the United States for the first time with a global data set updated on a seasonal basis (3–4 times annually) for analysis of changes in land cover. These data will be critical for documenting land-cover change due to both natural disturbances and human influences.
- The Earth Observing System (EOS) AM-1 satellite will provide near-daily global measurements of indicators of photosynthetic processes, allowing determination of carbon uptake by the terrestrial biosphere.
- Interactions between terrestrial surfaces and the atmosphere will be better defined in terms of the transfer of energy, water vapor, and especially carbon dioxide, as the AmeriFlux and

Grassland CO_2 flux networks complete 2–3 years of measurements in forests and rangelands, providing critical information on the global carbon balance and providing modelers with better data sets.

Observing and Monitoring Global Change

- Scheduled for launch in 1998, the EOS AM-1 satellite will carry five state-of-the art instruments to observe the continents, oceans, and atmosphere and their interactions. EOS AM-1 will measure the radiative properties of the atmosphere, enabling estimates of the heating and cooling of the Earth and atmosphere.
- Scheduled for launch in 1998, Landsat-7 will add to the record of more than 25 years of continuous data on the condition of the Earth's terrestrial surface.
- Scheduled for launch in 1998, QuikSCAT, designed to replace the failed Japanese ADEOS spacecraft, will measure winds at the ocean surface, the key to the next major improvement in near-term weather forecasting.
- Surface levels of chlorine- and bromine-containing chemical compounds addressed under the Montreal Protocol will be measured, to quantify the decreasing concentrations of regulated compounds.

Global Change Data, Products, and Information Services

- The Global Change Data and Information System (GCDIS) will be expanded to meet the special data and information access needs of the national assessment of the conseqeunces and implications of climate change and variability for the United States.
- The application of the USGCRP "full and open" data access policy will be broadened to facilitate the incorporation of non-Federal data sources into national assessments of global change.
- The USGCRP will publish a list of citations, including authors, pertaining to global change-related data sets produced in FY99.
- The coordination of GCDIS with other data and information access system components of programs will be expanded to include the International Global Observing System (IGOS) and the Inter-American Biological Information Network (IABIN).

1. The Earth System: Global Change and Regional Impacts

As concerns about global change have become increasingly prominent issues of national and international policy, the importance of research into the causes and consequences of global change has grown. Today, a broadly based scientific research program is essential for society to take effective steps to address the possible side effects of a changing climate and other aspects of global change.

Sound decisions about global change require better documentation, understanding, and prediction of global changes and their environmental and societal implications. Global change research needs to be sustained and intensified so that it will continue to provide high-quality scientific understanding that can support national and international assessments to ensure that decisions are made wisely.

A broadly based scientific research program is essential for society to take effective steps to address the possible effects of global change.

The Earth System and Global Change Research

The broad array of research supported through the U.S. Global Change Research Program (USGCRP) is continuing to improve our understanding

Central Purposes of the U.S. Global Change Research Program

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

of global change. It is providing answers to important questions about the Earth system, documenting environmental change, and leading to a better understanding of the significance of this change for society. For example:

- Predictions of climate fluctuations from season to season are now being made with longer lead times than previously. Several forecasting methods based on computer models successfully predicted the onset of the 1997–98 El Niño event with sufficient lead time so that actions could be taken to minimize damage from predicted flooding rains.
- Paleoclimate studies—studies of past variations in the climate—indicate that, by the end of the next century, global average temperatures could be warmer than any that have occurred on the Earth in several million years. In addition, current climate models indicate that the rate of global warming projected for the next century could be more rapid than any natural warming that has occurred since the end of the last Ice Age more than 10,000 years ago.
- Recent research results, in concert with previously reported findings of decreasing halogen levels in the troposphere, prove that the regulation of halogen-containing molecules under the Montreal Protocol on Substances that Deplete the Ozone Layer is affecting stratospheric composition. The results further strengthen the evidence that the phaseout of chlorofluorocarbons (CFCs) will significantly reduce amounts of stratospheric chlorine.
- Observation and monitoring from space of changing land cover, along with the production and distribution of global land cover data sets, are providing an important foundation for efforts to make land use more sustainable. For example, satellite observations supported by the USGCRP in coordination with international projects have documented changes in tropical and subtropical land cover, especially the loss of tropical forests.

These and other findings about changes in the Earth system are leading to a deeper appreciation of how human activities influence and are influenced by global change.

Science in Support of the Policy Process

Changes in the global environment are the subject of wide-ranging debates, intense international negotiations, and policy decisions that have the potential to affect many aspects of society. Perhaps most far-reaching

in their potential implications are the negotiations under the Framework Convention on Climate Change (FCCC).

The FCCC was the first international policy agreement to address the issue of human-induced climate change due to increasing atmospheric concentrations of greenhouse gases. Based largely on the scientific assessments of the Intergovernmental Panel on Climate Change (IPCC), the FCCC was concluded in 1992. More than 160 nations are Parties to the FCCC, including the United States. Among other goals, the FCCC calls for enhancement of mitigation and adaptation policies based on our understanding of global change and its consequences.

In December 1997, the Third Conference of the Parties to the FCCC was held in Kyoto, Japan, to strengthen post-2000 commitments under the Framework Convention. Among other commitments relating to reduction of emissions of greenhouse gases, the Kyoto Protocol that emerged from the meeting recognized the need for the nations of the world to "cooperate in scientific and technological research to reduce uncertainties related to the climate system, the adverse impacts of climate change and the economic and social consequences of various response strategies."

The United States, through the USGCRP, supports the world's most comprehensive set of climate research activities. Research supported by the USGCRP has been and will remain central to the development of the international scientific assessments that underlie the Framework Convention and any related agreements. The 1995 IPCC Second Assessment Report provided much of the scientific basis for the negotiations leading to the Kyoto Protocol. The United States will continue to play a leading role in the IPCC, which is preparing to conduct the Third Assessment Report, scheduled for completion in late 2000 or early 2001.

Global Change and Regional Implications

Much of the research supported by the USGCRP has emphasized understanding at the global scale. This research produced valuable insights into the Earth's climate system and other aspects of global environmental change. It is essential that the program continue to deepen and extend scientific understanding of the entire Earth system.

At the same time, the USGCRP has been actively building links between research advances and society's application of new knowledge in particular regions and sectors. Key areas of research that could enhance these links include:

1) *Regional estimates of the timing and magnitude of global change.* An important USGCRP priority is to improve capabilities to

project climate change and other aspects of global change on a regional basis.

2) *Regional analyses of the environmental and societal consequences of global change, in the context of other stresses.* Policymakers, resource managers, and the public need projections of the consequences of global change for their regions. Each region is unique, and climate change and other aspects of global change will act with other stresses and conditions to affect society and regional ecosystems.
3) *Integrated assessments of the implications for society and the environment of global change.* Policy and management decisions related to global change could affect many aspects of society. To support these decisions, careful analyses combining economics, the social sciences, and the physical, biological, and health sciences are needed on both regional and global scales.

The Consequences of Climate Variability and Climate Change for the United States: A National Assessment Process

What are the risks and opportunities for the United States—its people, its environment, and its economy—associated with increased climate variability and climate change? This question is being addressed in a National Assessment of the Consequences of Climate Change for the United States being conducted by the USGCRP.

The process involves a broad spectrum of stakeholders from government, business, academia, and other interested parties. As an initial step, 20 workshops, encompassing every state and territory, are identifying distinctive regional characteristics and potential consequences of climate change and variability (see accompanying table). At a U.S. Climate Forum held in Washington, DC, in November 1997, more than 400 participants started discussion of the national-scale issues that must be addressed during the assessment.

The next phase will include a set of regional assessments, a set of sectoral assessments, and a synthesis that draws together the regional and sectoral assessments in a summary for policymakers. A National Assessment report will be issued in 1999, which will incorporate the regional and sectoral analyses and the national synthesis (see Chapter 4 for more details).

Results of the National Assessment process will, in turn, feed back into the research enterprise, by helping to clarify the critical societal needs that research must help to address. An assessment-oriented

research program dedicated to supporting the development of policy-relevant information for decisionmakers will be implemented as part of the USGCRP.

1997 Workshops

Region	Organizing Institution(s)	Coordinating Agency(s)	Dates
Central Great Plains	Colorado State U. and U. of Nebraska/NIGEC	DOE	May 27–29
Alaska	U. of Alaska	DOI	June 3–6
Southeast	U. of Alabama–Huntsville and Florida State U.	NASA, NOAA	June 25–27
Pacific Northwest	U. of Washington	NOAA, NASA	July 14–16
Southwest	U. of Arizona	DOI, NOAA	September 3–5
New England	U. of New Hampshire	NSF	September 3–5
Middle-Atlantic	Pennsylvania State U.	EPA	September 9–11
Northern Great Plains	U. of North Dakota	NASA	November 5–7

1998 Workshops

Region	Organizing Institution(s)	Coordinating Agency(s)	Dates
Rocky Mountains and Great Basin	Utah State U.	DOI	February 16–18
Gulf Coast	Southern U. and A&M College	EPA	February 25–27
Southwest Border	U. of Texas–El Paso	NASA	March 2–4
Hawaii and Pacific Islands	Center for App. of Research on the Environment; U. of Hawaii	FEMA, DOI, NOAA	March 3–6
California	U. of California–Santa Barbara	NSF	March 9–11
Metro East Coast	Columbia U.	NSF	March 23–24
Great Lakes	U. of Michigan	EPA	May 5–7
Appalachians	West Virginia U.	USDA–FS	May 26–29
Eastern Midwest	Indiana U.	USDA	June 29–30
Caribbean/Southern Atlantic Coast	Florida International U.	NOAA	July 21–23
Southern Great Plains	Texas A&M U.	USDA	June or September
Tribal Lands		NASA	September

2. Global Change Issues: Highlights of Recent and Ongoing Research

The USGCRP Focus: Four Key Global Change Issues

The USGCRP is based on the premise that an improved understanding of global change will make possible a sustainable relationship between human society and the global environment. To achieve this improved understanding, the USGCRP is focused on four areas of particular scientific and practical importance:

1) **Seasonal to Interannual Climate Variability**—The USGCRP seeks to obtain the understanding and skills needed to forecast short-term climate fluctuations and to use these predictions in social and economic planning and development in the United States and abroad.
2) **Climate Change Over Decades to Centuries**—The USGCRP seeks to understand, predict, and assess changes in the climate that will result from the influences of projected changes in population, energy use, land cover, and other natural and human-induced factors; to understand, predict, and assess the consequences of climate change for society and the environment; and to provide the scientific information society needs to address these changes.
3) **Changes in Ozone, Ultraviolet Radiation, and Atmospheric Chemistry**—The USGCRP seeks to understand and characterize chemical changes in the global atmosphere and their consequences for human well-being.
4) **Changes in Land Cover and in Terrestrial and Aquatic Ecosystems**—The USGCRP seeks to understand, predict, and assess the causes, magnitude, and consequences of changes in land cover and in terrestrial and aquatic ecosystems, and to strengthen the scientific basis for sustainable environmental and natural resource practices.

Seasonal to Interannual Climate Variability

The USGCRP is playing a major role in the ongoing global endeavor to develop and enhance predictions of seasonal and interannual climate fluctuations. Such forecasts can have many benefits. For example, they can help farmers maintain their agricultural productivity in spite of extreme climatic events such as droughts and floods. They can help water resource managers ensure reliable water deliveries, limit flood damage, and maintain optimal reservoir levels. They can help plan fishery harvests. And they can help foresters allocate resources effectively to safeguard forests (and the public) from major fires during droughts.

The following research highlights demonstrate some of the ways in which greater understanding of seasonal and interannual climate variability can produce substantial benefits to human society.

Improved Prediction of El Niño Events and their Regional Impacts

The El Niño Southern Oscillation (ENSO) is a natural phenomenon that causes warming and cooling of large areas of surface water in the tropical eastern and central Pacific Ocean every several years. (Warming phases are termed El Niño events, and cooling phases are termed La Niña or El Viejo events.) These large-scale ocean disturbances also have significant effects on the atmosphere. Research has linked El Niño events to an increased probability of severe weather anomalies, including the failure of the Indian monsoon, droughts in Brazil, Australia, and Southern Africa, and heavy rains and droughts in the United States and in other areas around the world.

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

The goal of the seasonal to interannual climate variability component of the USGCRP is to obtain the understanding and skills needed to forecast short-term climate fluctuations and to use these predictions in social and economic planning and development in the United States and abroad.

A central focus of research in this area has been on developing numerical models that can forecast whether coming seasons will be warmer or cooler, and wetter or drier, than normal. Several of these forecasting systems successfully predicted the onset, though not the full amplitude, of the 1997–98 El Niño event, which is comparable in amplitude to the 1982–83 warming—the previous "event of the century."

Atmospheric model forecasts for North America have captured the general meteorological features of El Niño's effects, providing the forecast information with sufficient lead time that actions could be taken to limit damage. Research is now focusing on making these forecasts even more timely and reliable. Information on extreme rainfall and drought conditions is of particular interest for emergency and water resource managers and others involved in planning endeavors.

Several forecasting methods successfully predicted the onset of the 1997–98 El Niño event with sufficient lead time that actions could be taken to limit damage.

An important research challenge is to forecast the differing characteristics among El Niño events that cause differences in regional impacts. All El Niño and La Niña events are not the same, and research has documented that different events have different effects. Understanding these differences and the irregularity of El Niño events will enhance forecast capabilities (see Color Plate 1 on page 107).

Major efforts are being undertaken to develop more comprehensive numerical models that represent the complete scope of interactions between the ocean and atmosphere. Efforts also are being made to extend the models to include interactions of the atmosphere with the land surface, vegetation, and hydrology. Such models will refine the regional accuracy of climate forecasts.

The 1997–98 El Niño event is much better documented than any previous El Niño event. An array of observing instruments was placed in the tropical Pacific Ocean as part of the Tropical Ocean-Global Atmosphere (TOGA) program starting in the 1980s. In addition, satellite-derived observations of sea-level elevation and ocean-surface conditions generated by winds were a factor in the 1997 forecasting success and have extended observations to higher latitudes. Satellite measures of water vapor in the upper atmosphere have helped document the event and will improve future forecasts. In addition, new satellite observations of ocean color will document future ENSO variability and help gauge the impacts of warming and cooling events on the marine biosphere.

Changes in precipitation are among the most important features of El Niño events. The USGCRP is merging satellite-based data and ground-based data to produce the best possible depiction of fluctuations in precipitation patterns. The Tropical Rainfall Measuring Mission (TRMM), a joint U.S.-Japan satellite mission, was launched successfully in November 1997, and is expected to provide high-quality satellite observations of precipitation for the entire region between 35°N and 35°S latitudes. TRMM also will provide a basis for estimating how the rainfall associated with El Niño events and other tropical phenomena affects the atmospheric wind patterns on a global basis and thereby generates anomalous conditions in far-removed regions of the world.

Climate Variability in North America

A number of studies are underway to improve the representations of physical, chemical, and ecological processes in computer models, thus increasing their ability to predict climate variations. For example, research in the Global Energy and Water Cycle Experiment (GEWEX) Continental-Scale International Project and the Global Ocean-Atmosphere-Land System (GOALS) Pan-American Climate Studies program is seeking to determine the extent to which year-to-year variations in summer precipitation over North America is predictable and how it is linked to forcing influences in other parts of the world, such as ENSO events.

During FY99, research will focus on atmospheric and land-surface processes leading to heavy precipitation in the eastern part of the Mississippi River Basin, the effects of mountain geography on precipitation and hydrology in the northwestern Great Plains, and demonstration projects to show how climate information can be used more effectively to manage water resources in the central United States. Researchers also are developing strategies for assessing the role of the Pacific Ocean, the Gulf of Mexico, and soil-moisture conditions in contributing to the variability of warm-season precipitation in central and western North America.

Using Seasonal Climate Forecasts to Reduce Costs of Impacts

Seasonal climate forecasts can both be used to reduce the impacts of natural disasters and identify potential social and economic opportunities. For example, research is showing that the intensity, frequency, and paths of storms, including hurricanes, are modulated by ENSO events. While

it is not possible to prevent destructive storms, improved forecasts can be used to reduce some of the losses associated with these storms.

Better predictions of possible weather extremes could, over time, save the United States billions of dollars in damage costs. Recent estimates of weather-related damages include the 1982-83 El Niño event ($2–3 billion), 1988 Midwest drought ($40 billion), 1993 Midwest floods ($15 billion), 1995 California flooding ($3.3 billion), and 1995–96 Southwest drought ($4 billion).

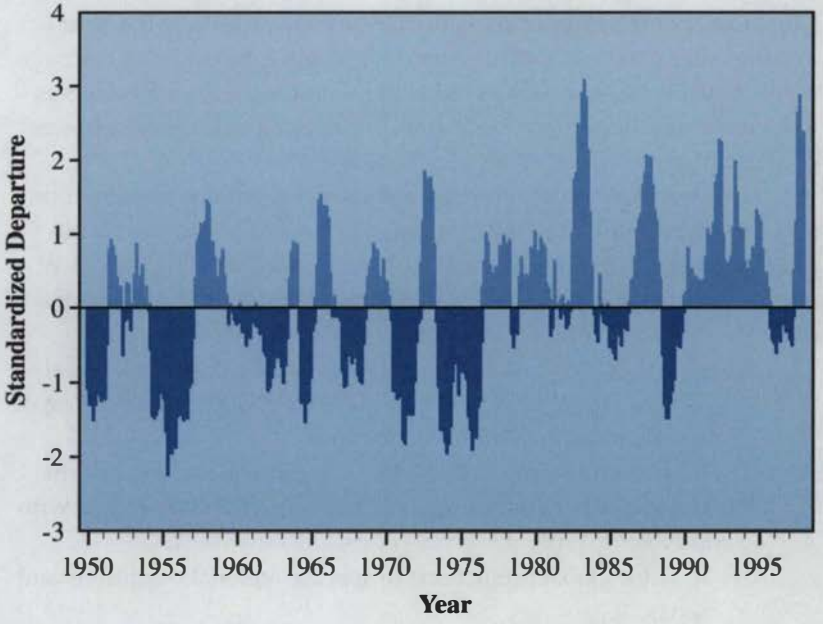


Figure 1: Multivariate ENSO Index, 1950–Present. The El Niño Southern Oscillation (ENSO) is the most important coupled ocean-atmosphere phenomenon causing year-to-year global climate variability. The Multivariate ENSO Index (MEI), developed mainly for research purposes, monitors the coupled oceanic-atmospheric character of ENSO events based on the main observed variables over the tropical Pacific Ocean. The MEI can be understood as a weighted average of the main ENSO features contained in the following six variables: sea-level pressure; the east-west and north-south components of the surface wind; sea surface temperature; surface air temperature; and cloudiness of the sky. Positive values of the MEI represent the warm phase of ENSO (i.e., El Niño events), and negative values represent the cold phase of ENSO (i.e., La Niña, or El Viejo, events). The observations used to generate this index are collected and published in the Comprehensive Ocean-Atmosphere Data Set (COADS). For more information, see the NOAA Climate Diagnostics Center Web sites:
<http://www.cdc.noaa.gov/ENSO/enso.mei_index.html>
<http://www.cdc.noaa.gov/~kew/MEI/mei.html>
<http://www.cdc.noaa.gov/coads/>.

Source: Klaus Wolter and Michael Timlin/NOAA-CIRES Climate Diagnostics Center.

Advance warning of such events can help water, energy, and transportation managers and agricultural producers to plan ahead and limit some losses. During the 1997–98 El Niño event, national and international mechanisms are being developed for responding to future climate variations. For example, FEMA, NOAA, NASA, USDA, USAID, the Army Corps of Engineers, and the Department of the Interior are cooperating to reduce the impacts of extreme rainfall events and identify opportunities for social and economic benefits. Researchers are working with planners and managers to identify how improved predictions can be used to improve disaster preparedness of Federal, state, and local agencies.

Better predictions of possible weather extremes could, over time, save the United States billions of dollars in damage costs.

To encourage the development of similar capabilities internationally, NOAA is sponsoring the International Research Institute for climate prediction (IRI). The IRI will include a multinational network of research centers and activities related to use of information from forecasts. Among the Institute's objectives are the following:

1) To develop and issue experimental seasonal to interannual climate predictions based on global and regional modeling of ocean-atmosphere-land interactions.
2) To disseminate forecast guidance to nations and regions that are particularly affected by climate variability associated with El Niño.
3) To tailor global predictions to specific regional conditions and needs.

Climate Change Over Decades to Centuries

Determining the consequences of global change for the environment and for society requires better estimates of the rate, pattern, and magnitude of future climate change. Management of natural resources, the design and planning of long-term infrastructure, and business decision-making are all examples of areas where more complete understanding could reduce the potential adverse consequences of climate change.

The past several years have seen considerable progress in advancing our understanding of global climate processes and the climate changes expected in the decades and centuries ahead. Despite this progress, important uncertainties remain, particularly concerning projections of the detailed regional patterns of climate change. USGCRP research activities are dedicated to reducing these uncertainties.

Global Carbon Cycle

Stabilization of greenhouse gas concentrations in the atmosphere (including the concentration of carbon dioxide), at a level that would prevent dangerous anthropogenic interference with the climate system, is the ultimate objective of the Framework Convention on Climate Change. At the present time, however, emissions of greenhouse gases continue to rise, as do their atmospheric concentrations (with the exception of CFCs and other halocarbons, which are now controlled by the Montreal Protocol). While it is known that slowing or halting the rise in the atmospheric CO_2 concentration would require significant cutbacks in emissions over the next century, it is not yet possible to be precise

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

The goal of the climate change component of the USGCRP is to understand, predict, and assess changes in the climate that will result from projected changes in population, energy use, land cover, and other natural and human-induced factors; to understand, predict, and assess the consequences of climate change for society and the environment; and to provide the scientific information society needs to address these changes.

about the needed cutbacks because uncertainties continue to surround the factors determining the rates and magnitudes of changes in the concentrations of CO_2 and other greenhouse gases in the atmosphere.

USGCRP-supported research is underway to reduce the differences between modeled and measured concentrations of CO_2 in the atmosphere. Investigations are in progress to better determine the sources of CO_2 to the atmosphere and its removal to the ocean and land surface via sinks, both natural and as altered by human activities. Studies are showing that processes that control CO_2 concentrations are variable over seasons, years, and decades, revealing a more dynamic and complex carbon cycle than was previously recognized. Support for long-term measurements of atmospheric CO_2 concentrations and research to understand the natural processes controlling atmospheric CO_2 levels remains a high priority for the USGCRP.

USGCRP-supported research continues to reduce the differences between modeled and measured concentrations of CO_2 in the atmosphere.

In the late 1980s, scientists established the existence of a net CO_2 sink in Northern Hemisphere terrestrial ecosystems. The effect of increased atmospheric CO_2 on photosynthesis, long known from laboratory studies, was proposed as one factor causing the additional ecological uptake of CO_2. Early research focused on this "CO_2 fertilization" effect. In the mid-1990s, it was recognized that the ability of plants and soils to store carbon through CO_2 fertilization is limited by the availability of nitrogen, deposition of which is also being affected by human activities. This process is difficult to test experimentally, but its implications have been examined in a series of modeling exercises. This modeling work suggests that CO_2 fertilization alone can account for only part of the terrestrial carbon sink. With the new awareness that nutrients may also be influencing carbon cycling, several researchers have shown that nitrogen pollution resulting from human activities could, unintentionally, be creating a substantial terrestrial sink of CO_2.

Predictive Models of Climate Change

Over the past 10 years, largely as a result of USGCRP-sponsored research, atmospheric and oceanic general circulation models have improved significantly. There is strong potential for continuing

advances through improved representations of critical climate processes and through finer model resolution for regional-scale predictions.

As the spatial resolution and detail in predictive climate models increases, the need for better descriptions of clouds and ocean processes in these models also increases. Researchers are seeing the early benefits of data gathered by USGCRP-sponsored field research and satellite programs. The rate of progress can be expected to increase with the additional investments that have been made in both surface- and space-based measurement systems.

Climate variations on time scales of years to decades are largely controlled by how the ocean stores and transports heat from the warm regions near the equator to the colder regions at higher latitudes. Weather patterns change in response to changes in sea-surface temperatures, resulting in climate oscillations ranging from El Niño events to smaller but longer-term interdecadal variations.

More accurate simulation of ocean circulation is now possible through very-high-resolution ocean models. One example is the work of scientists at the Los Alamos National Laboratory, in collaboration with university scientists. Using a high-resolution global ocean model, they reproduced the long-term average behavior of the ocean currents that transport heat, as well as the shorter term fluctuations that lead to climate variations (see Color Plate 2 on page 108).

Natural climate variability on decadal and longer time scales results from the complex interactions between the climate system components—the atmosphere, oceans, land surface, and sea ice. Theoretical and observational studies are planned to quantify the sources, patterns, and magnitudes of long-term variability, as well as the possible effects of long-term climate change on shorter term seasonal to interannual climate variations.

Climate models are judged by how closely their results simulate nature. New climate system model results are a strong indication that significant advances are being made in climate modeling.

An important USGCRP-supported advance was a recent 300-year computer simulation conducted to assess the ability of one of the new generation of climate models to reproduce the natural variability of the Earth's climate. This simulation, which used a model developed by scientists from the National Center for Atmospheric Research, universities, and other Federal laboratories, included coupled representations of the atmosphere, oceans, land surface, and sea ice. A control run of the model used fixed current-day CO_2 concentration levels to simulate natural variability.

Several interesting results emerged from this simulation. Until now, even the best climate models, after simulating a few decades, produced results that "drifted off" into unrealistic climates unless fairly large "flux adjustments" were made to adjust for limitations in representing physical processes. For this model, however, the control run reproduced a stable value for the long-term global average temperature without the need for corrections. Moreover, the simulated short-term fluctuations were about the same magnitude as those observed in the real world during the past 100 years. The model also succeeded in reproducing, with a good degree of realism, the observed seasonal and geographical variability of the climate system.

Climate models are judged by how closely their results simulate nature and how well they simulate past climate. These results, which are available to all interested climate researchers for further analysis, are a strong indication that significant advances are being made in climate modeling.

Climate Change and Deep Ocean Circulation

New attention is being given to the couplings among components of the Earth system. For example, climate changes in the Arctic polar region could affect ocean salinity by changing the amount of freshwater runoff. This salinity plays an important role in determining the intensity of the deep ocean circulation that brings substantial amounts of heat to the North Atlantic Ocean. Warming temperatures in polar regions therefore could trigger reductions in the poleward transport of heat by the Atlantic Ocean, with significant effects on the climates of Europe and North America (see Figures 2 and 3). New ocean model simulations are able to represent the Arctic region with impressive realism.

Change in the strength of the deep ocean circulation could trigger changes in the poleward transport of heat, with significant effects on climate.

Past Climate Changes

Current research is seeking to understand how natural forcing mechanisms and internal climate dynamics affect climate change on the time scales of seasons to centuries. Information about past climates

allows researchers to reconstruct conditions beyond the short time span of modern instrumental records. This "paleoclimate" record of past variations in the climate also is vital for developing and validating

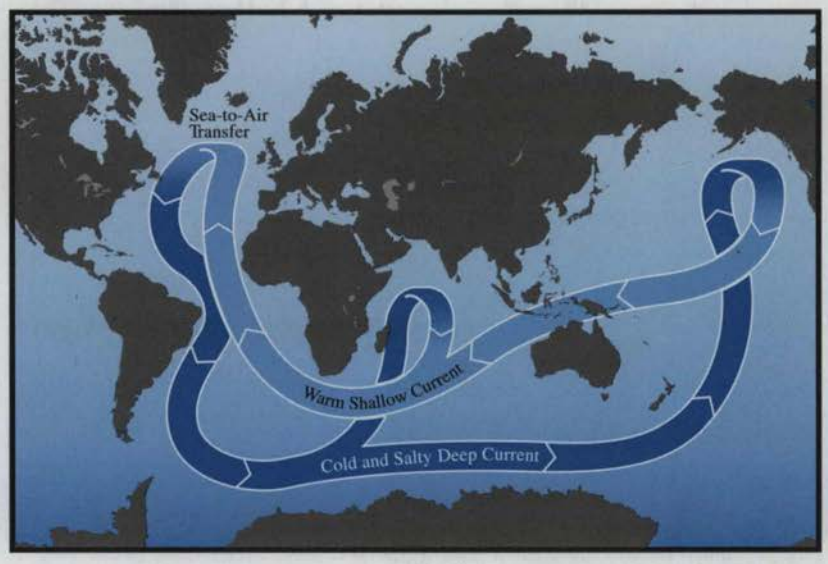


Figure 2: Ocean Thermohaline Circulation. *The global ocean thermohaline circulation, which involves the joint effects of temperature (thermodynamics) and salinity (haline dynamics), is sometimes referred to as the ocean's "conveyor belt." It important because it is responsible for a large portion of the heat transport from the tropics to higher latitudes in the present climate. For example, the Gulf Stream in the Atlantic Ocean forms part of the global thermohaline circulation, transporting warmer waters northward, thereby contributing to western Europe's relatively mild climate for its latitude.*

The conveyor is a simplified diagrammatic representation of a major globe-encompassing ocean circulation system. Salty water near the surface of the Atlantic Ocean is carried northward (largely by the Gulf Stream) to the vicinity of Iceland. There, during the winter months, the heat this waters carries is extracted by the cold, westerly winds that flow across the Atlantic from North America. The air is warmed, greatly ameliorating the winter conditions downwind in northern Europe. The water is cooled by the heat extraction (hence made denser) and sinks to the abyss, forming the lower limb of the Atlantic's conveyor. The amount of water transported by the Atlantic's conveyor averages about 16 million cubic meters per second (i.e., comparable to the world's total rainfall, or 100 times the amount of water transported by the Amazon River).

The water carried by the Atlantic's lower limb passes around the southern tip of Africa, where it joins a powerful circum-Antarctic current. This current is also fed by new deep water generated beneath the ice shelves surrounding the Antarctic continent. The mixture created in this way feeds northward flows into the deep Indian and Pacific Oceans. This water eventually upwells to the surface. As shown in the figure, one branch of the return flow to the Atlantic passes through the Indonesian Straits, across the Indian Ocean and around the tip of Africa into the South Atlantic.

Sources: *W.J. Schmitz, Jr.,* **Reviews** of Geophysics, *May 1995; W. Broecker/Lamont Doherty Earth Observatory, with illustration courtesy of Lawrence Berkeley National Laboratory.*

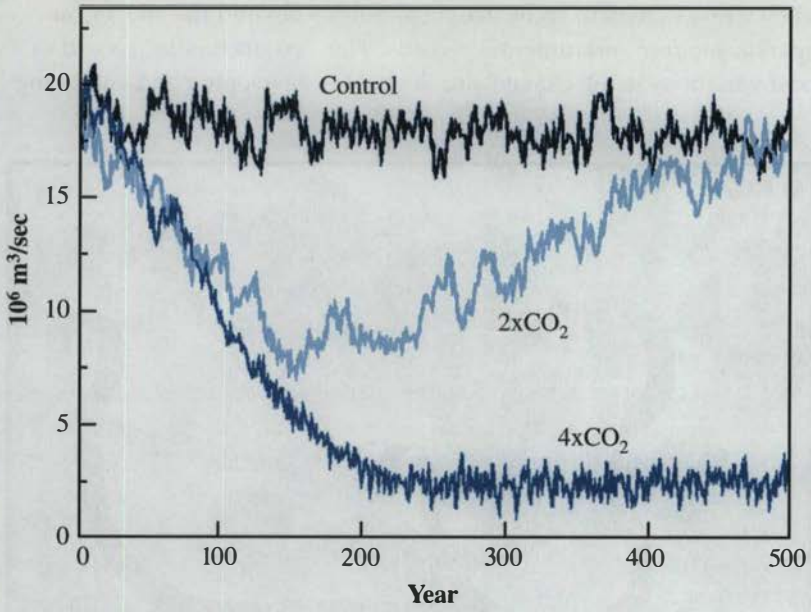


Figure 3: Impact of Climate Effects Caused by Increased CO_2 on Ocean Circulation. *New attention is being given to the couplings among components of the Earth system. For example, climate changes in the Arctic polar region could affect ocean salinity by changing the amount of freshwater runoff. This salinity plays an important role in determining the intensity of the deep ocean thermohaline circulation that brings substantial amounts of heat to the North Atlantic Ocean. Warming temperatures in polar regions therefore could trigger reductions in the poleward transport of heat by the Atlantic Ocean, with significant effects on the climates of Europe and North America.*

The figure shows North Atlantic Circulation Intensity on atmospheric concentration pathways that lead to stabilization at $2xCO_2$ and $4xCO_2$, using the NOAA Geophysical Fluid Dynamics Laboratory (GFDL) coupled ocean/atmosphere climate model. ("$2xCO_2$" refers to an atmospheric CO_2 concentration of twice the preindustrial level; "$4xCO_2$" refers to an atmospheric CO_2 concentration of four times the preindustrial level.) GFDL climate model simulations project that the global thermohaline circulation will decrease in intensity as greenhouse gas warming occurs, due to enhanced precipitation and runoff from the continents in high latitudes. In the $4xCO_2$ experiment, the thermohaline circulation essentially disappears in the GFDL model. In the $2xCO_2$ experiment, the thermohaline circulation initially weakens to less than half its original intensity, but eventually recovers to its initial strength after several centuries. Further experiments have shown that the rate of CO_2 build-up has an important effect on the evolution of the thermohaline circulation: The faster the build-up of CO_2, the greater the eventual reduction in the thermohaline circulation and the longer the delay in its recovery (see caption for Figure 2).

For additional information on GFDL's analysis of the climate change impact of a concentration pathway leading up to a quadrupling of atmospheric CO_2, see the GFDL Web space: <http://www.gfdl.gov/~tk/climate_dynamics/climate_impact_webpage.html>.

Source: Jerry Mahlman/NOAA Geophysical Fluid Dynamics Laboratory.

models and hence for reducing uncertainties in predictions of future climate.

Until recently, the climate of the past 10,000 years was thought to be relatively stable, with none of the abrupt variations that characterized the cold climates of the previous Ice Age. New terrestrial, marine, and ice core data, however, document significant climate swings during historical times. Research attention is being focused on changes such as the Little Ice Age (approximately 1400–1850 AD) when the annual temperatures of the Northern Hemisphere were about 0.5–1°C cooler than today—enough to choke ports with ice and freeze rivers in North America and Europe.

Based on ice cores recovered from Greenland, the paleo-atmospheric circulation record of the Little Ice Age shows the most abrupt onset (1400–1430 AD) of any climate fluctuation since the last full Ice Age. In addition, a comparison of annually resolved ice cores from Greenland and Antarctica demonstrates the near-synchronous onset of increased marine storminess in the North Atlantic and South Pacific at the beginning of the Little Ice Age. These preliminary studies point to a joint ocean-atmosphere process underlying these historical climate cycles.

Understanding the Implications of Climate Change

A large and growing proportion of the world's population lives in coastal areas. USGCRP-supported work on new ocean models, together with more accurate measurements of the Earth's shape from a future satellite mission, will provide improved estimates of the potential rise in sea level due to global warming. Research suggests that rising sea level will flood some coastal wetlands and communities, and amplify the impacts of storm surges, in which sea levels rise because of severe storm winds. Improved models of vegetation also will provide estimates of shifts in vegetation, soil moisture, and runoff, allowing more complete studies of the consequences of long-term climate change.

Research suggests that rising sea level will flood some coastal wetlands and communities and amplify the impacts of storm surges.

USGCRP-supported work on integrated assessment models is improving the ability to predict the impacts of climate change on society. A particular challenge is modeling the impacts of global climate change at regional scales. Another challenge is modeling the impacts on various natural resources, on sectors of the economy, and on public health.

Changes in Ozone, UV Radiation, and Atmospheric Chemistry

Progress in understanding global atmospheric chemistry will help policymakers protect human health, preserve the cleansing and shielding qualities of the atmosphere, and ensure that new chemical compounds released into the atmosphere do not lead to adverse consequences from changes in atmospheric composition. The following research areas represent important advances.

Unusually Low March Total Ozone Observed in Arctic

Unusually low values of total ozone were observed over the Arctic in the spring of 1997. During an approximately 2-week period in March 1997, the satellite-based Total Ozone Mapping Spectrometer (TOMS) instruments found that the ozone levels over a large region centered over the North Pole were as much as 40 percent below the normal amount for this time of year. These levels, which were confirmed by ground-based measurements, are significantly lower than levels observed in most recent years.

Observations clearly demonstrate that appreciable chemically induced ozone depletion resulting from human activities occurs in the Arctic as well as the Antarctic.

The low ozone amounts were closely correlated with the position of the wintertime polar vortex, a cold and relatively isolated region of air in the lower stratosphere. The Northern Hemisphere polar vortex in 1997, which was the most persistent on record, allowed the ozone-depleting chemistry to persist well into the spring, significantly later than in a typical northern winter, resulting in large ozone losses. This ozone-depleting chemistry involving CFC-derived chlorine and other

Understanding Atmospheric Chemistry and its Links to Human Well-Being

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

manufactured chemicals is the same as that which produces the Antarctic ozone hole each year.

The lowest ozone values observed in the Arctic are still much higher than the corresponding values observed in the Antarctic and the area of ozone depletion is much smaller. This reflects meteorological differences between the poles, which lead to persistently colder conditions with concomitantly greater chlorine activation and ozone loss in the Antarctic. However, the losses demonstrate that, for appropriate meteorological conditions (which can vary significantly from one year to the next), appreciable chemically induced ozone depletion resulting from human activities can also occur in the Arctic. The Arctic ozone losses are clearly worsening and are becoming comparable to those observed over Antarctica in the mid-1980s (see Figure 4, and Color Plate 3 on page 109).

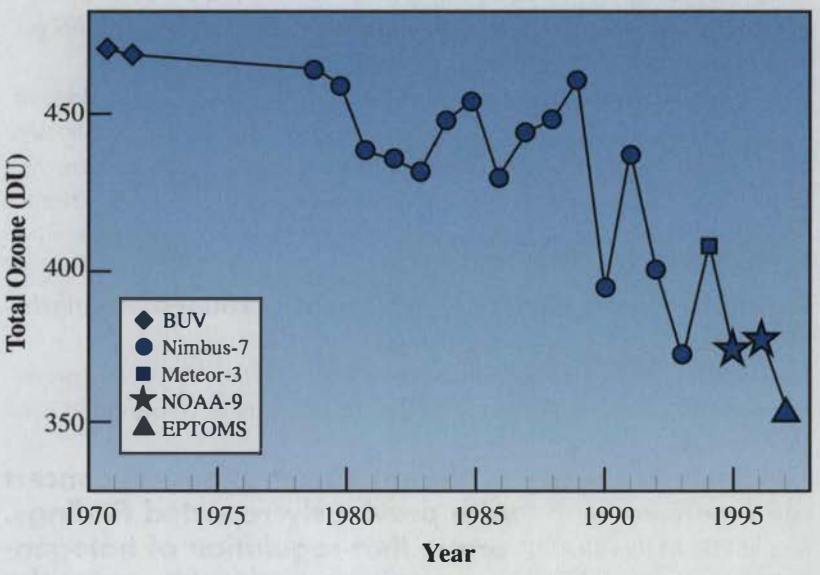


Figure 4: Average Total Ozone over the Arctic. *The time sequence of total ozone values, in Dobson units, over the Arctic (63°-90°N) for March shows a large decline in average ozone values during the 1990s. The 1971 and 1972 satellite data are from the BUV instrument aboard the Nimbus-4 satellite; the 1979 through 1993 data are from the Total Ozone Mapping Spectrometer (TOMS) instrument aboard Nimbus-7; the 1994 data are from the Meteor-3 TOMS; the 1996 data from from the NOAA-9 SBUV/2; and the 1997 data are from Earth Probe TOMS.*

Source: *Paul Newman/NASA Goddard Space Flight Center. The figure is taken from P.A. Newman, J.F. Gleason, R.D. McPeters, and R.S. Stolarski, "Anomalously low ozone over the Arctic,"* Geophysical Research Letters, *Vol. 24, No. 22, pp. 2689-2692, November 15, 1997.*

Additional Source of Upper Tropospheric Hydroxyl

Direct observations made for the first time from high-flying research aircraft suggest that the abundance of hydroxyl (OH) in the upper troposphere is appreciably different from the predicted abundance. Clarifying the reasons for this may lead to a major advance in our understanding of atmospheric chemistry. Knowledge of hydroxyl abundance is important because of the pivotal role OH plays in removing many trace gases from the atmosphere. Hydroxyl is known as the "scavenger" of the atmosphere because of the way it cleanses the troposphere of many chemicals produced naturally or by human activities.

Until recently, the production of OH was thought to come mainly from photochemical reactions involving ozone and water vapor. To explain the difference between expected and observed OH abundance, laboratory measurements and computer modeling both suggest that the observed greater OH concentrations could result from the breakup by ultraviolet light of other hydrogen-containing precursors, such as acetone or simple peroxides.

Improvements in our understanding of OH production should lead to corresponding improvements in our ability to simulate the distribution of OH with computer models of atmospheric chemistry. This, in turn, should lead to increased confidence in climate-related model predictions.

Slowing Observed Growth of Stratospheric Halogen Amounts

Observations by the Upper Atmosphere Research Satellite of hydrogen fluoride (HF) levels near the top of the stratosphere have provided conclusive evidence for a reduction in the growth rate of the concentration of HF. At this altitude, because there are no natural sources of stratospheric fluorine, HF is a very good indicator of the total amount of industrially produced halogens (especially fluorine and chlorine) in the atmosphere.

Recent observations, in concert with previously reported findings, prove that regulation of halogen-containing molecules under the Montreal Protocol is affecting stratospheric composition.

A time series of the HF measurements in the stratosphere shows a distinct flattening of the growth curve. These measurements are consistent with the reduced growth rates of the major fluorine-containing chemicals—notably several of the more abundant CFCs—observed

previously near the Earth's surface, with a time lag of several years needed for the gases to reach the stratosphere.

In concert with previously reported findings of decreasing halogen levels in the troposphere, these results prove that regulation of halogen-containing molecules under the Montreal Protocol on Substances that Deplete the Ozone Layer is affecting stratospheric composition. The results further strengthen the evidence that the phaseout of CFCs will significantly reduce amounts of stratospheric chlorine.

Biomass Burning and Global Tropospheric Ozone

Several areas of research show that biomass burning, which is concentrated in the tropics, is having a global effect on the distribution of ground-level ozone and radiative forcing in the troposphere.

First, aircraft observations over the tropical Pacific Ocean (thought to be one of the cleanest areas in the atmosphere) have demonstrated that effluents from biomass burning can be transported over thousands of kilometers. Such effluents are known to be a source of ozone in the troposphere, because ozone is photochemically produced from precursor molecules released during biomass burning of forests and grasslands. Recent analyses of satellite data over South America and New Guinea provide strong evidence that tropospheric ozone levels have been increasing in areas affected by biomass burning.

Several related areas of research show that biomass burning, which is concentrated in the tropics, is having a global effect on the distribution of tropospheric ozone and radiative forcing.

In addition, computer model simulations show that upper tropospheric ozone from biomass burning can contribute significantly to radiative forcing over large areas of the tropics, and that the resulting effects on forcing and then on climate may be significant even when averaged over the entire globe. Identification of this tropical warming effect should improve the understanding of the spatial patterns of temperature change caused by human activities.

Cooling Role of Aerosols

Atmospheric aerosol particles like dust and soot cool the Earth by scattering sunlight back to space and by altering the properties of clouds.

Several international projects have measured the impact of both natural and anthropogenically derived aerosols on the radiative balance of the Earth. Direct measurements of the physical, chemical, and optical properties of aerosol particles have enhanced confidence in estimates of their effects on the global radiative balance, and thus their calculated effects on climate.

These studies have shown that there are major aerosol components (such as sea salt and organic compounds) that are not yet included in aerosol-climate calculations. Airborne measurements over Brazil, however, have shown that the radiative cooling due to smoke from biomass fires may be smaller than previously estimated. These refinements to understanding of the link between aerosols and climate should lead to improved estimates of the climate change to be expected from future emissions of greenhouse gases.

Changes in Land Cover and in Terrestrial and Aquatic Ecosystems

Issues such as tropical deforestation and the collapse of major marine fisheries have attracted international attention in recent years. In the United States, changes in terrestrial and marine ecosystems, including the loss of productive agricultural land, the severe reductions in salmon populations in the Pacific Northwest, and concerns about the sustainability of important ecosystems have underscored the importance of documenting and understanding ecosystem changes.

Increasing concentrations of atmospheric carbon dioxide and other chemicals and changes in climate will add to the challenges of maintaining the benefits of healthy and productive terrestrial and aquatic ecosystems. To provide society with the information needed to manage and preserve these ecosystems, researchers must document and understand the human and natural factors that influence land cover and ecological systems. This task is particularly complex because it involves wildlife, forests, croplands, rangelands, wetlands, lakes and rivers, settlements, transportation arteries, ecosystem fragmentation, migration of species, and such disturbances as pests, diseases, and fires.

Documenting Changes in Land Cover and Ecosystems

At the global scale, many data collection and analysis activities rely on satellites. Key examples include the use of satellite data to produce global and continental land-cover maps (see Color Plates 4 and 5 on pages 110 and 111), and the analysis and cross-comparison of ocean color data from several international missions to document the extent and quantity of marine phytoplankton.

The first-ever global synthesis of information on land cover at a spatial resolution of 1 km (about 0.6 miles) has been developed and is

Global Ecosystems and Sustainability

The goal of the land cover and ecosystems component of the USGCRP is to understand, predict, and assess the causes, magnitude, and consequences of changes in land cover and in terrestrial and aquatic ecosystems, and to strengthen the scientific basis for sustainable environmental and natural resource practices.

already in wide use. These data are of great utility in a wide range of environmental research and modeling applications. During FY99, the EOS AM-1 platform will be used in an intensified effort to acquire higher quality terrestrial and marine data on ecosystem processes, vegetation conditions, and ocean color. These data will have a resolution from 0.25 to 1 km.

Also during FY99, the Landsat-7 mission will provide global data with even finer spatial resolution. Within the United States, several agencies are collaborating to produce the first national fine-scale map of vegetation distribution using Landsat data. These data will be exceedingly valuable for understanding the current distribution of land-cover types across the United States. The documentation of current conditions also will serve as a baseline for evaluating future changes.

The first-ever global synthesis of information on land-cover at a resolution of 1 km has been developed and is already in wide use.

Better understanding of land cover, ocean color, and their changes will enable better calculations of sources and sinks of carbon dioxide. This will contribute both to improved climate predictions on national and global scales and to more reliable calculations of sources and sinks of greenhouse gases on national levels.

Ecosystem Dynamics and Responses of Ecosystems to Climate Change and Increases in Atmospheric Carbon Dioxide

The USGCRP supports field research and observational studies that investigate both the dynamics of ecosystems and the interactions of ecosystems with the atmosphere. For example, as a partner in a Brazilian-led effort to understand the consequences of rapid land-use change in the Amazon Basin, the United States is supporting investigations into basic terrestrial and aquatic ecosystem processes that control the movement of carbon and nutrients within the Amazon Basin and back and forth to the atmosphere.

As a second example, field studies of the dynamics of fish and plankton communities are examining the patterns and causes of variability in marine biological populations. This research seeks to quantify the relationship between this variability and both climate variations and direct human impacts.

Several USGCRP agencies are cooperating to support experiments that expose ecosystems to increased concentrations of atmospheric CO_2.

The ecosystem-level responses revealed by these experiments can be used in models that predict future changes in ecosystems caused by rising CO_2 concentrations. Mechanistic models are beginning to use the experimental information for predictions of ecosystem response to CO_2 and associated climate variables.

This combination of experimental, observational, and theoretical work is leading to better scientific understanding of the processes that control ecosystem change. Such understanding will lead to an improved ability to assess the impacts of increasing atmospheric CO_2 concentrations and climate variability on local to regional to global scales. It will also produce an improved ability to understand the combined effects of climate and air pollution on natural ecosystem dynamics.

A combination of experimental, observational, and theoretical work is leading to better scientific understanding of the processes that control ecosystem change.

The Role of Ecosystems in the Global Carbon Budget

A key uncertainty about the global carbon cycle has been the role of the terrestrial biosphere. On the one hand, deforestation and the loss of soil carbon through plowing of the soil and other agricultural practices transfer carbon from the terrestrial biosphere to the atmosphere. On the other hand, forests have regrown in some areas, for example in the northeastern United States, and rising CO_2 concentrations appear in controlled experiments to stimulate plant growth and carbon sequestration.

Summing up the overall effects of these processes on atmospheric CO_2 thus requires consideration of diverse influences. Although we cannot measure all of the effects of these processes individually, the collective evidence indicates that the sum over the globe of natural processes affecting the terrestrial biosphere have caused it to act as a net sink for atmospheric CO_2 during the 1980s and 1990s, although the magnitude of the sink has varied considerably from year to year. In contrast, human influences have caused tropical forests to be a net carbon source to the atmosphere due to deforestation, although variation in cutting rates, regrowth of cleared land, and interannual climate variations have caused variations in the magnitude of the source. Due to forest regrowth, forests outside the tropics have generally been a net carbon sink that has varied in size from year to year, depending mainly on climatic conditions. In some years, the terrestrial carbon sinks outside the

tropics are collectively large enough to allow the terrestrial biosphere as a whole to act as a net sink in the global carbon budget, while in other years this may not be so. Major questions remain about the size, location, and magnitude of each of these influences, and, most importantly, about whether or not the terrestrial biosphere will continue to act as a significant sink throughout the next century.

The USGCRP is supporting a series of observational studies, such as AmeriFlux, to quantify better the movements of carbon between terrestrial ecosystems and the atmosphere over time. These studies are coordinated with other, similar programs internationally. These programs also are being augmented with measurements of land-cover change to help evaluate changes in the total stock of carbon stored in terrestrial vegetation.

Sustainable Land and Resource Management in a Changing Environment

The agencies represented in the USGCRP have accumulated a great deal of information through studies involving the sustainable management of the Nation's natural resources. For example, case studies and natural resource assessments in such regions as the Columbia River Basin and the Sierra Nevada are providing the land management agencies and their regional partners with important insights into the current stresses on these landscapes. These investigations also are suggesting potential strategies for the long-term management of these systems to ensure their sustainable provision of goods and services.

Case studies in the Columbia River Basin and Sierra Nevada forest ecosystems are providing important insights into potential management strategies for long-term sustainability.

Over the last several years, the USGCRP agencies have initiated several case studies, both in the United States and abroad, of the relationships between ecosystem changes and the human activities related to global change. In 1997, USGCRP-supported research projects on land-cover and land-use change were initiated that specifically involve collaborations among ecologists, social scientists, economists, and remote-sensing experts on issues of importance to global change. While this research is currently in an early stage, it will provide important information on the links between human activities, including economic decisions, and landscape change, and on the social and economic consequences of this change.

3. Integrating Activities: Highlights of Current Developments

The USGCRP supports a number of integrative and cross-cutting efforts that contribute in varying degrees to all of the priority science issues described in Chapter 2. These efforts provide the basis for continuing advancement in scientific understanding and fulfill the U.S. commitment to international leadership in global change research. Integrative and cooperative activities fall into six categories:

1) Observing and monitoring global change
2) Global change data, products, and information services
3) Earth system science
4) Human contributions and responses to global change
5) International research cooperation
6) Global change education and communication.

Observing and Monitoring Global Change

Long-term, high-quality observations of the global environmental system, its natural variability, its past history, and changes that are occurring over a broad range of space and time scales are essential for defining the current state of the system and for establishing a benchmark against which future changes can be compared. This task requires both space- and surface-based systems and networks.

Recent advances in observing, data processing, and communications technologies have provided unprecedented opportunities for the development of an integrated global observing system. At the same time, existing key measurements must be maintained to the extent possible to minimize avoidable gaps in the data records. Such gaps reduce the ability to estimate trends and to predict and assess global change and its associated impacts.

A New Era of Satellite Observations

A new era of satellite observations of the Earth will begin during 1998, as crucial data from the first of several Earth Observing System (EOS) missions start to become available. Significant additional steps will be taken in FY99. The EOS spacecraft are a key component of a long-term coordinated research effort to study the Earth as a global system and the effects of natural and human-induced changes on the global environment. The EOS missions will provide data that will make significant contributions to research being conducted throughout the USGCRP.

Efforts are well underway to develop an Integrated Global Observing Strategy (IGOS). IGOS is being developed to ensure that those nations that are providers of satellite-based and *in situ* measurements work cooperatively to meet the needs of the international

Moving Toward an Integrated Global Observing and Monitoring System

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

research, environmental monitoring, and impact assessment communities as they investigate large-scale environmental issues, such as climate change.

The concept of IGOS arose from the realization that the integration of existing and new worldwide space-based and *in situ* observing capabilities into a coherent system, or family of systems, will most efficiently serve the needs of society while meeting the requirements of the scientific community. IGOS is envisioned as a mechanism to improve coordination between data users—especially those scientists working on projects under the World Climate Research Programme and the International Geosphere-Biosphere Programme—and data providers in the definition and operation of global observing programs. IGOS is being developed to match observational requirements with existing and planned observing systems and to create a forum for national and international agencies to commit to providing specific needed capabilities.

As a first step to test the potential effectiveness of IGOS in ensuring the long-term availability and use of observational data, six prototype projects are being undertaken by the international Committee on Earth Observation Satellites, other data providers, and teams of researchers, working with the International Group of Funding Agencies for Global Change Research. The projects involve observations pertaining to:

- Ocean conditions
- Upper air conditions (winds, temperature, and humidity)
- Stratospheric ozone concentrations
- Forest cover
- Biological activity in the oceans
- Disaster management.

The following subsections highlight major recent accomplishments and plans for FY99.

Space-Based Measurements

Tropical Rainfall Measuring Mission

The first mission in the EOS era, the Tropical Rainfall Measuring Mission (TRMM), is a cooperative program with Japan. The TRMM satellite carries instruments to measure three-dimensional rainfall distribution and total rainfall, cloud distribution, the Earth's radiation balance, and lightning.

TRMM observations will be particularly important for studies of the global hydrological cycle and for testing the ability of models to

simulate and predict climate accurately on a seasonal to interannual time scales, including especially El Niño events. This NASA satellite was successfully launched by Japan in November 1997.

SeaWiFS

Images from the Sea-viewing Wide Field-of-view Sensor (SeaWiFS), launched in 1997 on the SeaStar satellite, are playing a major role in understanding the behavior and consequences of the 1997–98 El Niño event and in other global change research. The SeaWiFS data, which are the first readily available ocean-color data in more than 10 years, provide scientists with a new source of information about the global biosphere.

Images from SeaWiFS, launched in 1997, are playing a major role in understanding the behavior and consequences of the 1997–98 El Niño event and in other global change research.

Ocean color is largely determined by the concentration of microscopic marine plants called phytoplankton. Accurate measurements of phytoplankton concentration from this instrument are important to climate and global change research and to local and regional economic concerns (see Color Plate 6 on page 112). Measurements being taken include observations of coastal blooms of algae, which have been associated with cholera outbreaks around the world. Early detection of these blooms, and subsequent in-water sampling, may allow actions that could significantly reduce the impact of such outbreaks. Red tides, ocean dumping of organic and chemical waste, and, conceivably, oil spills can also be tracked with SeaWiFS data.

SeaStar and SeaWiFS are private-sector enterprises that benefited from a government-industry partnership. This partnership is expected to lead to commercial data applications, such as the development of maps of the changing regions of high biological primary productivity in the oceans that are important for commercial fishing.

EOS AM-1

The EOS AM-1 satellite will carry five state-of-the-art instruments to observe the continents, oceans, and atmosphere and their interactions, including the cycling of water and nutrients in the Earth system. The

satellite, scheduled for launch in June 1998, will simultaneously observe clouds, water vapor, aerosol particles, trace gases, terrestrial and oceanic properties, the Earth's radiation budget, and the interaction between these factors and their effects on the climate system.

These observations are needed particularly to study exchanges of energy and water among the atmosphere, oceans, and land—key processes for understanding global climate change and ongoing changes in ecosystems. The EOS spacecraft are the cornerstone of NASA's Earth Science Enterprise (formerly Mission to Planet Earth).

Landsat-7

Landsat-7 will become the next in the series of U.S. Land Remote-Sensing Satellites. Scheduled for launch in July 1998, Landsat-7, through its seven-channel Enhanced Thematic Mapper Plus instrument, will add to the continuous record of land imagery of previous Landsat flights.

Landsat data provide more than 25 years of continuous data on the condition of the Earth's terrestrial surface, by far the longest calibrated global change data set from satellite remote sensing. Landsat data are crucial for addressing issues of ecosystem mapping, deforestation, and land-cover change. In addition, the data are used in many commercial and environmental monitoring applications.

NASA Scatterometer

The NASA Scatterometer (NSCAT) was launched successfully on Japan's ADEOS Spacecraft in August 1996. Regrettably, ADEOS was lost in June 1997 as a result of solar panel failure. During its period of operation, NSCAT successfully measured global ocean surface winds with very high precision and showed the capability to provide observations that can be used to achieve significant improvements in weather and climate monitoring and prediction. Recognizing the important contributions made by NSCAT, NASA plans to launch a new SeaWinds scatterometer in late 1998 as part of a dedicated mission named QuikSCAT.

National Polar-orbiting Operational Environmental Satellite System

For almost 3 decades, the military and civilian sectors have each had separate operational satellite systems. By providing long-term monitoring

and continuous data sets, these systems have supported needs related to national security and weather prediction, and have provided useful data for climate and global change research.

In 1994, a process to merge the planning, development, and operations of these separate systems was begun. The resulting National Polar-orbiting Operational Environmental Satellite System will satisfy the meteorological needs of both the civil and national security communities.

Atmospheric Chemistry and Aerosols

In 1998, a new version of the Stratospheric Aerosol and Gas Experiment instrument (SAGE III) will be launched aboard a Russian Meteor-3 satellite. SAGE III will provide measurements of ozone, aerosols, and nitrogen dioxide. In addition, the Polar Ozone Aerosol Monitor (POAM) instrument will be launched aboard the French SPOT-4 satellite, providing additional information on atmospheric chemistry at high latitudes.

Surface-Based Measurements

Atmospheric Radiation Measurements

The Atmospheric Radiation Measurements (ARM) program focuses on the improvement of climate prediction and climate parameters by providing data on clouds and their interactions with solar and terrestrial radiation. The effect of clouds on the Earth's radiative energy balance is a major source of uncertainty in climate models. ARM data are obtained through ground-based, airborne (crewed and uncrewed), and satellite platforms.

The Atmospheric Radiation Measurements Program focuses on the improvement of climate prediction by providing data on clouds and their interactions with solar and terrestrial radiation—a major source of uncertainty in climate models.

The ARM Cloud and Radiation Testbed (CART) facility in the U.S. Southern Great Plains became the first operational site in this DOE program in the spring of 1992. The second ARM site, in the tropical western Pacific Ocean, and the third ARM site, on the North Slope of Alaska, began phased operations in 1996 and 1997, respectively.

ENSO Observing System

The El Niño Southern Oscillation (ENSO) Observing System is a composite system of ocean and atmosphere observations in the tropical Pacific Ocean. The system is comprised of four complementary networks: the Tropical Atmosphere/Ocean (TAO) array of deep-ocean moorings; surface drifting buoys; tide gauges; and measurements made on Volunteer Observing Ships (VOS). These measurements of oceanic and atmospheric variables are used in conjunction with remotely sensed measurements from satellites to document what is happening at and below the sea surface.

These networks provide data that form the basis for early warnings of impending ENSO events and for monitoring the events as they progress. The composite system ensures real-time observations of surface and upper ocean temperatures and currents, and of meteorological conditions over the ocean. NOAA, with several international partners, supports the ENSO Observing System.

Atlantic Observing System

The understanding of climate variability in the Atlantic Ocean is not nearly as advanced as the understanding of the ENSO phenomenon in the Pacific Ocean. NOAA and NSF, together with international partners, have begun a pilot program to expand its ocean and atmosphere observations into the Atlantic. The Atlantic Observing System is built from the same proven technologies used in the ENSO Observing System. The data from the Atlantic Observing System are used with data from the ENSO Observing System to improve the integration of global satellite- and surface-based observations. The data also are used to improve the predictive skill of climate forecast models.

The Atlantic system will help monitor ocean conditions in areas of the tropical Atlantic where hurricanes form. Better definition of existing conditions can improve predictions of storm intensity and the tracks of hurricanes approaching the East and Gulf Coasts of the United States, thus helping to reduce the costs associated with evacuations over areas larger than necessary.

Global Cooperative Air Sampling Network

Data from air sampling instruments at a network at about 50 sites around the world document how the concentrations of CO_2 and CH_4,

two important greenhouse gases, are changing. In addition, using a global model, the data can be used to estimate the magnitude and locations of the sources and sinks of these greenhouse gases. NOAA operates this air sampling network.

AmeriFlux

A network of continuous, year-round CO_2 flux measurements across North and Central America (AmeriFlux) is being created to determine the net exchanges of CO_2, water, and energy between the atmosphere and representative ecosystem types. These measurements will better quantify the role of terrestrial ecosystems in the atmospheric CO_2 budget—for example, by observing whether a forest is gaining or losing carbon and providing important information about ecosystem metabolism. A companion flux measurement program has been established in Europe. In the future, data from the two networks will be combined to build a more complete database that can be used to validate global carbon cycle models and to confirm changes in the terrestrial carbon stock in different areas.

An additional network, established by USDA during FY97, continuously monitors net CO_2 fluxes of grasslands at 10 sites in the central and western United States. Data from this network will be used to complement measurements being taken in forested areas.

Ground- and Balloon-Based Ozone Measurement Network

NOAA operates a 16-station, ground-based, global network to monitor changes in the ozone layer. NASA and NOAA also support the regular flights of balloon-based ozonesondes used to measure the vertical distribution of ozone. These measurements are used to determine trends in ozone concentration for the international Scientific Assessments of Stratospheric Ozone Depletion and to validate the performance of satellite instruments. NOAA also operates a network of instruments to monitor the springtime Antarctic ozone hole.

Surface UV Monitoring Network

In 1995, the agencies involved in UV monitoring finalized a plan for a comprehensive and coordinated monitoring network to measure a

range of radiation variables needed in studies of human and ecosystem health and of global change. Implementation of the plans is now well-advanced and a multifaceted and coordinated interagency observation program is in place, with instruments across the United States.

Atmospheric Chemistry Measurements

Several ground-based networks make measurements of concentrations of CFCs and other ozone-depleting compounds and of greenhouse gases. These networks have documented the decrease in concentrations of several compounds regulated under the Montreal Protocol on Substances that Deplete the Ozone Layer. They also have measured increasing concentrations of compounds being used as CFC substitutes.

Global Change Data, Products, and Information Services

Data and information on global change are needed for a wide range of scientific research as well as for the provision of information to policymakers, educators, the communications media, and the public. Data and information to meet these needs cover the physical, chemical, biological, and social sciences.

Data Access Policies

Since 1991, the United States has had a policy of "full and open" access to data developed through global change research and monitoring (see the FY98 edition of *Our Changing Planet*). As a result of a series of threats to this policy, a committee of the National Research Council reviewed the policy and endorsed it in its 1997 report *Bits of Power: Issues of Global Access to Scientific Data.*

The report alerted the scientific community to the potential threat to full and open access to data from a proposed database protection treaty being considered by the World Intellectual Property Organization. The USGCRP agencies played a leading role in bringing the concerns of the scientific community into government discussions. As a result, the proposed treaty is being given further consideration. Maintenance of full and open access to data remains a necessity to ensure the continuing progress of the research enterprise.

Recognizing that valuable data products are developed by researchers not only under Federal contracts but under Federal grants, language was drafted for agencies to use in awarding their grants to ensure that the data that are generated are made available in a timely manner. Such grant provisions would become particularly important if databases were to become protected by law.

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

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

Data and Information Access Capabilities

The interagency Global Change Data and Information System (GCDIS) underwent major expansions in 1997. The GCDIS World Wide Web site may be accessed at <http://www.gcdis.usgcrp.gov>. These expansions include:

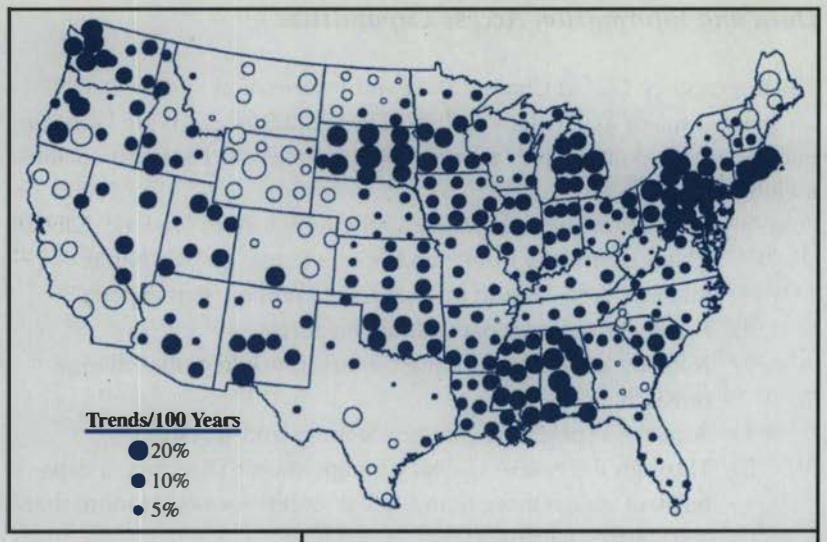
1) A question and answer capability on the Web, "Ask Dr. Global Change," for the public and others to ask global change-related questions and have access to replies from experts
2) Pointers to agency educational resources
3) A listing of agency funding opportunities in global change research
4) A calendar of global change meetings and workshops
5) Through the NASA Global Change Master Directory, a capability to search more than 5,000 data sets located at more than 700 sources worldwide
6) Through the NOAA Environmental Services Directory, a search capability of more than 10,000 NOAA data set descriptions.

The Global Change Research Information Office (GCRIO), which is associated with GCDIS, was established in 1993 to disseminate USGCRP information nationally and internationally. In 1997, GCRIO mailed more than 40,000 copies of publications to people in the United States and 110 other countries, had 100,000 visitors to its World Wide Web site (http://www.gcrio.org/), and responded to 1,200 information requests, about half from educators.

Examples of New Data Products

A DOC/NOAA data set has been developed giving the rainfall intensity and frequency over the United States for the past 100 years. The data show a 5–10 percent increase in the amount of rainfall during this time. Even more importantly, they show that the increase is primarily due to the increased frequency and intensity of severe rainfall events (see Figure 5). Such severe events are a major cause of floods and other damage across the United States.

The DOE Carbon Dioxide Information and Analysis Center (CDIAC) maintains records of how atmospheric carbon dioxide (CO_2) is changing with time. CDIAC has released data products that show that global emissions of CO_2 grew by about 5 percent from 1992 to 1995, and have reached the highest level ever recorded. In addition, the data set containing the Mauna Loa atmospheric CO_2 measurements now



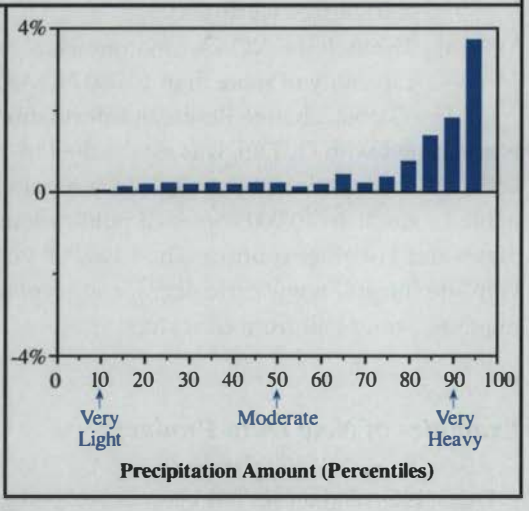


Figure 5: 20th Century U.S. Precipitation Trends. *The map above shows U.S. precipitation trends from 1900 to 1996 (in percent of normal annual precipitation), within state climatic divisions. The diameter of the circle centered within each climatic division reflects the magnitude of the trend. Larger circles have the greater trends. Solid circles reflect increasing precipitation; open circles reflect decreasing precipitation.*

The accompanying histogram shows precipitation trends (in percent per century) for various categories of precipitation amounts (in percentiles) over the contiguous United States, from 1910 to 1996.

Sources: ***Map***

Thomas Karl/NOAA National Climatic Data Center. See Karl, T.R. and R.W. Knight, 1996: Indices of climate change for the United States. Bull. Amer. Meteor. Soc., *77, 279-292.*

Histogram

Thomas Karl/NOAA National Climatic Data Center. See Karl, T.R. and R.W. Knight, 1998: Secular trends of precipitation amount, frequency, and intensity in the USA. Bull. Amer. Meteor. Soc., *in press, February 1998.*

includes information through 1996. This data set began in 1958, and is the world's longest continuous record of the atmospheric concentration of CO_2.

The DOI U.S. Geological Survey created two major global land data sets and made them available over the Internet. These are the first global digital topography and land-cover data sets covering the Earth's entire land surface at 1-km resolution. As a result of these efforts, global change researchers now have a significantly better representation of the Earth's land surface and land cover. These data sets are expected to improve models of Earth system processes. The Global Land Cover Characterization Database was developed from a global 10-day composite of satellite data from the Advanced Very High-Resolution Radiometer (AVHRR) instrument, collected in conjunction with NOAA, NASA, and many international partners. The Global 30 Arc-Second Elevation Data Set was produced in cooperation with NASA, USAID, the UN Environment Programme/Global Reseource Information Database, and other cooperators. See Color Plates 4 and 5 on pages 110 and 111.

The NASA Goddard Space Flight Center produced and is making available a multi-year global atmospheric data set for use in climate research, including tropospheric chemistry applications. The data are well-suited for climate research because they are produced by a stable assimilation system that incorporates weather ballon reports, winds measured from cloud motions, and aircraft, ship, and small rocket flight reports. The system's output data includes all atmospheric prognostic variables and a large number of diagnostic quantities, such as heating rates, precipitation, and fraction of cloud coverage. All quantities are made available for every 6 hours during 1985–1990 on a global grid (2.0 x 2.5 degrees) and at 18 pressure levels up to the stratosphere.

NASA is archiving and distributing ocean color data from the Sea-viewing Wide Field-of-view Sensor (SeaWiFS), which was launched in 1997 on the SeaStar satellite (see Color Plate 6 on page 112).

Appendix E lists a more extensive, yet still only representative, set of data products first made available in 1997 by USGCRP agencies.

Earth System Science

Global environmental changes are the result of a complex interplay among a number of natural and human systems. Understanding the behavior of and interactions among the atmosphere, oceans, land, snow, ice, and life—together referred to as the Earth system—is an exceedingly complex scientific challenge.

The coordinated international research effort that has been organized to understand the Earth system emphasizes a number of areas: the study of the Earth's history to understand the extent and character of natural changes; coordinated field campaigns and process studies to deepen understanding of how the Earth system works; and the development and application of predictive models to understand and project human-induced effects on the Earth system.

Process Studies in Earth System Science

Focused field studies are used to gain a detailed understanding of Earth system processes. Such studies, undertaken around the world, are designed to measure a relatively large number of quantities for use in testing theories of how components of the Earth system interact. The comprehensive nature of these studies is critical to enhancing understanding.

To increase understanding of how the Earth system works, the nations of the world have joined to create the World Climate Research Programme (WCRP) and the International Geosphere-Biosphere Programme (IGBP). These programs, which are coordinated with each other, expand intellectual capabilities and reduce costs for each participating nation through shared contributions. Each of these major activities

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

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

includes more specific sub-activities, creating an interconnected international framework that has greatly accelerated the rate of scientific progress.

There are a number of carefully designed process studies underway. For example, as part of these programs, detailed studies of atmospheric chemistry are being conducted using airborne instruments to measure simultaneously a large number of chemical compounds, aerosol properties, and meteorological quantities. The resulting data are being used to test ideas about such questions as the partitioning of chemical compounds between forms that are more and less reactive in ozone destruction. Studies of the effects of aerosol particles on atmospheric radiation, as well as aerosol and cloud particle characteristics, are being used to test representations of these processes by models. Similarly, field experiments to study the exchange of trace gases between the oceans and atmosphere are using instruments aboard ships to measure simultaneously trace gases in both the ocean surface layer and the atmosphere, as well as quantities relating to the meteorological processes that lead to air-sea exchange.

In focused field campaigns and process studies, a large number of measurements are taken to support testing of theories of how the Earth system works.

Process studies are also of great value in providing the information necessary for the interpretation and application of satellite data, because the studies can be used to relate satellite observations to direct measurements of desired quantities, thereby assisting in calibration of satellite observations. In many cases, satellites provide a much less direct measurement, so ground-, ship-, and aircraft-based measurements can be used to validate the satellite instruments, as well as to test model performance.

The satisfactory interpretation of the data from process-oriented field studies generally requires that fundamental chemical, physical, and biological properties of the underlying processes be understood quantitatively. Laboratory measurements and experiments in controlled environments are carried out to gain such understanding. Measurements in controlled studies also provide a base of information needed for analysis and interpretation of space-based measurements and serve as critical input for predictive models of the Earth system.

Predictive Models of Global Change

The integration, testing, and application of existing and new knowledge produced by the full suite of USGCRP programs is proceeding by

World Climate Research Programme

The WCRP focuses primarily on the physical aspects of the Earth system. Major WCRP research activities, and examples of USGCRP supporting activities, include:

- Global Energy and Water Experiment (GEWEX), within which the USGCRP provides major support for the Continental-Scale International Project (GCIP) and the Atmospheric Measurements Program (ARM)
- World Ocean Circulation Experiment (WOCE), within which the USGCRP provides major support for ocean sampling and analyses
- Climate Variability and Predictability (CLIVAR) program, within which the USGCRP supports studies of seasonal to interannual climate variability and longer term climate change, through focused programs such as the Atlantic Climate Change Program (ACCP) and the Global Ocean-Atmosphere-Land System (GOALS) program
- Arctic Climate System Study (ACSYS), within which the USGCRP supports studies of the role of the Arctic in climate change through focused projects such as the Surface Heat Budget of the Arctic (SHEBA) program
- Stratospheric Processes and Their Role in Climate (SPARC) program, within which the USGCRP has supported extensive studies of stratospheric ozone interactions.

means of both detailed analysis and the development and use of fully coupled and interactive Earth system models. The simulations supported through these programs are an important tool for integrating the results of process studies and observations into a view of the Earth system as a whole.

Both the WCRP and the IGBP sponsor activities promoting international coordination in the development and testing of Earth system models. In this way, WCRP's global climate modelling programs and IGBP's Global Analysis, Interpretation, and Modelling (GAIM) program both help to advance understanding of the climate system.

Over the past 2 decades, relatively limited atmosphere and ocean models have evolved into highly sophisticated models that couple the atmosphere, oceans, land surface, and sea ice, using improved and tested representations of physical and biogeochemical processes. A number

of the coupled models are now becoming able to carry out simulations of the climate extending over centuries, including the effects of human activities.

In spite of these successes, available models still need further refinements to address new science questions and improve their accuracy. Improvements continue to flow from process studies in the four key areas of global change research discussed in Chapter 2. One important improvement needed for all types of global change studies is an

International Geosphere-Biosphere Programme

The IGBP focuses primarily on the chemical and biological aspects of the Earth system. Major areas of IGBP research, and examples of USGCRP supporting activities, include:

- Biospheric Aspects of the Hydrologic Cycle (BAHC), within which USGCRP activities are closely tied to GEWEX
- Global Change and Terrestrial Ecosystems (GCTE), which includes USGCRP activities such as the Program on Ecosystem Research (PER) and the Terrestrial Carbon Processes (TCP) program
- International Global Atmospheric Chemistry Project (IGAC), which is coupled to SPARC and includes USGCRP activities such as the Indian Ocean Experiment (INDOEX)
- Joint Global Ocean Flux Study (JGOFS), which is closely coupled to WOCE and includes such USGCRP activities as the Ocean/Atmosphere Carbon Exchange Study (OACES)
- Global Ocean Ecosystems Dynamics (GLOBEC), within which U.S. activitities are part of the USGCRP as well as NOAA's Coastal Oceans program
- Land-Ocean Interactions in the Coastal Zone (LOICZ), within which U.S. activities are primarily part of NOAA's Coastal Oceans program
- Past Global Changes (PAGES), which covers paleoclimate research activities such as drilling of the Greenland ice core
- Land Use/Cover Change (LUCC), which is a joint IGBP-IHDP activity and includes, for example, research on land-cover change in the Amazon region
- Data and Information Systems (IGBP-DIS), which coordinates the development of data requirements and access to data by the scientific community.

improved ability of models to represent the Earth system's physical and biogeochemical processes at regional-scale resolution. Better representations of a number of physical and chemical processes also are needed, particularly for clouds and aerosol effects.

Climate models also are being improved so they can incorporate observed changes in the concentrations of individual greenhouse gases and aerosols. Models of ecosystems are emerging that can simulate the distribution of vegetation over the world. Of particular importance have been the continuing improvements of vegetation models for the United States as a result of GAIM's VEMAP project (see the back cover illustration of the FY98 edition of *Our Changing Planet*). These and related improvements should generate more realistic simulations of climate change. Spatially resolved carbon cycle models also are being developed that can calculate the fate of CO_2 emissions. Analyses of these simulations, in the context of what is being learned from ongoing process studies, will provide valuable guidance on the most important remaining uncertainties.

Highly sophisticated models are becoming able to carry out simulations of the climate extending over centuries, including the effects of human activities.

Human Contributions and Responses to Global Change

USGCRP agencies conduct a complementary set of programs designed to improve knowledge of the ways that humans, an integral component of the Earth system, contribute and respond to global change. These programs focus on three major forms of interaction:

1) Human contributions to global change
2) The consequences of global change for people
3) Understanding strategies for dealing with global change.

Human Contributions to Global Change

Humans have many different impacts on natural systems, including changes in land use, industrial processes, agricultural and forest management practices, and emissions of air and water pollutants.

Research on the environmental effects of human activities is critical for understanding longer term climate change, changes in atmospheric chemistry, and changes in land cover and ecosystems. For example, increasing amounts of carbon in harvested wood, the "fertilization" effects of increasing atmospheric carbon dioxide on ecosystem productivity, and large reforestation programs may all have a substantial effect on the rate of carbon sequestration in biomass. By planting trees and altering management regimes, foresters can have a significant impact on the atmospheric concentration of carbon dioxide, offsetting some of the emissions from societal activities and land-use change. Additional management opportunities include increased recycling, substitution of biomass combustion for that of fossil fuel, and increased use of durable wood products.

Toward an Understanding of the Human Dimensions

The goal of the human dimensions component of the USGCRP 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 respond to problems associated with environmental change.

The Human Consequences of Global Change

Enhanced short-term climate variability, longer term climate change, the changing composition of gases in the atmosphere, and changes in land cover and ecosystems all have implications for human health and well-being. These consequences include the effects of global change on different economic sectors and on managed resources, such as water resources, agriculture, forestry, fisheries, energy, transportation, financial and insurance services, and coastal infrastructure. Consequences also include the health effects of exposure to ultraviolet radiation, the effects of changes in natural systems on the incidence of diseases, and the factors that increase or decrease societal vulnerability to environmental variability and change.

Enhanced short-term climate variability, longer term climate change, the changing composition of gases in the atmosphere, and changes in land cover and ecosystems all have implications for human health and well-being.

Understanding and modeling the consequences of short-term variations in climate are critical for making more efficient decisions. For example, research has examined a range of options for more efficient fisheries management in the face of El Niño events and has demonstrated the economic value of adjusting these management decisions to incorporate climate variability. Other studies are showing the significant effects of government policies and institutional constraints on the potential use of climate information for better planning in agriculture. Research on the impacts of climate variability is expanding into transportation, public health, forestry management, insurance, and water management. Other studies are evaluating how international trade, cultural practices, public policies, and other social and economic factors come into play in adjusting to climate.

The USGCRP agencies are working to enhance the use of their observing systems, models, and data to explore relationships between human health and changes in climate and the global environment. Research includes studies of heat-wave mortality and winter mortality; the effects of climate change on atmospheric chemistry and the consequences for air pollution and air quality; the relationships between El Niño events and diseases; toxic algal blooms and the relationship between algal blooms and cholera; and the relationship between ultraviolet radiation and the immune system, retinal damage, cataracts, and skin cancers.

USGCRP-sponsored researchers are applying satellite data, geographic information systems, global positioning systems, and computer modeling to the study of diseases such as malaria, Lyme disease, yellow fever, cholera, filariasis and schistosomiasis. The Interagency Research Partnership in Infectious Diseases (INTREPID) is investigating the link between disease and weather patterns, with an initial focus on dengue fever.

The Interagency Research Partnership in Infectious Diseases is investigating the link between disease and weather patterns.

Research on the human consequences of global change is also an integral part of the USGCRP's new National Assessment program. Special emphasis is being placed on identifying and analyzing the consequences of climate variability and change for different geographical regions within the United States and for different economic sectors (see Chapter 4).

Understanding Strategies for Dealing with Global Change

Current and proposed strategies for responding to environmental change comprise an important facet of research on human contributions and responses to global change.

Researchers are developing capabilities to examine the environmental implications of alternative policy approaches and to identify ways to anticipate global change and develop strategies for dealing with it. For example, USGCRP-supported researchers are developing economic models to examine the implications for the global environment of policies relating to international trade. Results from these models can be combined with other analyses to evaluate the implications for sectors of the national economy.

Other USGCRP-sponsored research suggests that perceptions play an important role in determining acceptable strategies. Studies have shown, for example, that many people believe that general environmental pollution causes climate change, without understanding that carbon dioxide released from the burning of coal and oil is the principal driver of climate change. Thus, when asked to list actions that could reduce the risk of climate change, they do not place energy conservation and renewable energy technology high on their lists.

Integrated Assessment Methods and Models

Researchers focusing on human contributions and responses to global change have been improving models and other representations of the complex feedbacks among human and natural systems. Progress has been made, for example, in the development and refinement of methods and models for "integrated assessment."

Research on integrated modeling and assessment of human-environment interactions includes a range of approaches. Integrated assessments use quantitative models and other methods to investigate individual component systems and their interactions, with particular emphasis on how changes in one or more component systems will affect other systems. Integrated assessment models have become increasingly sophisticated in their representation of socioeconomic factors.

International Research Cooperation

International collaboration is a key element of many components of the USGCRP, both because of the complex nature of the Earth system and to help share the costs of research. This collaboration is implemented by agencies and scientists across the breadth of the program. A number of recent developments have reiterated the importance of such collaboration to the United States and to the advancement of scientific understanding.

The International Research Institute for Climate Prediction

In addition to participating actively in the international planning and conduct of research, the USGCRP is involved in extensive coordination to realize the benefits of research. One such effort is the International Research Institute for climate prediction (IRI), which has entered a stage of rapid multilateral development. A number of countries and agencies are taking steps to ensure its long-term sponsorship and management, with fully multilateral status expected in about 2000. Development of a multinational IRI network of research centers and activities to apply the information from forecasts has progressed through a series of regional projects and cooperative planning in the Americas, Africa, and Asia.

In 1997, the International Research Institute began issuing experimental El Niño climate forecast assessments and guidance for several regions of the world.

In 1997, the IRI began issuing experimental climate forecast "net assessments" and guidance as part of the international response to

The U.S. Commitment to Leadership and Coordination

The goal of the international research cooperation component of the USGCRP is to support and assist the program and its participating scientists and their interactions with related international research, observing, and assessment activities. The program continues to support the full and open international sharing of scientific data and results, which is essential for global change research.

anticipated El Niño-related impacts. For example, forecasts were developed for and distributed in Southern Africa, Southeast Asia, and South America.

Regional and Bilateral Cooperation in Global Change Research

In 1997, Vice President Gore and the Prime Minister of Japan indicated the intention of their two countries to expand cooperation in global change research and prediction. The bilateral Joint High Level Committee for Science and Technology agreed to implement such cooperation based on existing arrangements. With substantial Japanese support, the International Pacific Research Center in Hawaii was opened in October 1997, and the International Arctic Research Center in Alaska is expected to open in 1998, for joint research on global change in the Pacific and Arctic regions.

The United States and Japan are expanding cooperative global change research in the Pacific and Arctic regions.

To expand multilateral efforts, the three hemisphere-scale regional institutes for global change research—the Inter-American Institute (IAI), the European Network (ENRICH), and the Asia-Pacific Network (APN)—have all begun implementing programs and have invited research proposals. For example, the IAI has recently issued the fourth of its calls for proposals.

Cooperation in Remote Sensing and Observing Systems

The TOPEX/Poseidon satellite, a cooperative U.S.-France mission, is tracking the ongoing El Niño event of 1997–98. Its measurements of sea-level height allow the development of the event to be followed across the Pacific Ocean.

Cooperation with the Canadian Space Agency on Canada's RADARSAT satellite reached a milestone in 1997, with the completion of data collection for the Antarctic Mapping Mission. These data have made possible the first complete, high-resolution satellite map of Antarctica and will enhance understanding of changes in the Antarctic ice sheet, which holds more than 60 percent of the world's fresh water. (Sea level could potentially rise about 70 meters if this ice were to melt.)

Intergovernmental Panel on Climate Change (IPCC): Current Activities

The IPCC was established with U.S. leadership in 1988. Since then, the IPCC has provided governments, international bodies, and the public with unbiased assessments of scientific and technical information related to climate change. The United States has consistently played a leading role in the IPCC, by co-chairing working groups and by supporting the world's most comprehensive set of climate research activities. Since 1993, the United States has co-chaired Working Group II (on climate change impacts, adaptation, and mitigation), and the USGCRP has sponsored the Technical Support Unit (TSU) for the Working Group.

The IPCC Second Assessment Report provided the scientific basis for the negotiations leading to the Kyoto Protocol to the UN Framework Convention on Climate Change (FCCC).

A U.S. citizen, Dr. Robert T. Watson, has been elected overall Chair of the IPCC, replacing Professor Bert Bolin of Sweden. Professor James McCarthy of Harvard University has been elected Co-Chair of Working Group II, which will assess impacts and adaptation options. The USGCRP will continue to provide support to the Working Group II Technical Support Unit.

Special Reports and Technical Papers

In addition, at the request of the subsidiary bodies of the FCCC, the IPCC, supported by the U.S. Working Group II Technical Support Unit, prepared a special report entitled *The Regional Impacts of Climate Change: An Assessment of Vulnerability*, and technical papers on the following key issues in the negotiations:

1) What technical and policy options are available for reducing emissions in different sectors of the economy? (Technical Paper #1, *Technologies, Policies, and Measures for Mitigating Climate Change*)
2) What impacts are associated with different concentrations of greenhouse gases, and how much might it cost to achieve those concentrations? (Technical Paper #3, *Stabilization of Atmospheric Greenhouse Gases: Physical, Biological, and Socioeconomic Implications*)
3) What greenhouse gas concentrations, temperatures, and sea-level rise would result from some of the proposed emissions reductions being considered at Kyoto? (Technical Paper #4, *Implications of Proposed CO_2 Emissions Limitations*).

IPCC Current Activities (cont.)

An Introduction to Simple Climate Models Used in the IPCC Second Assessment Report also was prepared for the FCCC as Technical Paper #2. USGCRP researchers played leading roles in preparing all of these reports.

The IPCC is in the process of completing a number of additional special reports in response to requests from the FCCC:

1) *Aviation and the Global Atmosphere*, which will provide Parties to the FCCC, Parties to the Montreal Protocol, and members of the International Civil Aviation Organization (ICAO) with a comprehensive assessment of potential impacts of aviation on the global atmosphere, aviation technology, and socioeconomic aspects of aviation
2) *Methodological and Technological Issues in Technology Transfer*, which will provide improved information about the process of technology transfer as a basis for Parties to the FCCC and others to take advantage of opportunities to address global climate change
3) *Emissions Scenarios*, which will contain an improved set of greenhouse gas emission projections for use in the Third Assessment Report, thus increasing the relevance of the report to policymakers. Special efforts will focus on improving projections of aerosol emissions.

The USGCRP is participating in the efforts to complete these projects.

Third Assessment Report

The IPCC is preparing to write the Third Assessment Report (TAR), which is scheduled for completion in late 2000 or early 2001. Climate scenarios based on model results from Atmosphere-Ocean General Circulation Model (AOGCM) experiments from four centers—the Canadian Centre for Climate Modeling and Analysis (CCCMA), the Deutsches Klimarechenzentrum (DKRZ/MPI) in Germany, the NOAA Geophysical Fluid Dynamics Laboratory (GFDL) at Princeton University, and the Hadley Centre in the United Kingdom—are being compiled and will be made available in several formats for use in analyses of impacts of climate change in preparation for the Third Assessment Report.

For the Third Assessment Report, improvements in the review process are being made, as are efforts to involve more

IPCC Current Activities (cont.)

actively technical experts from the private sector in assessments of the market and technological potential of promising technologies for reducing emissions. The USGCRP will actively support preparation of the Third Assessment Report.

For further information about the IPCC, please contact the U.S. Coordination Office, Intergovernmental Panel on Climate Change, 400 Virginia Avenue, SW, Suite 750, Washington, DC 20024. Fax: 202 488-8678. E-mail: ipcc@usgcrp.gov.

A U.S.-Japan collaboration, the Tropical Rainfall Measuring Mission (TRMM), has led to orbiting of the first instrument dedicated to studying tropical and subtropical rainfall. The TRMM satellite was launched successfully in November 1997 (see Color Plate 7 on page 113).

The international Committee on Earth Observation Satellites (CEOS) and the International Group of Funding Agencies for Global Change Research (IGFA) continue their planning for a series of six pilot projects for integrated observation of the global environment. Such cooperative efforts reduce duplication and costs among missions planned by the space-faring nations.

The IPCC Second Assessment Report provided the scientific basis for the negotiations leading up to the Kyoto Protocol to the UN Framework Convention on Climate Change (FCCC).

Climate Research

The widely attended Scientific Conference for the World Climate Research Programme (WCRP) in 1997 reviewed the results of recent climate change research and recommended that priorities for such research over the next decade should be (see discussion of WCRP in Earth System Science section):

1) To study seasonal-to-interdecadal variations both globally and regionally to develop the soundest possible scientific basis for climate prediction
2) To detect climate change and its causes and project the rate of human-induced climate change.

Global Change Education and Communication

Current Agency Initiatives

Many of the USGCRP agencies are engaged in efforts to increase public awareness of how the Earth system is changing.

EPA, for example, has been sponsoring educational efforts that emphasize the scientific assessment of climate change, its causes and potential impacts. Outreach efforts focus on communities and groups potentially at risk from climate change, including coastal communities, people at risk from heat waves, communities potentially affected by the spread of infectious diseases, business sectors at risk from the costs of severe weather events, and groups potentially affected by impacts on wildlife and outdoor recreation. EPA is hosting a series of regional global climate change conferences around the country, focused on helping citizens and organizations identify measures they can take to reduce emissions and thereby slow future climate change.

NOAA, NASA, NSF, DOE, and EPA support the periodical *Consequences: The Nature and Consequences of Environmental Change.* In addition, NOAA produced and released the fourth in its "Reports to the Nation on Our Changing Planet" series, entitled *Our Changing Climate.* This report describes and explains the human forcing of climate change in the context of a naturally varying Earth system. It is being distributed with a teacher's guide to science teachers and other educators nationwide. NOAA also has produced a Spanish-language version of its popular monograph *El Niño and Climate Prediction.*

NASA conducts an ongoing education and outreach program focused on promoting a broad public understanding of Earth system science and climate change. NASA is currently developing a series of regionally oriented educational materials focused on climate change and its specific regional impacts. This material will be based on the information being generated by the National Assessment.

Encouraging Global Change Science Literacy

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 education on a wide range of global environmental change issues.

The USGCRP on the World Wide Web

The USGCRP home page on the World Wide Web (http://www.usgcrp.gov/) is a gateway to a wealth of global change information. The Web site provides access to:

1) An introduction to the USGCRP, with links to detailed information about U.S. Government agency programs related to global change research, USGCRP-sponsored research institutions, and related international programs.
2) The U.S. Global Change Research Information Office (GCRIO) Web site. GCRIO provides access to data and information on global change research, adaptation and mitigation strategies and technologies, and educational resources related to global change.
3) The Intergovernmental Panel on Climate Change (IPCC) and its publications.
4) The Global Change Data and Information System (GCDIS). GCDIS, a cooperative activity of USGCRP agencies, is a collection of distributed information systems that provide global change data to scientists and researchers, policymakers, educators, industry, and the public.
5) Global change and environmental education resources. Multidisciplinary and international in scope, this collection includes a wide range of resources on global change and environmental education in a variety of formats for educators and students at all levels (K–12 and higher education), librarians, citizens, and community groups.
6) USGCRP-related documents and official statements, including the text of the annual editions of *Our Changing Planet* from FY95 through FY98.
7) Summaries of all presentations made as part of the USGCRP Seminar Series.
8) Many other global-change-related Web sites around the world, including sites focused on data sources, observing programs, weather-related issues, seasonal variations, long-term climate change, stratospheric ozone and atmospheric chemistry, ecosystems, and general sources of information.

USGCRP Seminar Series

Each month the USGCRP sponsors a seminar on a current global change research topic that is of current interest. At the seminar, which is held on Capitol Hill as a means of drawing a wide audience from the Washington, DC, community, one or two scientists present recent findings from their own research and that of the broader scientific community and answer questions ranging from scientific methods to the policy implications of their work. Recent seminar topics have included:

1) Observed Climate Change in Alaska: The Early Consequences of Global Warming
2) Global Warming and the Earth's Water Cycle: What Do the Changes Mean and Why be Concerned?
3) The 1997–98 El Niño Forecast: What are the Societal Implications and Opportunities?
4) Wetland Losses in the United States: Scope, Causes, Impacts, and Future Prospects
5) Antarctic Update: An Ecosystem Perspective on Ultraviolet Radiation and Climate Change Impacts
6) Natural Hazards, Human Impacts, and Disaster Reduction.

For information on this series, contact the USGCRP Coordination Office (see Appendix F for contact information).

4. National Assessment of the Consequences of Climate Change for the United States

In 1997, the Subcommittee on Global Change Research (SGCR), which coordinates the U.S. Global Change Research Program, initiated a national, scientifically based assessment of the consequences of climate change and climate variability for the people, environment, and economy of the United States. This assessment will provide an opportunity to foster the participation of people who use global change information throughout the country and to enhance their ability to plan for and cope with climate changes and variations.

Approach of the Assessment: Regions, Sectors, and National Synthesis

The National Assessment process has been designed to create a continuing dialog among government, business and industry, labor, non-profit organizations, the scientific research and education communities, and the public. A multi-pronged approach will be used to generate the needed information about the implications of climate change and variability for the United States:

1) *Regional* assessment activities will focus on the issues of most importance at the regional level across the United States. As an initial step, 20 workshops, encompassing every state and territory, are identifying the distinctive regional characteristics and potential consequences of climate change and variability (see the table in Chapter 1, and Color Plate 8 on page 114).

Goal of the National Assessment

The goal of the National Assessment is to determine the local, regional, and national implications of climate change and climate variability within the United States in the context of other existing and potential future environmental, economic, and social stresses. Of particular importance is understanding the regional mosaic of what has been and will be occurring as a result of global change.

2) *Sectoral* assessment activities will focus on issues that are national in scope and related to the goods and services on which people, society, and the economy depend. Initially, sectors being considered include food availability; water availability; human health; forests; ecosystem services; urban activities and services; and commerce, industry, and trade.
3) *National* synthesis activities will identify common themes and core issues concerning the implications of long-term climate change and variability for the United States. These findings will be integrated and consolidated into a synthesis report that will serve as a national summary for decisionmakers.

To promote consistency and coherence across the regions and sectors, a series of guideline scenarios will be prepared that estimate how the Nation is expected to develop economically, demographically, and technologically over the next 25 to 100 years. A series of scenarios also will be developed that define a range of changes in climate, resource use, and ecosystem distribution so that the potential consequences of long-term climate change for the United States can be evaluated.

Critical Questions

In conducting the regional workshops leading into the assessment, four fundamental questions are being posed:

1) What are the current environmental stresses?
2) How will projected changes in climate and climate variability exacerbate or ameliorate existing stresses, or introduce new stresses (see Figure 6)?
3) What information is needed to provide better and more certain estimates of the consequences of climate change and variability?
4) What strategies may help the region or sector cope with the anticipated consequences of changes in climate? What opportunities exist for win-win solutions and approaches?

Organization

The Global Change Research Act of 1990 mandates the preparation of scientific assessments of global change. The National Assessment will be a core activity of the USGCRP. The USGCRP's conduct of the assessment will be overseen by the National Science and Technology Council and the Office of Science and Technology Policy.

Southeast: Lessons Learned from El Niño Events Should Help Farmers Adjust to Climate Changes Caused by Emissions of Greenhouse Gases

The El Niño-Southern Oscillation (ENSO) signal is quite pronounced in the southeastern United States. Studies of the relationship between El Niño and agricultural production in the region are helping farmers adjust to changing climate conditions, providing an example of how a better understanding of these short-term, interannual climate variations may help those who will be affected in the future by climate change.

Central Great Plains: Turning Problems into Solutions

The agricultural sector in the Great Plains faces a number of challenges. Farmers and ranchers must cope with extreme weather events—floods, droughts, blizzards, hail storms, tornadoes, and others—that might become more severe and frequent in the future. They also are working to reduce runoff of crop and animal wastes into water supplies and to slow the loss of soil to erosion.

But theirs is not a message of despair. Already they are developing and implementing sustainable land practices, both because these practices increase their incomes and because they protect the environment. One example of such a win-win solution occurs when ranchers supplement their incomes by converting animal wastes into marketable biomass fuels, which simultaneously reduces the amount of the greenhouse gas methane released into the atmosphere. Likewise, by increasing the carbon content of the soils and thus pulling carbon dioxide from the atmosphere, farmers are adding to the resilience of their fields to drought, whether natural or enhanced by climate change.

Southwest: Meeting the Water Needs of a Rapidly Growing Population

Communities in arid and semi-arid environments of the Southwest are especially sensitive to impacts on water resources. They depend on access to adequate supplies for their people and their agriculture, but are at risk to the extremes of flood and drought cycles. Most water in the Southwest comes from melting snow in the Rocky Mountains or underground aquifers. As population in the region increases, overuse is depleting the aquifers and climate change is expected to affect the amount of water from snowmelt. At the same time, rising temperatures over land could intensify the strong convective storms that can occur in the Southwest. Understanding how all of these factors interrelate would provide the information needed by regional decisionmakers to consider options and develop plans for meeting societal needs.

As the USGCRP conducts the National Assessment, a number of public-private partnerships will be established with the intent of creating a collaborative network of decisionmakers, scientists, and other interested parties. Those partnerships will underlie a continuing process that will produce periodically updated, scientifically based evaluations and summaries of current understanding.

The assessment process will be designed to be comprehensive and integrative, to couple research by scientists with specific policy-relevant needs of stakeholders, to ensure scientific excellence and credibility, to be open to broad participation, and to provide planners, managers, organizations, and the public with information they will need to cope with natural climate fluctuations and projected climate changes.

Products of the National Assessment Process

A series of summary reports will describe the consequences of climate change and variability for regions and sectors. These will be based on

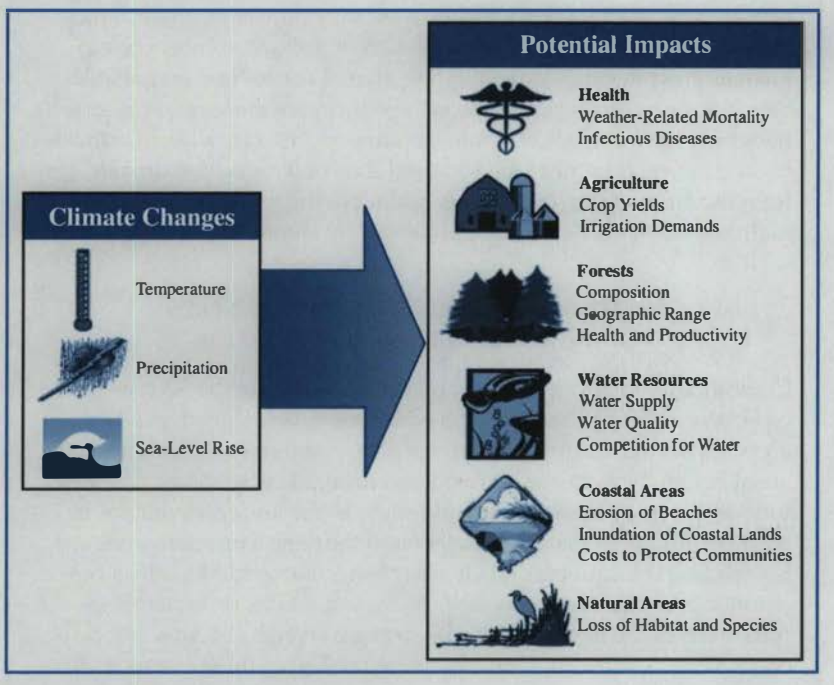


Figure 6: Potential Climate Change Impacts. *Schematic diagram illustrating the types of consequences that can result from changes in the most critical climate parameters.*

Northwest: Adjusting Planning for Columbia River Water Management

The Columbia River is the lifeblood of the Northwest. Variations in climate already require management of competing water demands along the river system in order to protect fisheries while providing water for irrigation, hydroelectric power, and communities. Changes in the seasonal timing and amount of precipitation are expected to affect the timing of peak runoff and river discharge, creating a potential mismatch between water supplies and user needs. Understanding these changes would provide opportunities for the various sectors to adjust by improving irrigation efficiency, changing crops, and developing alternative energy sources.

New England: Reducing Emissions Improves Air Quality

Because the upstate New York and New England region is downwind from emissions from industrial, utility, and transportation sources in the rest of the United States and parts of Canada, the quality of life there is threatened by poor air quality. If CO_2 emissions were reduced, the region would see benefits far beyond the prevention of climate change. Emission reductions would help abate the region's air pollution and acid rain, while improving visibility during summer months. Improving the gas mileage of automobiles, via new hybrid technologies and other innovative approaches, as well as conversion of midwestern power production facilities to alternative energy sources, would result in lower levels of nitrogen oxides, sulfur dioxide, organic compounds, and tropospheric ozone affecting the region. Human health would benefit immediately from emission reductions; the health of the region's ecosystems also could benefit, and healthier forests would take up more CO_2 from the atmosphere.

Alaska: Already Experiencing Warming

Alaska has warmed about 5°F over the past 30 years and this warming is already having a significant influence. Warmer days can bring more personal comfort and longer farming seasons, but they also affect fisheries and cause a thawing of the permafrost layer. This thawing is particularly significant because it results in damage to buildings, roads, railroads, and other infrastructure, while also causing slumping in forests that leads to their transformation into wetlands. Drier summers have reduced forest health, leading to an increase in forest fires and in insect infestation. Alaska is faced with developing the means to cope with what may prove to be the most pronounced climate change in the United States.

more detailed findings and documentation published by each regional or sectoral assessment activity. The set of summary reports will be accompanied by a synthesis report that provides an overview and integration of the regional and sectoral reports. The first series of assessment reports will be completed in late 1999. These reports will point to many issues requiring elaboration as part of the continuing research and assessment process.

Integration with USGCRP Research Activities

To support the various assessment activities, a significant USGCRP priority will be an assessment-oriented research agenda as well as a strong, broadly based research program aimed at improving fundamental understanding of the Earth system. A number of agencies already have regional research and assessment programs underway, and additional activities are being planned by a broader set of USGCRP agencies.

Ensuring Scientific Credibility and Relevance

An open and inclusive process that encourages the participation of the most qualified scientific, technical, and socioeconomic experts will

Mid-Atlantic Region: Protecting the Coastal Zones

In the Mid-Atlantic region, climate change could have profound effects on human health, ecosystems, and outdoor recreation because of the region's unique combination of geography, aging infrastructure, economic structure, population density, and mixed land use. One of the prime issues for the Chesapeake Bay is sea-level rise. Past rises have caused coasts to erode, threatened homes, narrowed recreational beaches, and eroded wetlands and bay beaches that are important habitat for birds and fish. Information is needed to evaluate new construction or re-building within areas of high risk from natural hazards (e.g., zones prone to flooding, coastal storms, or tidal surges), and to determine the best means of protecting ecosystems and infrastructure. One of the most important elements of a response strategy would be the communication of climate change projections to improve land-use and drought planning efforts and strategies for managing water across regional or local districts.

Northern Great Plains: Rebuilding after Flood

The April 1997 flood of the Red River washed out homes and businesses that had been in Grand Forks, North Dakota, and East Grand Forks, Minnesota, for generations. The disaster was expected to occur, at least on the average, only once every 500 years. But now Mayors Pat Owens of Grand Forks and Lynn Stauss of East Grand Forks face a new uncertainty as they rebuild their cities. Will floods of this magnitude occur more frequently in the future? If so, what level of protection must be provided? Can dikes or diversion channels be built to withstand even greater floods? No one is quite certain how severe or how frequent future floods—or their opposites, droughts—will be. But the climate change that is already underway is likely to change the pattern of storms and spring melts in this region. The historical pattern of seasonal river flows might change as well.

For Mayors Owens and Stauss, climate change is a current issue. Displaced people and businesses need decisions now on how close to the river they can build and what level of protection will need to be provided. These decisions affect future generations as well. To protect lives, property, and livelihoods for residents both today and tomorrow, the two mayors need the best possible information about future climates.

ensure the credibility of the National Assessment reports. Draft assessment reports will be subject to an open and wide-reaching review process, and well-documented and reviewed alternative interpretations will be accommodated. Continuing and close involvement of stakeholders and decisionmakers will ensure relevance to policymakers. Internal and external evaluation processes will ensure that the continuing series of assessment activities and reports present a clear and fair depiction of scientific understanding and stakeholder interests and needs.

Outreach and Communication

The value of the assessment process will depend on communicating the findings and lessons emerging from the dialog among the many and diverse stakeholders and scientific communities. The U.S. Climate Forum, held at the Department of Commerce on November 12–13, 1997,

was the first major step to encourage nationwide participation in the assessment process. Assessment activities, workshop reports, and analytic findings will be communicated broadly through the media, the World Wide Web, and other channels. Reports will be made widely and inexpensively available. Outreach also will occur through programs that target both the formal (i.e., school-based) and informal (i.e., museum, park, and community-based) educational communities.

APPENDIX A

THE PROPOSED USGCRP BUDGET FOR FY99

The proposed FY99 USGCRP budget totals $1.864 billion. As outlined in this edition and in the FY97 and FY98 editions 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 aquatic ecosystems.

The USGCRP budget also supports cross-cutting activities, including observing and monitoring global change; global change data, products, and information services; research on Earth system science and on human contributions and responses to global change; international research cooperation; and global change education and communication.

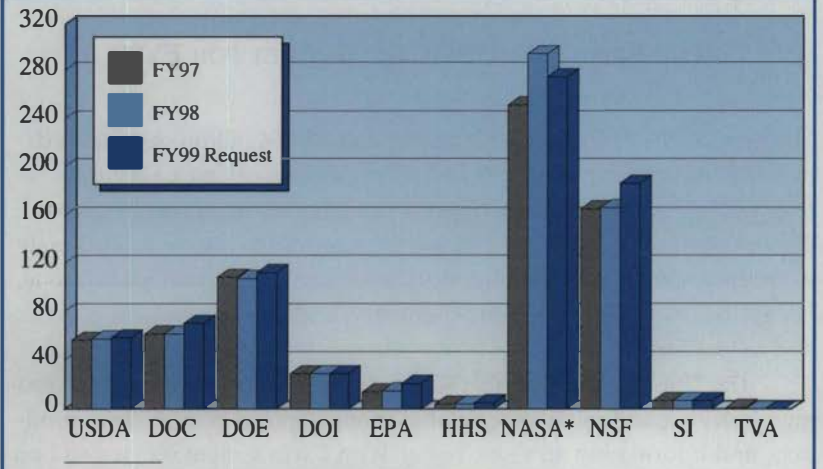
The figure and tables in Appendix A provide the following:

- USGCRP budget for FY97–FY99 by department and agency
- USGCRP budget for FY97–FY99 by budget function

The table below showing the USGCRP budget for FY97–FY99 by department and agency presents the USGCRP budget in two broad components: Scientific Research and Space-Based Observation Programs. This distinction is intended to make clearer the portion of the USGCRP budget that supports scientific research by individual investigators and small groups, as compared with the portion that supports NASA's Earth Science program components relating directly to space missions—particularly the Earth Observing System series of satellites and data information systems, which provide data in support of research activities.

Of the total USGCRP FY99 budget request, 59% supports Space-Based Observation Programs while 41% supports Scientific Research. The FY99 request for $767 million for Scientific Research is a 3% increase above the FY98 budget level. The $1.097 billion request for Space-Based Observation Programs is a 2.3% reduction from the FY98 budget level.

USGCRP Budget for FY97–FY99
by Department and Agency
(dollars in millions)



*Includes only the NASA USGCRP-related scientific research budget.

Agency	FY97	FY98	FY99 Request
Scientific Research[a]			
Department of Agriculture (USDA)	57	58	59
Department of Commerce (DOC/NOAA, DOC/NIST)	62	62	71
Department of Energy (DOE)	109	108	113
Department of the Interior (DOI)	29	29	29
Environmental Protection Agency (EPA)	14	15	21
Department of Health and Human Services (HHS)	4	4	5
National Aeronautics and Space Administration (NASA)	252	275	275
National Science Foundation (NSF)	166	167	187
Smithsonian Institution (SI)	7	7	7
Tennessee Valley Authority (TVA)	1	0	0
Scientific Research Subtotal	**701**	**725**	**767**
Space-Based Observation Programs			
National Aeronautics and Space Administration (NASA)	1117	1092	1097
U.S. Global Change Research Program Total	**1818**	**1867**[b]	**1864**

[a]The Department of Defense sponsors research with applications to national security needs, but is also relevant to stated goals of the USGCRP. The DOD budget in FY97–FY99 for defense-related research that contributes to USGCRP activities follows: FY97—$10.8M ($4.9M above request); FY98—$6.5M ($0.8M above request); and FY99—$6.7M. The Department of Transportation supports assessment efforts in the transportation sector that are relevant to the stated goals of the USGCRP.

[b]The FY98 USGCRP total includes $50M in the NASA budget to be transferred to the International Space Station, if necessary.

FY97–FY99 USGCRP Budget by Budget Function

Budget Function	Budget Function #	FY97	FY98	FY99 Request
General Science, Space, and Technology	250			
National Aeronautics and Space Administration (NASA)		1369	1367	1372
National Science Foundation (NSF)		166	167	187
Energy	270			
Department of Energy (DOE)		109	108	113
Tennessee Valley Authority (TVA)		1	0	0
Natural Resources and Environment	300			
Department of Agriculture (USDA/FS and NRCS)		18	18	18
Department of Commerce (DOC/NOAA and NIST)		62	62	71
Department of the Interior (DOI)		29	29	29
Environmental Protection Agency (EPA)		14	15	21
Agriculture	350			
Department of Agriculture (USDA/ARS, ERS, and CSREES)		39	40	41
Smithsonian Institution	503			
Smithsonian Institution (SI)		7	7	7
Health	550			
Department of Health and Human Services (HHS)		4	4	5
Total		**1818**	**1867[b]**	**1864**

[b]The FY98 USGCRP total includes $50M in the NASA budget to be transferred to the International Space Station, if necessary.

APPENDIX B

FY97-FY99 USGCRP BUDGET BY AGENCY AND PROGRAM

Appendix B includes budgets 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." For each agency, a "FY99 Program Highlights" section briefly outlines some of the key USGCRP-related activities proposed for the coming year. In addition, the agencies conduct a broad range of "Related Research," as indicated, funding for which is not included as part of the USGCRP budget because the research is conducted primarily for other purposes.

The resources allocated to specific programs within agencies as reflected in these tables for FY98 appropriated funds and the FY99 budget request are estimates only, and are subject to change based on decisions on scientific and programmatic priorities among USGCRP agencies and their advisory bodies and on the input of the national and international scientific communities.

Each agency budget also includes a "Mapping of Budget Request to Appropriations Legislation." The entry for each department or agency points to the location (or 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 global change research activities are funded by seven 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.

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 validation of satellite measurements.

USDA	Program Title	FY97 Actual	FY98 Estimate	FY99 Request
ARS	Agriculture and Rangeland Global Change	11.6	12.1	11.3
ERS	Economics of Global Change and Agriculture	0.8	0.8	0.8
FS	Forest Global Change	16.9	16.9	16.9
CSREES	Improved Response Models	10.6	10.6	10.6
ARS	Methyl Bromide Research	14.6	14.9	16.6
NRCS	Soil Carbon Studies	1.2	1.2	1.2
CSREES	UV-B Monitoring Network	1.6	1.0	1.6
	Total	**57.3**	**57.5**	
	President's Request	56.7	62.1	**59.0**

ARS Agricultural Research Service
CSREES Cooperative State Research, Education, and Extension Service
ERS Economic Research Service
FS Forest Service
NRCS Natural Resources Conservation Service

FY99 Program Highlights. The goals of the ARS global change research program are to document and mitigate impacts of global change on agricultural and rangeland ecosystems, to assess agriculture's role as a contributor to the causes of global change, and to provide policymakers and agricultural producers with sound scientific information upon which to base their decisions. In FY99, the research will continue to focus on four broad areas: 1) Experimental determinations of the direct effects of rising atmospheric CO_2 levels, increasing temperatures, and their interaction with the physiology and performance of crop plants and with ecosystem processes that control productivity of grazing lands; 2) carbon and nitrogen cycling and fluxes between the terrestrial surface and the atmosphere, including sequestration of carbon in soils and vegetation; 3) changes in hydrological processes associated with climate change that may impact water quality, efficiency of use by crops, and availability for industry, urban use, and irrigated agriculture; and 4) the development of a suite of simulation models with required inputs for predicting responses of crops, watersheds, and managed ecosystems to global change.

CSREES is responsible for administration of USDA extramural research in partnership with the Land Grant University System. A major component of the Agency's FY99 global change research is continued development of a UV-B Monitoring Network. The purpose of the network is to provide USDA and the agricultural community with information necessary to determine whether changing levels of UV-B have an effect on food and fiber production in the United States. CSREES's National Research Initiative Competitive Grants (NRICG) program also supports fundamental and mission-linked

research, which is designed to increase our understanding of the possible impacts of global environmental change on the sustainability of agriculture and forestry. Research projects are supported that will reduce uncertainty regarding the effects of possible changes in temperature and precipitation patterns, rising CO_2 levels, and altered radiation (including UV-B) on crop productivity, natural resources, hydrological processes, and water availability. The NRICG solicits global change research in four programs: 1) Plant Responses to the Environment; 2) Forest/Range/Crop/Aquatic Ecosystems; 3) Soils and Soil Biology; and 4) NSF/DOE/NASA/USDA/EPA Joint Program on Terrestrial Ecology and Global Change (TECO).

In FY99, ERS will continue efforts to improve understanding of the economics of global change and agriculture. Global modeling and analysis will focus on agricultural links to biodiversity, land-use change, and the ability to satisfy increased demands for agricultural goods and services while minimizing damage to the world's natural resources. Farm-level analysis will focus on the role of learning in adaptation.

Forest Service global change research seeks to establish a sound scientific basis for making regional, national, and international resource management and policy decisions in the context of global change issues. Studies are currently being conducted to determine how atmospheric changes and potential climatic change may affect forest productivity, forest health, and species distributions. Ecosystem-scale experiments involving increased CO_2 and other environmental factors have begun at several sites representing major U.S. forest types. As the uncertainty in model predictions is reduced, analysts may begin to describe likely socioeconomic effects of global change on forests in the various regions of the United States. For example, the Mapped Atmosphere-Plant-Soil System simulates ecosystem distribution and function under current and potential future climates. Forests in the conterminous United States could experience partial decline or massive dieback over as much as 40–85% of their distribution. The Forest Health Monitoring Program aids global change research by establishing a long-term set of information describing changes and trends in forest ecosystems, helping scientists detect the effects of global change and other factors over time.

NRCS provides technical and financial assistance in conjunction with conservation partners to managers of privately owned lands for the conservation and wise use of natural resources. In the context of global change, impacts affecting nutrient cycling, animal waste management, air quality, hydric soil environments, soil carbon sequestration and dynamics, and the extent and role of permafrost-affected soils are studied as part of terrestrial ecosystem dynamics.

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 under 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 under 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 under 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's global change efforts are designed to provide a predictive understanding of the climate system and its modes of variability, and to advance the application of this information in climate-sensitive sectors through a suite of process research, observations and modeling, and application and assessment activities. Specifically, NOAA's research program includes ongoing efforts in operational *in situ* and satellite observations with an emphasis on oceanic and atmospheric dynamics, circulation, and chemistry; understanding and predicting ocean-land-atmosphere interactions, the global hydrological cycle, the role of ocean circulation, and biogeochemical dynamics in climate change; improvements in climate modeling, prediction, and information management capabilities; the projection and assessment of seasonal to interannual and decadal to centennial climate changes; the study of the relationship between the natural climate system and society; and archiving, management, and dissemination of data and information useful for global change research. NIST research is developing the science base to predict the fate and disposition of chemicals in the environment, environmentally benign alternatives, and measurement techniques for key environmental species in the atmosphere.

DOC	Program Title	FY97	FY98	FY99 Request
NIST	Global Change	1.4	2.4	9.4
NOAA	Aerosols Project	1.2	1.1	1.1
NOAA	Atmospheric Chemistry Project	6.8	6.8	7.0
NOAA	Climate Change Data and Detection	4.2	4.0	4.1
NOAA	Climate Dynamics and Experimental Prediction	13.3	15.6	16.1
NOAA	Climate Observations	10.0	6.1	6.4
NOAA	Climate Variability (CLIVAR-GOALS, ACCP/WOCE)	10.7	10.6	11.0
NOAA	Economics and Human Dimensions of Climate Fluctuations	1.4	1.8	1.9
NOAA	Global Energy and Water Cycle Experiment (GEWEX)	5.0	5.2	5.4
NOAA	Health of the Atmosphere*	0.7	0.7	0.7
NOAA	Ocean-Atmosphere Carbon Exchange Study (OACES/IGOFS)	2.7	4.1	4.2
NOAA	Paleoclimatology (PAGES)	4.0	4.0	4.1
	NOAA Subtotal	**60.0**	**60.0**	**62.0**
	Total	**61.5**	**62.4**	
	President's Request	70.9	62.3	**71.4**

*Not formally part of the NOAA Climate and Global Change Program; funding is transferred to the NOAA Health of the Atmosphere Program.

NIST National Institute of Standards and Technology
NOAA National Oceanic and Atmospheric Administration

FY99 Program Highlights. In FY99, NOAA will continue to advance understanding of 1) the study of the dynamic climate system and its modes of variability, for example the El Niño Southern Oscillation (ENSO) and the North Atlantic Oscillation (NAO); and 2) the application of information generated by this research to decision-making processes in climate-sensitive regions and sectors, such as agriculture, water management, hydropower, human health, and transportation infrastructure.

The influence of the Atlantic Ocean on climate is thought to be as important as the ENSO, yet the understanding of Atlantic modes of variability is not nearly as advanced. NOAA, together with international partners, is expanding ocean-atmosphere observations into the Atlantic in a pilot mode. The Atlantic Observing System is built from the same proven technologies used in the Pacific ENSO Observing System.

In FY99, the Global Ocean-Atmosphere-Land System (GOALS) research project will continue its priority research to improve the understanding, modeling, and prediction of ENSO, its teleconnections globally beyond the tropics to the extratropics, and its variability from decade to decade. A significant new research thrust is being mounted to improve regional-scale modeling and prediction of seasonal to interannual variability over North America.

During FY99, the current phase of the GEWEX Continental-scale International Project (GCIP) will begin moving to its fourth and final area, the Missouri River Basin. The work will complement other ongoing studies in the eastern Mississippi River Basin aimed at developing ways of using climate forecasts in water management at both the local and state levels and in a major national water management agency such as U.S. Army Corps of Engineers.

The Ocean/Atmosphere Carbon Exchange Study (OACES) focuses on measuring the transfer of CO_2 between the atmosphere and the ocean, to reduce the uncertainty in ocean uptake and air-sea exchange, both seasonally and spatially. These oceanographic and atmospheric data are then used to constrain models of the global carbon cycle. FY99 plans include completion of the global ocean CO_2 survey, with a focus on the influence of the North Atlantic on the global carbon, freshwater, nutrient, and heat budgets.

The overarching goal of the Atlantic Climate Change Program (ACCP) is to understand and model the long-term variability of the North Atlantic Oscillation and tropical Atlantic variability, and offer ways to monitor and forecast the evolving state of these two phenomena, including their influence on the neighboring continental regions.

Applied Research Centers are implemented as part of the Climate Dynamics and Experimental Prediction (CDEP) program element. Prediction research is developing both a suite of state-of-the-art climate models and mechanisms for integrating the output of multiple models into a single prediction system for the International Research Institute (IRI) for Climate Prediction and the National Weather Service.

The Climate Change Data and Detection (CCDD) program element supports data assembly, processing, inventory, distribution, and archiving for a variety of national and international programs. Planned activities include the development of data sets tailored to the study of natural hazards and extremes in weather events, the enhancement of the Nation's ability to monitor critical aspects of climate change by ensuring the integrity of the long-term climate record, and support for producing new and/or improved data sets for the next major scientific assessment of the Intergovernmental Panel on Climate Change (IPCC).

To enhance the use of paleoclimatic data in making improved climate predictions, NOAA's Paleoclimatology efforts are particularly being directed toward a detailed study of the climatic variability of the last 400 years (globally) and the last 1,000 years (where possible), and a comprehensive study of climate variability given climatic states and forcing that are significantly different from today.

The Aerosols Program seeks to provide improved information about the radiative forcing of human-influenced particles on the climate system in order to aid the detection and attribution of climate change, in particular, the estimation of the offset that anthropogenic aerosols may be providing to the greenhouse-gas-induced warming, and the prediction of future climate changes for various radiative-forcing scenarios, all in collaboration with other organizations and agencies. FY99 activities will continue to focus on reducing the uncertainties in the direct radiative forcing by tropospheric aerosols through an integrated program of monitoring, process, and closure studies, and modeling.

The Atmospheric Chemistry Program seeks to improve the predictive understanding of ozone-depletion and greenhouse-warming issues via integrated global measurements, laboratory studies, and theoretical modeling, and to help lead in the assessment of the research information. FY99 activities will focus on scientific issues associated with the "rehabilitation" of the stratospheric ozone layer anticipated by the Montreal Protocol, and improving the quantification of the radiative forcing associated with greenhouse gases in view of the information needs of the Climate Convention.

In FY99, the Economics and Human Dimensions of Climate Fluctuations program will support research focused on how human systems currently cope with climate variability and on issues affecting the use of climate information for planning purposes. In addition to agriculture and fisheries, other sectors, such as energy, transportation, insurance, and health, are affected by climate variability (e.g., ENSO events) and could make use of climate forecasts.

Pilot application and assessment activities are designed specifically to translate the results of research into regionally relevant information that can be used by decisionmakers, government officials, and the general public. In FY99, NOAA will continue its efforts in the U.S. Pacific Northwest, continue and expand its International Research Institute-related pilot applications activities, and launch assessment activities in the U.S. Southwest.

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 under 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. Defense research funding is planned and programmed specifically to address National Security requirements; programs described below concurrently satisfy Defense needs and stated goals of the USGCRP. Defense research programs are described in four research "themes" that capitalize on unique DOD capabilities related to USGCRP goals: Boundary Layer Dynamics (BLD), High Latitude Dynamics (HLD), Ocean Measurements (OM), and Regional Resolving Models (RRM).

DOD	Program Title	FY97	FY98	FY99 Request
ONR	BLD/Marine Aerosols	1.0	1.0	1.0
ONR	BLD/Ocean Ecological Dynamics	0.5	0.0	0.0
ONR	HLD/Arctic Acoustic Properties	3.0*	0.0	0.0
ONR	HLD/Arctic Ice Dynamics	1.0	0.5	0.5
ONR	HLD/Arctic Marine Sediments	0.2	0.0	0.0
ONR	HLD/SCICEX Submarine Data Collection	0.5	0.7	1.0
ONR	OM/Coastal Remote Sensing	0.0	1.0	2.0
ONR	OM/MEDEA Data Declassification	1.0*	0.8*	0.0
ONR	OM/North Pacific Acoustic Laboratory	2.0*	1.0	0.5
CRREL	RRM/Coupled Hydrologic and Thermal Models	0.2	0.0	0.2
ONR	RRM/Coupled Ocean-Atmosphere Models	1.4	1.5	1.5
	Total	**10.8**	**6.5**	
	President's Request	5.9	5.7	**6.7**

*Funded above budget request (Congressional add-on).

CRREL Cold Regions Research and Engineering Laboratory
ONR Office of Naval Research

FY99 Program Highlights. For FY99, Defense programs associated with the USGCRP continue to key on research and data collection to enhance prediction of seasonal to interannual climate variability. The Surface Heat Budget of the Arctic (SHEBA) project—a multidisciplinary field program jointly funded by Navy, NSF, DOE, NASA, and Canada—will continue to provide a continuous set of integrated measurements of the atmosphere, ocean, and Arctic ice pack. Another multi-agency program (SCICEX) with Navy, NSF, NOAA, and USGS support will employ a specially configured Navy submarine to collect detailed bathymetric, gravimetric, and oceanographic measurements under the Arctic ice canopy. These data have significantly altered earlier descriptions of the Arctic environment.

The multi-agency environmental group called MEDEA, charged to examine classified data sets and make recommendations regarding releasing these data to the public, will continue in FY99. Fundamental research in marine aerosols will develop unique instrumentation to measure air-sea gas transfer mechanisms; the resulting data will be used to develop new models of air-sea gas and energy fluxes within the marine boundary layer. The Navy Ocean Modeling Program (NOMP) will concentrate efforts in the Western Pacific region this year. Methodologies to determine an objective Defense Greenhouse Gas Emission Inventory will be supported in FY98–99. All data and research results described above are routinely made available to the civil science community.

Related Research. DOD-sponsored research, not described above, also contributes to observing, understanding, and predicting environmental processes related to global

change. Associated programs include theoretical studies and observations of solar phenomena; monitoring and modeling of unique features in the middle and upper atmosphere; fundamental research in physical and biological oceanography; terrestrial and sea ice modeling; global cloud specification and modeling; terrestrial and marine environmental quality research; and energy conservation measures.

Mapping of Budget Request to Appropriations Legislation. In the Department of Defense Appropriations Bill, research associated with the USGCRP is funded under Title IV–Research, Development, Test, and Evaluation. 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 Biological and Environmental Research (formerly Office of Health and Environmental Research) addresses the effects of energy production and use on the global Earth system primarily through studies of climate response. It includes research in climate modeling, atmospheric chemistry and transport, atmospheric properties and processes affecting the Earth's radiant energy balance, sources and sinks of energy-related greenhouse gases (primarily CO_2), consequences of atmospheric and climatic changes on vegetation and ecosystems, critical data needs for global change research and for early detection of climatic change, support of scientifically based assessments of environmental and economic consequences of climate change, and funding for education and training of scientists and researchers in global change.

DOE	Program Title	FY97	FY98	FY99 Request
OBER	Atmospheric Chemistry and Carbon Cycle	22.8	22.6	24.9
OBER	Climate and Hydrology	64.7	61.7	64.1
OBER	Ecological Processes	12.6	12.3	12.0
OBER	Human Interactions	8.9	9.0	9.2
OBER	Small Business Innovative Research/Technology Transfer	0.0	2.8	3.0
	Total	**109.0**	**108.4**	
	President's Request	112.4	110.1	**113.2**

OBER Office of Biological and Environmental Research

FY99 Program Highlights. To support its global change research efforts, the DOE Biological and Environmental Research (BER) program utilizes the unique multidisciplinary capabilities and facilities of the DOE National Laboratories and supports research projects and research infrastructure at National Laboratories, universities, and other research institutions. A new focus of activities is carbon management and fundamental studies underpinning the development of new techniques for climate mitigation, including carbon sequestration and ecosystem adaptation. In support of the USGCRP, the BER program includes activities in four key areas:

1) *Climate and Hydrology*: The Atmospheric Radiation Measurement (ARM) program, developed in recognition that the effects of clouds on the Earth's radiative energy balance are a major source of uncertainty in climate models, focuses on the improvement of climate prediction and climate parameters by providing data addressing clouds and their interactions with solar and terrestrial radiation obtained through ground-based, airborne (manned and unmanned), and satellite platforms. In FY99, key activities of the ARM program will be the further development and utilization of measurement capabilities at the Tropical Western Pacific site, deployment of instruments on an ice island in cooperation with the SHEBA Program, initial operation of the Barrow site on the North Slope of Alaska, and unmanned aerial vehicle (UAV) flights over the Southern Great Plains and Pacific ARM sites.

   Climate modeling, with an emphasis on the Computer Hardware, Advanced Mathematics and Model Physics (CHAMMP) program, expands the current theoretical basis of climate dynamics and continuously optimizes computer models (from all agencies) for climate prediction and assessment of climate change. The Program on Climate Model Diagnosis and Intercomparison (PCMDI) develops

and implements improved methods and tools for the diagnosis, testing, and intercomparison of general circulation models (GCMs). Key FY99 activities of the CHAMMP program will center on improvements in GCM parameterizations for cloud liquid water structure and resultant radiation fields at tropical, arctic, and mid-latitudes.

2) *Atmospheric Chemistry and Carbon Cycle*: The Atmospheric Science Program is focused on developing a comprehensive understanding of the atmospheric processes that control the transport, transformation, and fate of energy-related air pollutants. Research activities to improve understanding, both through experimental and modeling efforts, of the chemical and physical processes affecting energy-related air pollutants such as sulfur and nitrogen oxides, tropospheric ozone, and aerosols, and of meteorological processes that control the dispersion of material released to the atmosphere are of particular interest. A Gulfstream 1 twin turboprop aircraft research facility equipped for measurements in atmospheric chemistry, aerosols, turbulence, and radiant energy will be maintained and deployed to support field measurement campaigns.

   The Terrestrial Carbon Processes (TCP) program improves the understanding of the biophysical processes of terrestrial ecosystems that affect exchanges of CO_2 between the atmosphere and biosphere. Removal of excess CO_2 from the atmosphere and sequestration by natural mechanisms are estimated through a network of sites making CO_2, biophysical, and ecological measurements. In FY99, TCP, the Program on Ecosystem Research (PER), and the National Institute for Global Environmental Change (NIGEC) will continue the AmeriFlux CO_2 measurement network for estimating net exchange of CO_2 between the atmosphere and major terrestrial ecosystems in North and Central America. The resulting empirical data are used for testing ecosystem process models of net carbon exchange and for calibration of inverse and global carbon cycle models. New efforts will focus on an increased understanding of the way natural systems can be induced to increase the net uptake of CO_2 in the terrestrial biosphere, including the role of microorganisms in relevant biochemical processes. Other new activities will focus on the climate variability impact on ecological parameters, including carbon sequestration.

3) *Ecological Processes*: The BER programs dealing with ecological processes focus on improving understanding of the consequences of atmospheric and climate changes and variation on terrestrial ecosystem properties and processes. Emphasis is on experimental studies to understand the combined effects of changes in climate and atmospheric composition, including elevated temperature, altered precipitation, and elevated CO_2 and ozone. The vegetation subprogram of TCP and PER investigate the response of terrestrial vegetation and ecosystems to human-induced changes in atmospheric composition and climate variables. In FY99, PER, TCP, and the NIGEC programs will continue to support experimental and modeling studies to improve the scientific basis for assessing the consequences of human-induced climate changes and increases in atmospheric CO_2 and tropospheric ozone on major terrestrial ecosystems and resources. The research includes Free-Air Carbon Dioxide Exchange (FACE) experiments to examine responses of terrestrial vegetation and ecosystems, including forest, desert, grassland, and savannah ecosystems to elevated concentrations of atmospheric CO_2. It also includes a major field experiment to examine the effects of altered precipitation on a deciduous forest ecosystem.

4) *Human Dimensions*: The Integrated Assessment program analyzes the entire climate change system, from emissions through impacts. The program supports the analysis of benefits and costs as well as helps in presenting the results of the USGCRP to the policy process. Specific topics, such as technology innovation and diffusion, are funded in addition to general assessment modeling efforts. NIGEC supports research to develop and improve models used to assess the

regional economic and social consequences of climate change due to alterations in water, agricultural, and forestry resources. A combined education and research program for minority colleges and universities focuses on developing collaborative global change research ties between minority colleges and universities and ongoing global change research programs at the DOE laboratories, thereby diversifying and increasing America's scientific workforce in global change research.

The Carbon Dioxide Information Analysis Center (CDIAC), a component of the U.S. Global Change Data and Information System (GCDIS), provides access to current global-change information and quality-assured and fully documented numeric data, technical publications, newsletters, and research summaries.

The National Institute for Global Environmental Change (NIGEC) supports research at universities on all four programmatic areas of DOE's global change research priorities, with emphasis in FY99 on supporting research at several of the AmeriFlux sites and on implementing scientifically-based assessments of the consequences of climate change on forest, agricultural, and water resources in the western, central, and southeastern United States.

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 gas emissions through changes in energy supply and improvements in energy efficiency and conservation. DOE has a major role in meeting the President's challenge to develop new technologies for decreasing greenhouse gas emissions, and its basic research portfolio has increased focus on science that will underpin carbon mitigation and carbon sequestration and increase our understanding of ecosystem adaptation. In addition, DOE conducts research related to energy issues, including basic research in plant and microbial biology; technologies to improve energy efficiency and conservation 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 under Title III–Department of Energy, within the Energy Supply, Research, and Development Activities account. In Appropriations Committee reports, funding for DOE's USGCRP programs is included within the Biological and Environmental Research account.

Department of Health and Human Services/National Institute of Environmental Health Sciences

Areas of Global Change Research. National Institute of Environmental Health Sciences 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	FY97	FY98	FY99 Request
NIH	Human Health Effects of Exposure to UV Radiation	4.1	4.3	4.5
	Total	**4.1**	**4.3**	
	President's Request	4.0	4.3	**4.5**

NIEHS National Institute of Environmental Health Sciences

FY99 Program Highlights. Research conducted by NIEHS on UV radiation, a known human carcinogen, has long been an important component of its research agenda to determine how environmental exposures initiate and promote disease. This research could help to reduce the substantial burden on individuals and society imposed by cancer and the need for cataract surgery. From 1973 to 1993, the age-adjusted rate for melanoma in the United States increased from 5.7 to 12.2 per 100,000. More than 1.5 million cataract and more than 800,000 nonmelanoma skin surgeries are performed annually.

Highlights of the FY99 research program include studies to determine how UV radiation-induced inununosuppression and genetic damage contribute to skin cancer in humans and experimental animals; to understand the roles of DNA repair and mutant frequency in cancer susceptibility to UV exposure; and to understand the photobiological mechanisms involved in aging caused by chronic UV damage. Other research projects include the testing of antimalarial drugs in order to determine whether the cutaneous and ocular side effects associated with their use are light-induced, and studies of the photochemistry of all light-absorbing components of the eye in order to determine whether long-term exposure to light contributes to the deterioration of clarity of the lens and functioning of the retina.

Related Research. In addition to research that is designated as part of the USGCRP, NIEHS conducts research related to other impacts of global change on human health, including the effects of environmental and occupational exposures to air pollution, agricultural chemicals, and materials used in alternative or new technologies to mitigate or adapt to climate change. Exposures of special concern for FY99 include those that contribute to the greatly increased incidence of childhood asthma and that disrupt the normal functioning of the endocrine system. Renewed concern about emerging and reemerging infectious diseases has prompted increased attention to a variety of diseases whose incidence would be affected by environmental change. Other HHS agencies provide significant resources for research on and development of vaccines and treatment for cholera and vector-borne diseases, such as encephalitis, malaria, dengue, and Lyme disease.

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 under 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, including the ecological linkage between environmental factors, climate change, terrestrial and aquatic ecosystems, and associated biological resources; arid, polar, and coastal regions and systems; impacts of sea-level change on coastal wetland and forest ecosystems, and the influence of climate on the ecological status and nutrient limits of large reservoir systems and associated fisheries; 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 for human activities, water resources, coastal wetlands, biological species, ecological systems, and land management; carbon cycle variation; and archiving and distribution of space- and land-based Earth science data.

DOI	Program Title	FY97	FY98	FY99 Request
USGS	Global Change Research	28.5	28.5	28.5
	Total	**28.5**	**28.5**	
	President's Request	28.5	28.5	**28.5**

USGS U.S. Geological Survey

FY99 Program Highlights. In FY99, the USGS will continue to support ongoing efforts across a broad area of global change research. A major project to document and understand the carbon budget of the Mississippi Basin will continue, as will work to develop an understanding of past climate variability with emphasis on terrestrial records from North America and adjacent oceans. Increased emphasis will be placed on documenting and understanding the potential impacts and consequences of climate variability and climate change, both natural and human induced, at the regional and continental scale.

Other FY99 activities involve the continued development of multi-scale data sets that describe the land surface. A 30-m spatial resolution data set of land cover for the conterminous United States will be completed. Continental-scale hydrologic databases derived from global 1-km elevation data will be developed. Detailed characterizations of the Arctic will produce vegetation maps of circumpolar regions. Biophysical remote-sensing research will enable vegetation state and health to be estimated using *in situ* and remotely sensed data. Landscape modeling research will apply regional-scale land use data sets in an effort to simulate land use under different input conditions.

Other activities include continuing the high-resolution reconstruction of past climate and fire regimes to aid in restoration of the natural role of fire in forest and rangeland ecosystems of the western United States and Alaska; determining rates of sea-level rise in coastal areas and the ability of coastal wetlands to adapt to predicted rates of sea-level rise; modeling vegetation response related to the restoration of native plant diversity and retarding the spread of invasive plants (weeds); and predicting the response of sensitive species, such as determining their thermal and hydrologic limits, changes in their habitat use and migratory patterns, and the influence of climate on their range, abundance, and distribution.

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 under Title I–Department of the Interior. Funding for U.S. Geological Survey USGCRP programs is included within the USGS Survey, Investigations, and Research account.

Department of Transportation

Related Research. A number of DOT assessment efforts that are not formally part of the USGCRP will help to improve understanding of the human dimensions of global change in the transportation sector. The DOT Federal Highway Administration worked with the National Research Council's Transportation Research Board (TRB) to support a study on the long-term effects of motor vehicle transportation on climate and ecosystems. This work focused on climate change and biodiversity, and emphasized the global nature of the problem. The National Cooperative Highway and Transit Research Programs were also involved. The results of this effort are summarized in TRB's Special Report #251, *Toward a Sustainable Future*. The Travel Model Improvement Program (TMIP) is supporting some initial efforts to strengthen the interaction between land use and transportation forecasting in the infrastructure planning process. TMIP is a cooperative venture of DOT, DOE, and EPA.

Environmental Protection Agency

Areas of Global Change Research. EPA's Global Change Research Program supports the emphasis the USGCRP is placing on a National Assessment of the consequences of climate change and climate variability. The goal of the National Assessment is to determine the local, regional, and national implications of climate change and climate variability within the United States in the context of other existing and potential future environmental, economic, and social stresses. Of particular importance is understanding the regional mosaic of what has been and will be occurring as a result of global change. EPA's global change research was reorganized in FY98 to reflect the emphasis on the National Assessment, and the increase requested in FY99 continues to support this effort:

- *Indicators of Change.* EPA will enhance research in the development of ecosystem indicators as sentinels of global change. The focus will be on the terrestrial, aquatic, and coastal indicators that can detect and quantify the effects of climate change on ecosystems and will include research into indicators that integrate ecosystems with human health. Some of the candidate integrative indicators are rodent and mosquito populations as they cycle and respond to climate change and variability. EPA will continue to monitor UV-B radiation in rural sites as an indicator of global change.
- *Ecosystem Services.* EPA has major responsibility for assessing the impacts of global change on ecosystem services. Ecosystem services include a wide range of ecological functions that are highly regarded by society, yet are often difficult to value economically. This area of research includes evaluating the impacts on storage of water, nitrogen, and other nutrients, including carbon; mitigation of floods; air and water purification; generation and renewal of soil and soil fertility; pollination and seed dispersal; and maintenance of biological diversity. There is little information on the impacts of global change on natural ecosystems and associated services and the economic valuation of these services. This work needs to be advanced to better understand the full economic impacts of lost or diminished ecosystem services.
- *Assessment of Consequences.* As an initial step in the National Assessment, a series of regional workshops, encompassing every state and territory, is identifying the distinctive regional characteristics and potential consequences of climate change and variability. The workshops will lead to a set of regional-scale assessments, led by the various USGCRP participating agencies. EPA has the lead coordinating responsibility for the Mid-Atlantic, Gulf Coast, and Great Lakes regions.

EPA	Program Title	FY97	FY98	FY99 Request
ORD	Assessment of Consequences	0.0	2.8	7.5
ORD	Developing Predictive Models	1.8	0.0	0.0
ORD	Ecosystem Services	0.0	4.8	6.0
ORD	Indicators of Change	0.0	6.0	7.0
ORD	Integrated Assessment Research	1.4	0.0	0.0
ORD	Regional Vulnerabilities	9.7	1.0	0.0
ORD	Stratospheric Ozone Depletion	1.3	0.0	0.0
	Total	**14.3**	**14.6**	
	President's Request	13.7	21.1	**20.5**

ORD Office of Research and Development

FY99 Program Highlights. Under the USGCRP, EPA conducts research to understand the consequences of global change, especially on ecosystem services, and develops indicators of global change. In FY99 EPA will evaluate indicators that integrate ecosystem and human health. Some likely examples include rodents and mosquitoes. Research in ecosystem services will be conducted to understand the role of ecotones—intersections of different ecosystem types—in providing ecosystem services, and how ecotones are impacted by global change. EPA will also look at the impacts of global change on the pollution-control infrastructure—for example, the impacts of sea-level rise and hydrologic alteration on water quality and the effects of temperature increases on air pollutants such as fine particulate matter. Assessment of the consequences of global change will be initiated at three regional-scale locations: The Mid-Atlantic, the Gulf Coast, and the Upper Great Lakes. EPA will also participate in the overall synthesis of regional-scale assessments as part of the National Assessment.

Related Research. In addition to the focused USGCRP research activities, EPA conducts contributing research to characterize and understand risks to ecosystems and to understand and predict ecosystem exposures, responses, and vulnerabilities to high-risk chemicals and non-chemical stressors at multiple levels of biological organization and geographic scales. Other related research includes monitoring of ozone and research on atmospheric chemistry.

Mapping of Budget Request to Appropriations Legislation. In the Departments of Veterans Affairs and Housing and Urban Development, and Independent Agencies Appropriations Bill, Environmental Protection Agency USGCRP activities are funded under the EPA section of Title III–Independent Agencies, within the Science and Technology 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, archiving, 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.

FY99 Program Highlights. The overall goal of the Earth Science (ES) program (formerly Mission to Planet Earth) is to understand the Earth system and the effects of natural and human-induced changes on the global environment. To preserve and improve the Earth's environment for future generations, policies and decisions worldwide should have the strongest possible scientific basis. The vantage point of space provides information that is obtainable in no other way about the Earth's land, atmosphere, ice, oceans, and biota, as well as the impact of humans on the Earth system.

The science and observations of NASA's ES program are becoming increasingly important as the demand for economic progress by the growing global population drives policies that encourage natural resource depletion and rapidly increasing emissions of environmental pollutants. In addition, remote sensing has the potential to improve dramatically crop and forest yield predictions, seasonal and interannual climate forecasts, urban planning, mineral exploration, and many other activities of socioeconomic importance. In concert with the global change research community, the ES program is utilizing space to lead the development of knowledge required to support the complex national and international policy decisions that lie ahead.

As was the case last year, this edition of *Our Changing Planet* divides the ES budget into two main components: 1) Scientific research costs, and 2) the costs associated with satellite, aircraft, and balloon measurements, operations, and data processing and distribution (including mission costs such as launch, flight, instrument and technology development, fabrication assembly, integration, and testing, as well as mission operation support).

- *Scientific Research Costs.* The scientific research component of the ES budget is supported by an integrated science plan that relates research plans to space observations, and fully integrates the Earth Observing System (EOS) and non-EOS science. EOS is a program of multiple spacecraft and interdisciplinary science investigations designed to provide a 15-year data set of key parameters needed in order to understand global climate change. The major themes of NASA's ES Science Research Plan are consistent with the USGCRP. They are Land-Cover and Land-Use Change Research, Seasonal to Interannual Climate Variability and Prediction, Natural Hazards Research and Applications, Long-Term Climate–Natural Variability and Change Research, and Atmospheric Ozone Research.

  Against the backdrop of the overall ES effort to better understand the state and health of the Earth's life-support systems, these five research focus areas target specific research issues important to national and international environmental and economic security. For example, an important priority is to provide an accurate assessment of the extent and health of the world's forests, grasslands, and agricultural resources. In a time of rapid, and often

NASA	Program Title	FY97	FY98	FY99 Request
ES	Airborne Science Program	19.0	20.7	20.1
ES	Applications Research Program	2.9	18.6[a]	4.6
ES	Atmospheric Chemical Modeling	6.5	6.5	6.5
ES	Atmospheric Dynamics and Remote Sensing	5.2	5.3	5.3
ES	Biological Oceanography	4.4	4.8	4.8
ES	Ecological Processes	15.7	16.4	16.4
ES	EOS Science	37.5	37.4	40.9
ES	Geodynamics and Geopotential Fields	13.5	13.6	13.6
ES	Geology	4.4	5.3	5.3
ES	Global Data Integration and Validation	3.7	3.8	3.8
ES	Global Modeling and Analysis Program	6.2	6.2	6.2
ES	GLOBE	5.0	5.0	5.0
ES	Interdisciplinary Research and Analysis	18.1	20.4	29.2
ES	Land Cover and Use Change	8.7	6.3	6.3
ES	Land Surface Hydrology	5.1	5.1	5.1
ES	Mission Analysis Program	32.9	40.0	42.0
ES	Natural Hazards Program	4.2	4.3	4.3
ES	Ocean Color Data Purchase/SeaWiFS	2.4	2.5	2.5
ES	Pathfinder Science Studies	6.6	3.4	3.5
ES	Physical Oceanography and Ocean Modeling	7.9	7.5	7.5
ES	Polar Programs	4.5	5.5	5.5
ES	Radiation Science Program	6.6	7.7	7.7
ES	Stratospheric Chemistry	17.1	17.2	17.2
ES	Tropical Rainfall Measurement Science	6.1	0.4	0.0
ES	Tropospheric Chemistry	7.8	8.8	9.8
ES	Uncrewed Aerial Vehicle Science	0.3	1.9	2.0
NASA Global Change Science Program		252.3	274.6	275.1
ES	Advanced Geostationary Studies	2.0	3.0	0.0
ES	Commercial Remote Sensing	19.0	21.5	24.8
ES	Data Purchase	50.0	0.0	0.0
ES	Earth Systems Science Pathfinder	14.0	33.9	70.0
ES	EOS Data and Information System (EOSDIS)	234.6	209.9	256.6
ES	EOS Flight Development	437.9	550.8	505.0
ES	EOS Special Spacecraft	72.5	101.2	152.1
ES	HPCC Earth Remote Sensing	28.3	18.3	14.5
ES	Information Systems	8.5	4.3	6.1
ES	Landsat	78.8	52.6	2.0
ES	Launch Services	84.7	34.8	0.0
ES	Lewis & Clark Land Imaging Spacecraft	12.0	3.0	5.0
ES	Light SAR	12.0	0.0	5.0
ES	Mission Operations	38.2	47.7	49.9
ES	Payloads and Instrument Development	2.6	2.6	1.0
ES	Total Ozone Mapping Spectrometer (TOMS)	3.9	8.2	4.9
ES	Tropical Rainfall Measuring Mission	17.3	0.9	0.0
NASA Global Change Hardware Development		1116.3	1092.7	1096.9
	Total	**1368.6**	**1367.3**	
	President's Request	1402.1	1417.3[b]	**1372.0**

[a]Funded above budget request (Congressional add-on).

[b]Includes $50M to be transferred to the International Space Station, if necessary.

ES Earth Science (formerly Mission to Planet Earth)

unrecorded, land-use change, observations from space are the only source of objective information on the human use of land. A closely related priority is to improve understanding and prediction of seasonal to interannual climate variation. Reducing uncertainties in climate predictions out to a season or a year in advance can help improve dramatically the efficiency of water use for agriculture and hydropower, as well as improve contingency planning for energy demand and in other economic sectors.

In addition, the ES natural hazards research priority emphasizes the use of remote-sensing observations for the characterization and mitigation of drought and flood impacts. There is increasing evidence that predictions of extreme weather events can be improved by understanding their links to interannual climate phenomena, such as the El Niño events. The ES Science Plan also calls for special attention to measuring and modeling the relative influence of forcing factors in long-term climate change, including clouds, aerosols, and greenhouse gases, in order to improve the understanding and prediction of climate on time scales of decades to centuries. A continuing priority area for ES is to understand the causes and consequences of changes in atmospheric ozone. Research to resolve questions related to stratospheric ozone depletion continues to make great progress, and increased emphasis is now being focused on the changing composition of the lower atmosphere, which is especially sensitive to the unprecedented growth of pollutant emissions in East Asia and other rapidly developing regions.

- *Costs Associated with Satellite, Aircraft, and Balloon Measurements, Operations and Data Processing and Distribution.* The Earth Observing System is a program of multiple spacecraft (the AM, PM, and CHEM series, Landsat-7, and others) and interdisciplinary science investigations to provide a 15-year data set of key parameters needed to gain a fuller understanding of global climate change. The first EOS satellite launches begin in 1998, with AM-1 and Landsat-7.

  Preceding EOS are a number of individual satellite and Shuttle-based missions which are helping to reveal the basic processes of atmospheric chemistry (Upper Atmosphere Research Satellite—UARS/1991), ozone distribution and depletion (Total Ozone Mapping Spectrometer—TOMS/1978, 1991, 1996, and 2000), ocean topography and circulation (TOPEX/Poseidon/1992), ocean winds (NASA Scatterometer—NSCAT/1996), and global tropical precipitation (Tropical Rainfall Measuring Mission—TRMM/1997), among others. These provide the scientific and technological foundation on which EOS builds. TRMM was launched in November 1997, and is now fully operational. It will provide important data on precipitation in the tropics that will help better understand the global hydrological cycle.

  Complementing EOS will be a series of small, rapid-development Earth System Science Pathfinder (ESSP) missions to study emerging science questions and make innovative measurements in parallel with the 15-year mission of EOS. ESSP will feature low life-cycle costs, peer-reviewed science, and missions based on best science value. The first two ESSP missions—Vegetation Canopy Lidar (VCL) and Gravity Recovery and Climate Experiment (GRACE)—were selected and are scheduled for launch in 2000 and 2001, respectively. In addition, the New Millennium Program (NMP) provides for the infusion of innovative new technologies into the ES program, with an initial focus on the second and third series of EOS measurements, and will emphasize fast-track development and low-cost demonstration missions. These technologies, which will lead to the development of smaller and lighter-weight instruments, will reduce annual program expenditures in the post-FY2000 time frame.

  In late 1998, QuickScat will be launched to fill the gap in critical sea surface wind data, resulting from the premature in-orbit failure of the Japanese ADEOS-1 spacecraft. The measurements to be made by these and other future

ES missions as well as current in-orbit missions provide data products that are used extensively in the ES science program. The program encompasses more than 1,700 scientific activities at universities, research laboratories, and government research organizations. These activities are providing an ever-increasing scientific understanding of the global environment and the effects of natural and human sources of change.

In November 1997, eleven vendors were selected under Phase 1 of the Commercial Data Purchase. The scientific evaluation of their example data products will be carried out by the scientific community, and those providing high science value will be selected for Phase 2, the commercial provision of scientifically useful data sets.

ES has adopted an evolutionary approach to fulfilling its mission and goals. NASA completed a comprehensive review of the entire ES enterprise. The goal was to enable a focus on near-term science and associated applications; explicit provisions for new technology infusion; reduction in life-cycle cost of the EOS program; provision of new science opportunities through smaller, quicker and less expensive missions; and closer participation with other Federal agencies, commercial firms, and international partners. This approach was endorsed by the National Research Council (NRC) through its Board on Sustainable Development.

In 1997, NASA conducted its first Biennial Review of ES, focusing on the following five key areas: Program balance and the restoration of Research and Analysis (R&A) funding; EOSDIS Core System; CHEM-1 mission architecture; technology infusion strategy; and implementation of the program after 2002. The first three areas address issues remaining in the time frame of the first EOS series. The latter two look to the future, and enable a fundamentally different and vastly more flexible means of planning and implementing Earth system science missions. A Science Implementation Plan to be produced in 1998 will lay out a strategy and priorities for implementing the program.

Related Research. NASA includes all research in support of global change within its accounting of 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, National Aeronautics and Space Administration USGCRP activities are funded under 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 Earth Science program, which is the NASA contribution to the USGCRP.

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 as well as 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, promote the enhancement of modeling designed to improve representations of Earth system interactions, and develop 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	FY97	FY98	FY99 Request
	Antarctic Ecosystems	1.0	1.0	1.0
	Arctic System Science	14.5	15.2	16.0
	Climate Modeling, Analysis, and Prediction	11.5	12.0	13.4
	Climate Variability and Predictability	10.9	11.0	13.2
	Coastal Long-Term/Land Margin Ecological Research	2.9	2.2	2.4
	Earth System History	10.4	11.2	14.1
	Ecological Diversity	4.8	5.0	6.7
	Ecological Rates of Change	3.0	3.2	3.2
	GEODATA	1.4	1.8	2.2
	Global Ocean Ecosystems Dynamics	8.8	10.0	12.3
	Global Tropospheric Chemistry Program	12.5	12.8	14.3
	Greenhouse Gas Dynamics	0.2	0.2	0.2
	Human Dimensions of Global Change	14.3	12.1	14.3
	Joint Global Ocean Flux Study	18.8	17.2	15.6
	Methods and Models for Integrated Assessment	3.4	3.4	3.4
	Ocean Observation, Data Assimilation, and Modeling	0.0	0.0	4.6
	Polar Ozone Depletion/UV Radiation Effects	3.5	4.2	4.2
	Regional Research Institutes	3.2	3.2	3.4
	Ridge Interdisciplinary Global Experiments	3.3	3.3	3.3
	Sea Level Changes	5.8	5.8	5.9
	Solar Influences	6.8	6.8	7.7
	Water & Energy: Atmospheric-Vegetative-Earth Interactions	8.6	8.8	10.2
	World Ocean Circulation Experiment	16.7	16.8	15.8
	Total	**166.3**	**167.2**	
	President's Request	183.4	170.0	**187.4**

FY99 Program Highlights. During FY99, NSF will continue to support research and related activities across all of its global environmental programs. A significant share of the agency's efforts will focus on continuation of major international collaborative field programs. The World Ocean Circulation Experiment (WOCE) and Joint Global Ocean Flux Study (JGOFS) will see enhanced analysis and synthesis of data gathered during previous years. As with other major international field programs, WOCE and JGOFS analyses and syntheses activities will be linked with data-assimilation and modeling activities. Significant growth is expected in the Earth System History

(ESH), Ecological Diversity, GEODATA, and Global Ocean Ecosystem Dynamics (GLOBEC) programs.

Among the most significant new emphases will be the Indian Ocean Experiment (INDOEX), which will investigate natural and anthropogenic climate forcing by aerosols. Over the Indian Ocean, during winter, polluted, aerosol-rich air flowing off central Asia encounters clean, pristine air from the southern Indian Ocean, the two air masses meeting at the highly convective intertropical convergence zone near the equator. The Indian Ocean thus provides a natural laboratory for studying the effects of aerosols on climate. INDOEX will contribute to CLIVAR, the Global Tropospheric Chemistry Program (GTCP), and the Water and Energy: Atmosphere-Vegetative-Earth Interactions (WEAVE) program.

The Ocean Observations, Data Assimilation, and Modeling Program (OODAM) will address the pressing need for the integration of products of the major global ocean field programs as they approach the end of their experimental observational phases. This activity will seek to develop global- and regional-scale coupled ocean predictive models. This will require, in turn, data assimilation research and identification of long-term observations necessary to support these activities.

NSF will continue to support the development, testing, and application of climate systems models and methods to improve model representations of related Earth system processes. In addition to continuing to accelerate the development of the community-use Climate System Model (CSM) at the National Center for Atmospheric Research (NCAR), NSF will continue to make available advanced computational facilities to a wide range of scientists for USGCRP-sponsored Earth system modeling. NSF also will maintain support for research on fundamental understandings of human contributions and responses to global change.

Related Research. In addition to focused global change research, NSF conducts contributing research on many topics, including laboratory and field studies of the atmosphere and the factors that affect it; the physical, chemical, and biological dynamics of ocean waters; the composition, structure, and history of ocean floors; geophysical, hydrological, geological, and geochemical processes operating at and below the Earth's surface; the generation, transport, and fate of chemicals in natural systems; global environmental history; and data management for scientific research and modeling.

Many NSF-sponsored research projects examine interactions that link ecosystems and human activities with other factors, of which climate variability and change are only one specific set. As a result, much of NSF's support for research that relates to the consequences of global change does not focus specifically on global change but falls into the "contributing research" category instead. For example, data-collection activities and field experiments at many of the nearly two dozen Long-Term Ecological Research (LTER) sites provide insights into the ways that different ecosystems respond to short- and longer term changes in climate, but they provide equally valuable perspectives on ecological responses to other kinds of environmental changes. In a similar way, NSF provides support for research projects that examine economic, cultural, and behavioral responses to different conditions that include, but are not restricted to, global environmental change. Especially noteworthy are studies of the ways that people and institutions anticipate and respond to risks, because risk assessment and risk management invariably entail making trade-offs among a large number of factors.

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

Smithsonian Institution

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

SI	Program Title	FY97	FY98	FY99 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
NZP/NMNH/SERC	Biological Responses	4.2	4.2	4.2
	Total	**7.0**	**7.0**	
	President's Request	7.0	7.0	**7.0**

NASM National Air and Space Museum
NMNH National Museum of Natural History
NZP National Zoological Park
SAO Smithsonian Astrophysical Observatory
SERC Smithsonian Environmental Research Center
STRI Smithsonian Tropical Research Institute

FY99 Program Highlights. At SAO, external contracts and grants continue to support a program of novel approaches to global change research, including studies of atmospheric composition, chemistry, and absorption/transmission of radiation. Remote sensing of stratospheric trace species that play an important role in ozone photochemical cycles will be undertaken using balloons, airplanes, and satellites. Solar activity and irradiance are being studied to better understand the climatic effects of solar variability. Ongoing global sea-level change is being estimated using space geodetic measurements.

Research at NASM emphasizes the use of remote-sensing data to improve theories of drought, sand mobility, soil stability, and climate change in the eastern Sahara. Researchers at NASM have found new drainage systems revealed by the Space Shuttle Imaging Radar experiment, and are dating the relict soils to determine periods of wet and dry climates that are related to global changes not influenced by humans.

Monitoring of the influx of UV-B radiation will be performed at SERC, where new spectral radiometers will be used to continue a more than 25-year record of UV-B in Maryland and to augment other domestic and international UV-B monitoring efforts. Several parts of the SI programs examine the biological responses to global change and increase public understanding of global change issues. At SERC, research is conducted on the responses of global ecosystems to increasing CO_2, exotic species introductions, and ozone depletion. A new center at SERC will monitor movement of marine species in the ballast water of ocean vessels. A new Institute for Conservation Biology provides a focus for cross-institutional activities in biodiversity education and research. Studies of tropical biological diversity are performed at the Smithsonian Tropical Research Institute (STRI). The Biological Diversity program at NMNH monitors global change effects through repeated sampling of flora and fauna in tropical

forests, and identifying the physical and biological processes of growth and decline of species. The general public and research community will be informed of global change research at the Smithsonian via exhibits, educational programs, and resources available over the Internet.

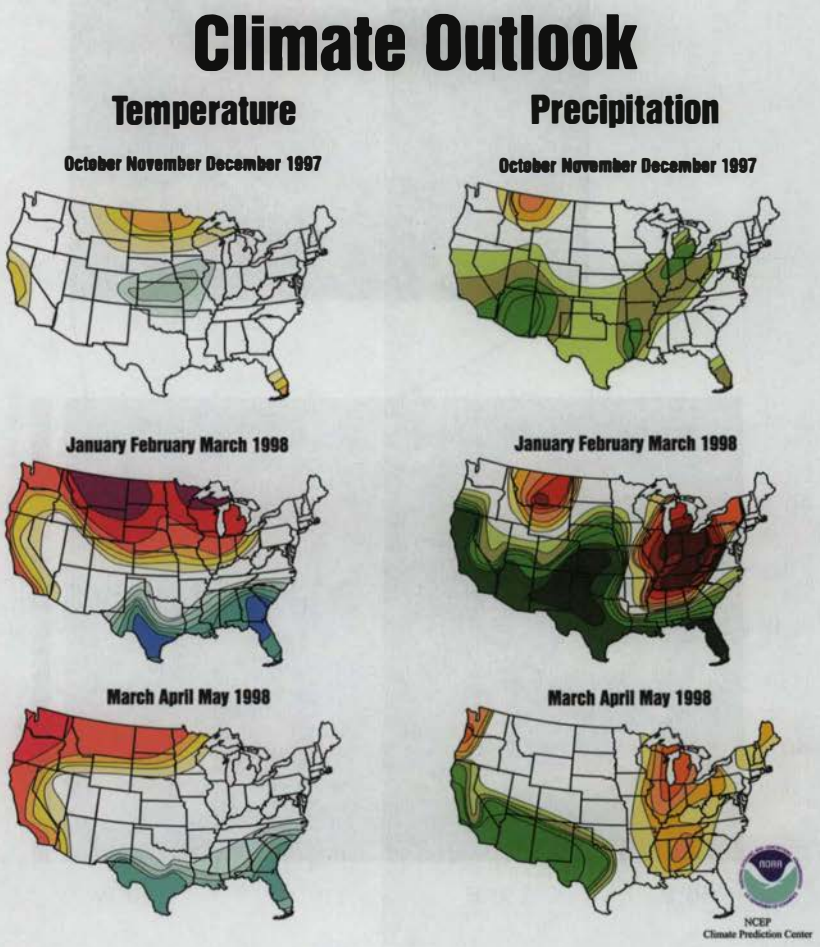
Related Research. Studies of environmental change over long time periods are aided by the Institution's collections. Utilized by staff and researchers from other institutions, these materials provide raw data for evaluating changes in the physical and biological environment that occurred before human influences.

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.

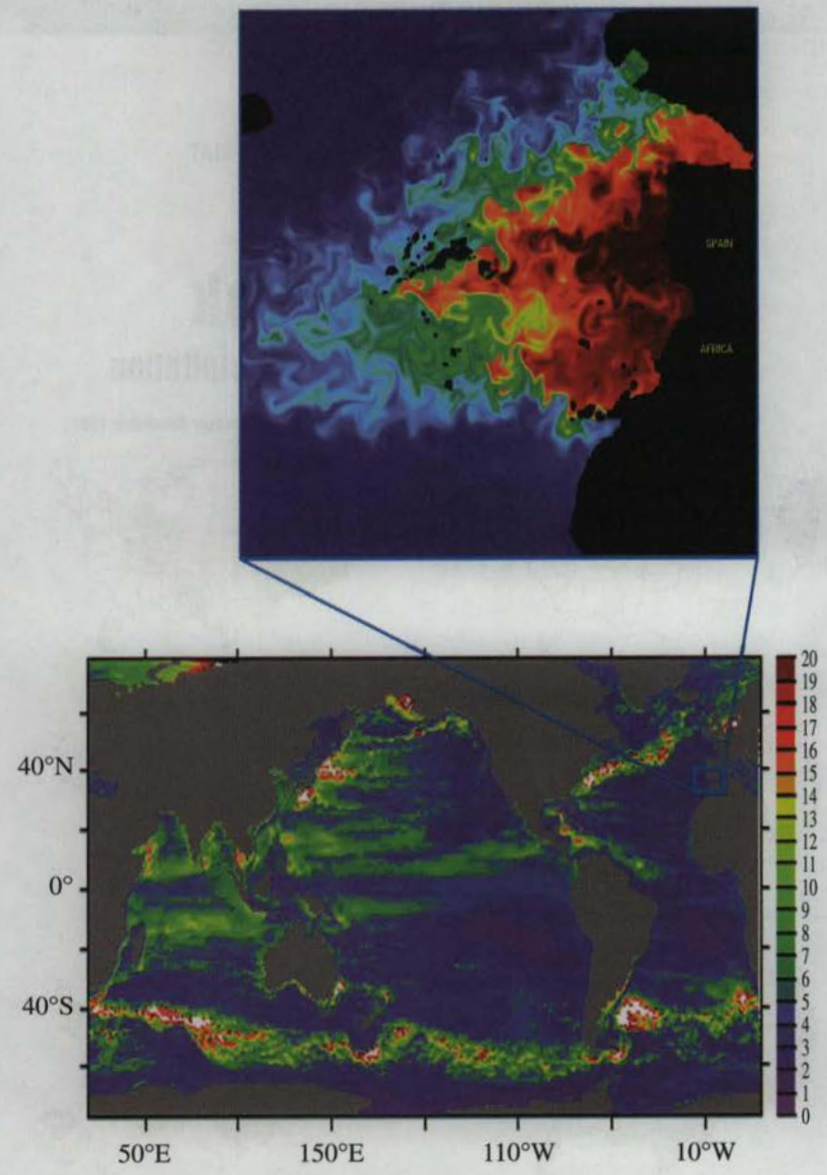
Appendix C

Color Plates

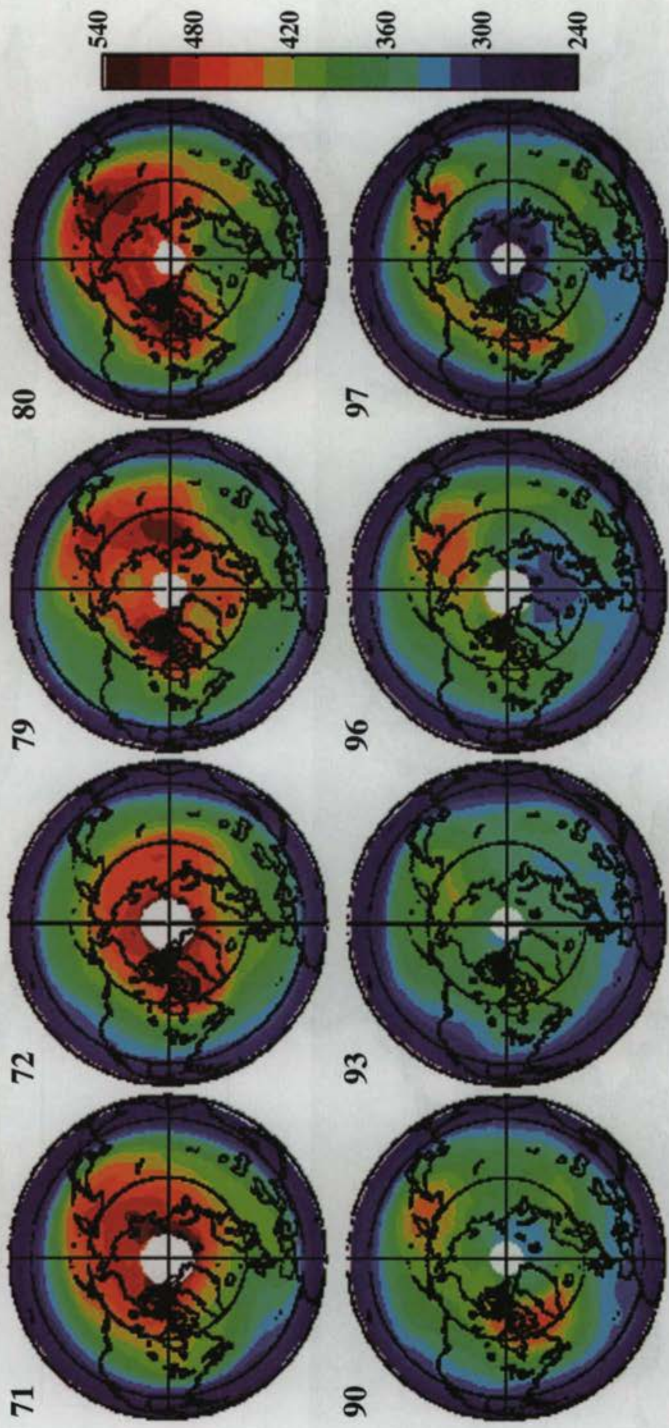
[captions can be found on pages 115–118]



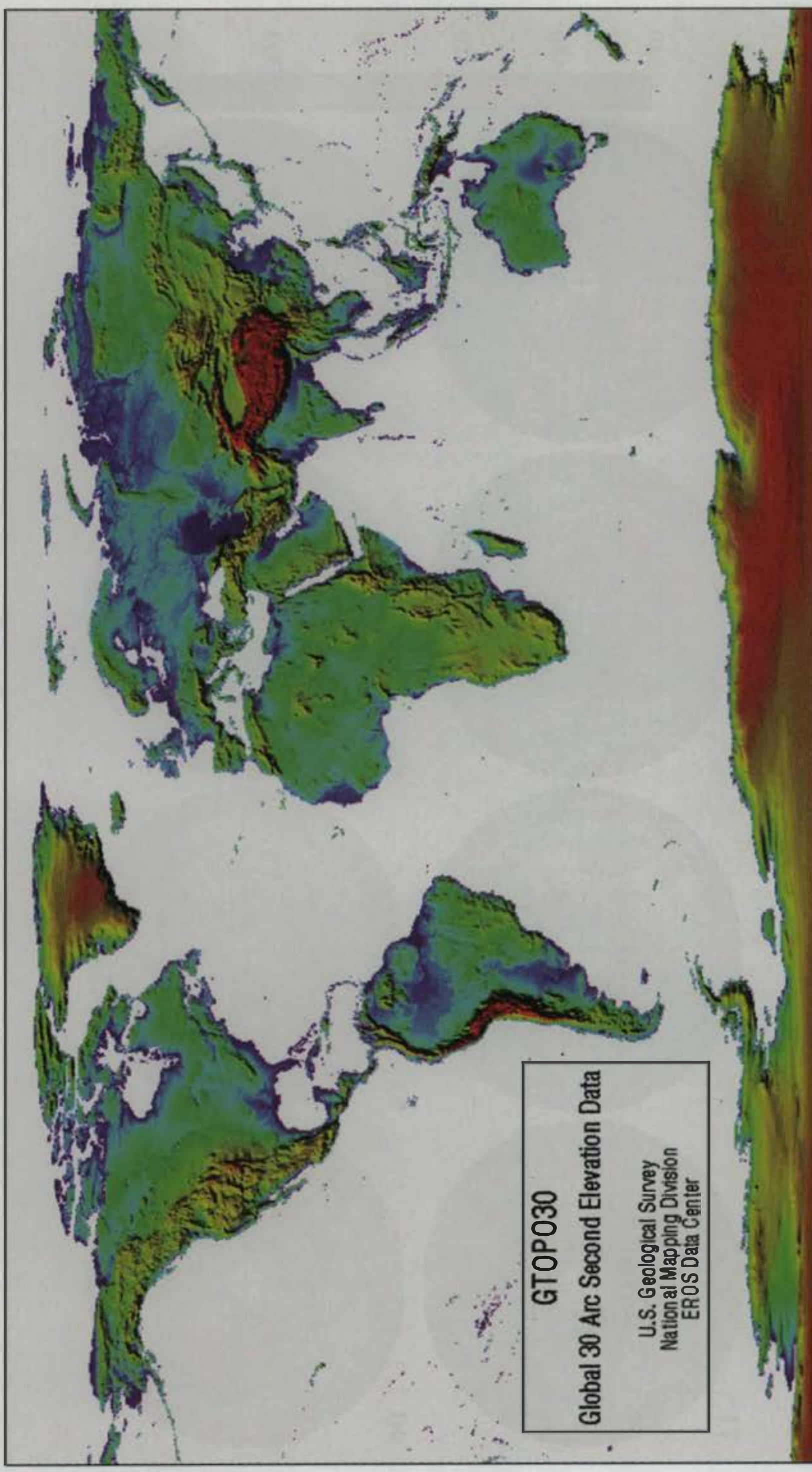
Color Plate 1. ENSO Forecast Maps

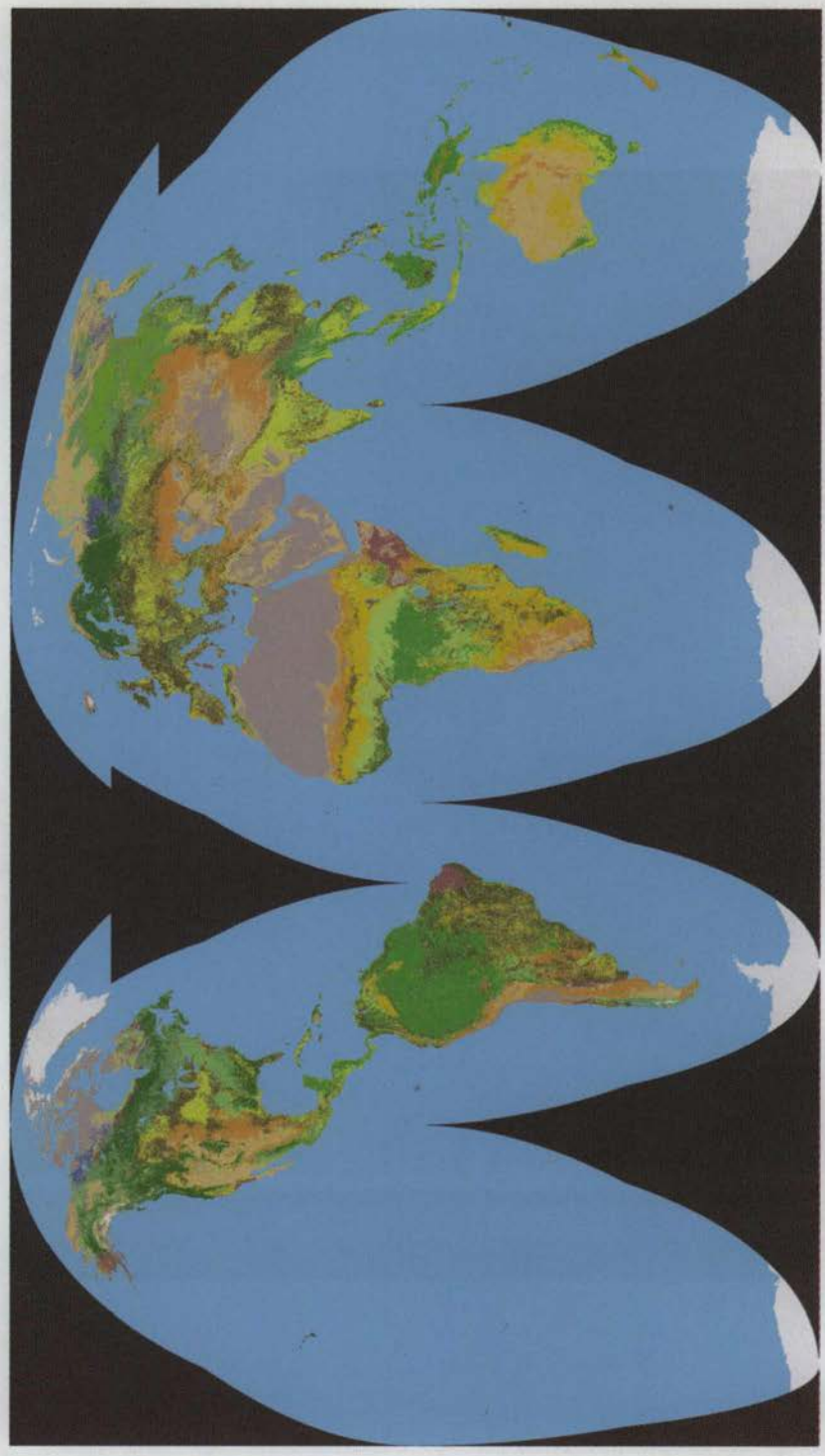


Color Plate 2. High-Resolution Ocean Modeling

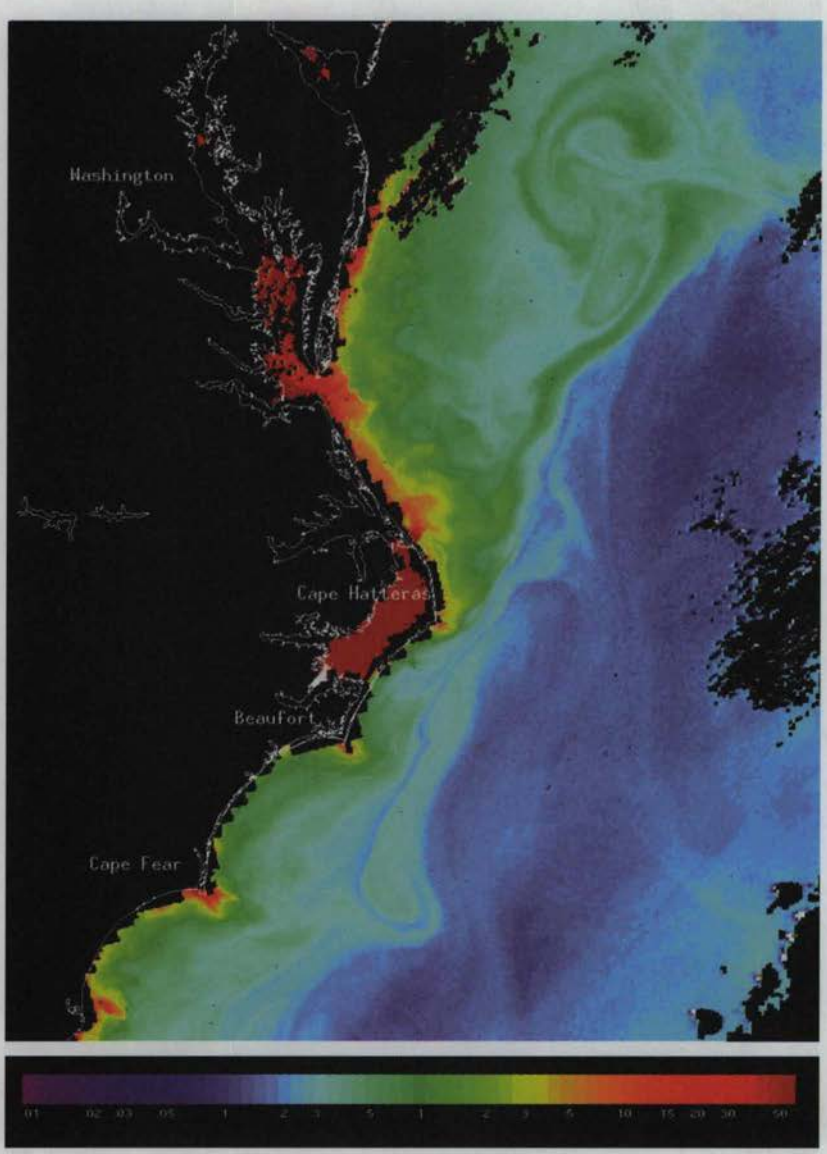


Color Plate 3. Arctic Ozone Image Time Series, 1971–1997


GTOPO30
Global 30 Arc Second Elevation Data
U.S. Geological Survey
National Mapping Division
EROS Data Center

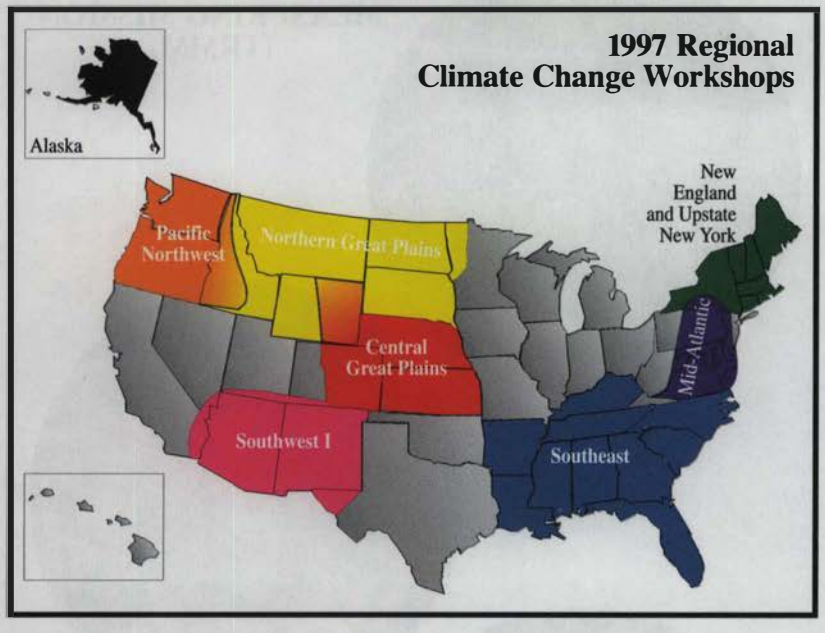


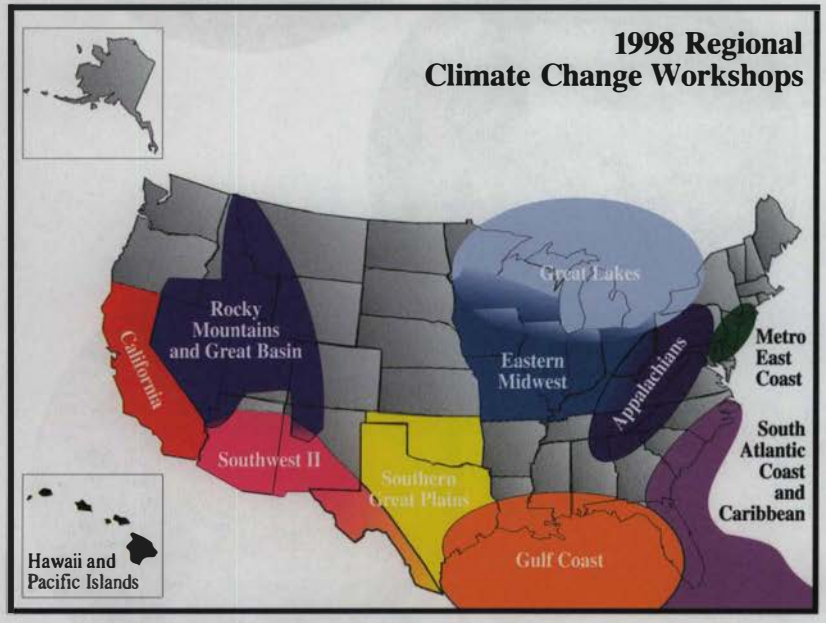
Color Plate 5. Global Land Cover



Color Plate 6. U.S. East Coast SeaWiFS Image

Color Plate 7. Tropical Rainfall Measuring Mission





An additional 1998 workshop will address the potential consequences of climate variability and change for tribal lands.

Color Plate Captions

Color Plate 1 (page 107)

ENSO Forecast Maps. Each month the NOAA Climate Prediction Center produces seasonal forecasts for temperature and rainfall for the United States out to a year in advance. The forecasts for the fall of 1997 through the spring of 1998 shown in this figure reflect the expected variations in temperature and precipitation that will be caused by the El Niño event of 1997–98. For precipitation, the green shades indicate regions where above normal precipitation is forecast, and the yellow shades indicate regions where below normal precipitation is forecast. The more intense the color, the more likely the odds that such excursions will occur. For temperature, the reds and yellows indicate regions where warmer than normal temperatures are forecast, and the blues indicate regions where colder than normal temperatures are forecast. The forecast for the October–December 1997 period was issued in mid-August 1997; the forecasts for the January–March and March–May 1998 periods were issued in mid-November 1997. Because of these early warnings, planners in different economic and emergency sectors have been able to use the forecasts to improve water management, prepare for potential flooding events, and adjust hydroelectric allocations.

Source: Ants Leetmaa/NOAA Climate Prediction Center.

Color Plate 2 (page 108)

High-Resolution Ocean Modeling—Global Image with Mediterranean Salt Eddies (inset). More accurate simulation of ocean circulation is now possible through use of very-high-resolution ocean models. One example is based on the work of scientists at the Los Alamos National Laboratory (LANL), in collaboration with the National Center for Atmospheric Research and the Naval Postgraduate School. Using a high-resolution global ocean model, they have achieved accurate simulations of the long-term behavior of the ocean currents that transport heat from the warm regions near the equator to the colder regions at higher latitudes, as well as the shorter term seasonal fluctuations that affect climate variability.

The global image was generated from a simulation using the Parallel Ocean Program (POP) at LANL, using a Mercator grid with 1/4-degree resolution at the Equator and an average latitudinal resolution of 1/6-degree over the globe. The field displayed is the 7-year average sea-surface height variability (in cm), which highlights the regions of active circulation. The inset figure shows, based on a different simulation using the same model, a snapshot of the ocean's salinity (salt content) at a depth of 1,100 meters in the Atlantic Ocean near the Strait of Gibraltar. Because enhanced evaporation in the Mediterranean Sea creates higher salinity water, very salty water (in red) flows out of the Mediterranean and mixes with the less saline water of the Atlantic Ocean (in blue). Very small features of the turbulent flow can be seen in this simulation of the Atlantic Ocean, which used a Mercator grid with 0.1° resolution at the equator.

Sources: ***Global Image***
Albert Semtner/Naval Postgraduate School. The modeling work was done by Robert Malone, Richard Smith, John Dukowicz, and Mathew Maltrud (LANL), and Albert Semtner (Naval Postgraduate School).

Mediterranean Salt Eddies Image
Robert Malone/Los Alamos National Laboratory. The modeling work was done by Richard Smith and Mathew Maltrud (LANL), and Frank Bryan and Matthew Hecht (National Center for Atmospheric Research), with support from the Department of Energy CHAMMP Program and the National Science Foundation.

COLOR PLATE 3 (page 109)

Arctic Ozone Image Time Series, 1971–1997. Unusually low values of total ozone were observed over the Arctic in the spring of 1997. During an approximately 2-week period in March 1997, the satellite-based Total Ozone Mapping Spectrometer (TOMS) instruments found that the ozone levels over a large region centered over the North Pole were as much as 40 percent below the normal amount for this time of year. These levels, which were confirmed by ground-based measurements, are significantly lower than levels observed in most recent years. The ozone losses demonstrate that, for appropriate meteorological conditions (which can vary significantly from one year to the next), appreciable chemically induced ozone depletion resulting from human activities can occur in the Arctic as well as the Antarctic. The Arctic ozone losses are clearly worsening and are becoming comparable to those observed over Antarctica in the mid-1980s.

The figure shows March monthly average total ozone polar stereographic images for 1971 and 1972 (Nimbus-4 satellite, BUV instrument); 1979, 1980, 1990, and 1993 (Nimbus-7 satellite, TOMS instrument); 1996 (NOAA-9 satellite, SBUV /2 instrument); and 1997 (Earth Probe satellite, TOMS instrument). High ozone values are yellow-red in color, while low total ozone values are blue-purple in color. Note the distinct differences in ozone between the earlier years and later years in the Arctic region.

Source: Paul Newman/NASA Goddard Space Flight Center.

COLOR PLATE 4 (page 110)

Global Topography. This global elevation image is based on data that provide a significant increase in detail over previously available elevation data. These data can provide information on slope, landforms, water drainage patterns, and mountain effects for users in many diverse fields of study, including studies involving global circulation models, water resources, geology and geophysics, ecology, soil science, botany, and glaciers. Topographic data are also critical to computer-based procedures used to correct and animate remotely sensed satellite and other global data.

The data set was developed by the U.S. Geological Survey in collaboration with other Federal agencies and international Earth science organizations, including NASA, UNEP, USAID, the Instituto Nacional de Estadistica Geografica e Informatica of Mexico, the Scientific Committee on Antarctic Research, the New Zealand Manaaki Whenua Landcare Agency, and the Geographical Survey Institute of Japan. The data are available via the Internet at <http://edcwww.cr.usgs.gov/landdaac/gtopo30/>.

Source: Susan Greenlee/USGS.

COLOR PLATE 5 (page 111)

Global Land Cover. At the global scale, many data collection and analysis activities rely on satellites. Key examples include the use of satellite data to produce global and continental land-cover maps. The U.S. Geological Survey (USGS), the University of Nebraska–Lincoln, and the European Union's Joint Research Centre generated this global synthesis of information on land cover at a spatial resolution of 1 km (about 0.6 miles). These data, already in wide use, are of great utility in a range of environmental research and modeling applications.

The global land cover characteristics database was developed on a continent-by-continent basis using data obtained by the Advanced Very High-Resolution Radiometer (AVHRR), a NASA-developed instrument that flies aboard a NOAA satellite, during a period spanning April 1992 through March 1993. Each continental data set contains unique elements based on the geographical aspects of the specific continent. In addition, a core set of derived thematic maps, produced through the aggregation of seasonal land-cover regions, is included in each continental data set. The continental data sets are combined to make six global data sets, each representing a different landscape based on a particular classification legend.

This effort is part of NASA's Earth Observing System Pathfinder Program. Funding for the project was provided by the USGS, NASA, EPA, NOAA, the USDA Forest Service, and the United Nations Environment Programme. The database has been adopted by the International Geosphere-Biosphere Programme Data and Information System (IGBP-DIS) office to fill its requirement for a global 1-km land-cover data set. These data are available on the Internet at <http://edcwww.cr.usgs.gov/landdaac/>.

Source: *Thomas Loveland/USGS.*

COLOR PLATE 6 (page 112)

U.S. East Coast High-Resolution Ocean Chlorophyll Image from SeaWiFS. Ocean color is largely determined by the concentration of microscopic marine plants called phytoplankton. Because different types of phytoplankton contain different concentrations of chlorophyll, they appear as different colors to sensitive satellite instruments such as the Sea-viewing Wide Field-of-View Sensor (SeaWiFS).

Images from SeaWiFS, launched in 1997 on the SeaStar satellite, are playing a major role in understanding the behavior and consequences of the 1997–98 El Niño event and in other global change research. The SeaWiFS data, which are the first readily available ocean-color data in more than 10 years, provide scientists with a new source of information about the global biosphere.

Accurate measurements of phytoplankton concentration from this instrument are important both to climate and global change research and to local and regional economic concerns. Measurements being taken include observations of coastal blooms of algae, which have been associated with cholera outbreaks around the world. Early detection of these blooms, and subsequent in-water sampling, may allow actions that could significantly reduce the impact of such outbreaks. Red tides, ocean dumping of organic and chemical waste, and, conceivably, oil spills can also be tracked with SeaWiFS data.

Source: *Provided by the SeaWiFS Project, NASA/Goddard Space Flight Center.*

Color Plate 7 (page 113)

Tropical Rainfall Measuring Mission. The Tropical Rainfall Measuring Mission (TRMM) is a cooperative program with Japan. The TRMM satellite carries instruments to measure three-dimensional rainfall distribution and total rainfall, cloud distribution, Earth radiation balance, and lightning. TRMM observations of rainfall will be particularly important for studies of the global hydrological cycle and for testing the ability of models to simulate and predict climate accurately on a seasonal to interannual time scale, especially El Niño events. This NASA satellite was successfully launched by Japan in November 1997.

The data for this 2-day composite of global rainfall comes from the TRMM Imaging Radar. Super Typhoon Paka can be seen in the Pacific Ocean (just off center of the top left image). The data were combined to highlight cold temperatures (bright yellow) found in many tropical storms. The cold temperatures are due to scattering effects of ice above the storm's freezing level. Darker blues are indicative of higher moisture in the atmosphere due to water vapor, clouds, and rainfall.

Source: *NASA/Goddard Space Flight Center, Laboratory for Atmospheres (Christian Kidd/Mark Sutton).*

Color Plate 8 (page 114)

Regional Climate Change Workshops. What are the risks and opportunities for the United States—its people, its environment, and its economy—associated with increased climate variability and climate change? This question is being addressed in a National Assessment of the Consequences of Climate Change for the United States being conducted by the USGCRP. As an initial step, 20 regional workshops, encompassing every state and territory, are identifying the distinctive regional characteristics and potential consequences of climate change and variability. The maps indicate the eight regions in which workshops were held in 1997, and the 12 workshops being held in 1998.

APPENDIX D

U.S. GLOBAL CHANGE RESEARCH PROGRAM ORGANIZATION AND MANAGEMENT

The USGCRP Mandate

The USGCRP was established in 1989, and was included as a Presidential Initiative in the FY90 budget as a high-priority research effort, designed to:

- Address key uncertainties about changes in the Earth system, both natural and human-induced
- Monitor, understand, and predict global change
- Provide a sound scientific basis for national and international decisionmaking on global change issues.[1]

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

- "...development and coordination of a comprehensive and integrated United States research program which will assist the Nation and the 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."[2]

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 approach recognizes the profound economic, social, and ecological implications of global changes and the need to maintain U.S. leadership in this area.

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

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

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, for development of mitigation strategies, or for the Climate Change Action Plan.

Presidents Bush and Clinton, and Congress, have supported the USGCRP as a high priority in the national scientific research agenda.

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 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. 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.

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. The SGCR currently includes representation from the Departments of Agriculture, Commerce (National Oceanic and Atmospheric Administration), Defense, Energy, Health and Human Services (National Institute of Environmental Health Sciences), Interior (U.S. Geological Survey), and State; the Environmental Protection Agency, the National Aeronautics and Space Administration, the National Science Foundation, and the Smithsonian Institution; and liaison representation from the Executive Office of the President (Office of Science and Technology Policy and Office of Management and Budget), the National Research Council, the Council on Environmental Quality, and the Office of the Federal Coordinator for Meteorology.

A few of the agencies participating in the USGCRP 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.

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 decade to century 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.

Organization and Management Plan

In April 1997, the SGCR approved a new Organization and Management Plan to explain and document the programmatic and management structure of the USGCRP. The Organization and Management Plan establishes a set of formal interagency panels and working groups composed of agency program leaders. Under the overall direction of the SGCR, these program leaders will assume responsibility for program direction and coordination in each of the following areas:

1) Program panels for four global environmental research issues: 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 Aquatic Ecosystems.
2) Working groups for four integrating issues: Integrated Global Observing and Monitoring Systems; Global Change Data, Products, and Information Services; Earth System Science; and Human Contributions and Responses to Global Change.

3) Working groups for functional issues: International Research Collaboration and Coordination; Global Change Education and Communications; and Assessment of the Consequences and Impacts of Global Change at Regional and National Scales.

Although these various aspects of the USGCRP can be differentiated, it is important to recognize that they are also closely coupled and that a major responsibility of the SGCR is to sustain the cohesiveness of the overriding responsibility to treat the Earth system as an integrated whole. The Organization and Management Plan defines the new structure and responsibilities of the panels and working groups and the organizational structure for both encouraging and coordinating this set of efforts.

The Organization and Management Plan continues the operation of the Coordination Office of the U.S. Global Change Research Program, which was established in 1993 to support program coordination and management. The USGCRP Office, which is staffed by the participating agencies and departments, is responsible for facilitating the year-to-year planning and day-to-day coordination and communication needs of the program, coordinating the preparation of the annual edition of *Our Changing Planet* and periodic research plans, maintaining budget and technical databases on USGCRP programs, and other functions in support of the SGCR.

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 Geosphere-Biosphere Programme, and the International Human Dimensions of Global Environmental Change Programme. These efforts underpin U.S. participation in and contributions to the international assessments related to aspects of global change.

The USGCRP maintains an active interaction with the National Academy of Sciences complex through the Board on Sustainable Development, the 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. Groups under the National Research Council evaluate the USGCRP periodically for scientific merit and continued relevance.

APPENDIX E

NEW 1997 GLOBAL CHANGE DATA PRODUCTS

This appendix contains a representative listing of global change research data products made available for the first time in 1997 by USGCRP agencies:

- **DOE**
  - Carbon dioxide emissions from fossil-fuel burning, hydraulic cement production, and gas flaring regions, 1950–1994
  - Carbon-14 measurements in atmospheric CO_2 from Northern and Southern Hemisphere sites, 1962–1993
  - Atmospheric CO_2 concentrations—Mauna Loa Observatory, Hawaii, 1958–1996
  - U.S. daily snow depth measurements from 195 stations
  - Annual and seasonal global temperature anomalies in the troposphere and low stratosphere, 1958–1996
  - Northern Hemisphere biome- and process-specific forest areas and gross merchantable volumes (1890–1990)
  - Comprehensive database of woody vegetation responses to elevated atmospheric CO_2
  - New data from ARM field sites, including cloud cover parameters, dew on leaves, soil heat flow and moisture, relative humidity, precipitation, atmospheric pressure, vapor pressure mixing ratio, IR radiation, longwave and shortwave radiation, solar radiation, sky brightness temperature, dew point and dry bulb temperatures, soil temperature, and water vapor
- **DOC/NOAA**
  - Daily temperature and precipitation for North America
  - ISCCP Level B2 data for NOAA-12 and NOAA-14 satellites
  - OACES data sets from shipboard CO_2 observations
  - Continental-Scale International Project data from the 1995 and 1996 enhanced seasonal observing periods
  - Data set for U.S. precipitation intensity and frequency for the past 100 years
  - 5,110 GOES data tapes rescued by transfer to new media

- **DOI/U.S. Geological Survey**
  - Global land 1-km AVHRR 10-day composites, April 1992 – July 1995
  - Global land cover characterization data base, 1-km AVHRR data
  - Global 30 arc-second elevation data set
  - Federal regional land cover data sets from Landsat TM data, Federal Region 3 (PA, DE, DC, MD, VA, and WV)
  - Declassified intelligence satellite photographs, 1960–1972
  - Digital UN-FAO soil map of the world
  - NASA Landsat data collection (MSS and TM Pathfinder data)
- **NASA/Jet Propulsion Laboratory**
  - SSM/I Pathfinder EASE-Grid ocean geophysical products (with NOAA and NSIDC)
  - AVHRR weekly global and regional 18-km gridded daytime/nighttime MCSST
  - NSCAT global 25-km and ocean winds science products
  - TOPEX/Poseidon Altimeter merged geophysical data record
- **NASA/Langley Research Center**
  - Langley 8-year shortwave and longwave radiation budget
  - Aerosol Research Branch 48-inch lidar observations
  - Biomass burning 5x5 degree data
  - ISCCP regional experiment cirrus Phase I/II data sets
  - FIRE Atlantic stratocumulus transition experiment data
  - Total solar irradiance data from UARS
  - Surface solar energy monthly data
  - ERBE S-7 monthly medium-wide data
  - Aerosol, nitrogen dioxide, and ozone profiles from SAGE-II
  - Brazil Field Experiment smoke, clouds, and radiation data
- **NASA/Goddard Space Flight Center**
  - Atlas of Northern Hemisphere storm patterns, 1957–1989
  - Surface-atmosphere exchange of methane
  - SBUV ozone and solar spectral irradiance data
  - Radiances and pigment concentration data from the Nimbus-7 CZCS
  - Climatology interdisciplinary data collection
  - Natural disaster reference database
  - MODIS airborne simulator data and imagery
  - Ocean Altimeter Pathfinder data set
  - Ocean optics and pigments data
  - Ice altimetry data for Greenland and Antarctica

- Airborne oceanographic lidar ocean color data
- Greenland airborne precision elevation survey
- SeaWiFS data
- Normalized differential vegetation index taken in near-real-time
- Global gridded (2x2.5 degree) atmospheric variables produced by an assimilation system using existing data, 1985–1990
- TOMS near-real-time data

- **NASA/Marshall Space Flight Center**
  - Products from SSM/I on the DMSP-F14, including integrated water vapor, cloud liquid water, and oceanic wind speed
  - GAI long-range lightning network data
  - Optical transient detector lightning products
- **NSF**
  - U.S. JGOFS Arabian Sea Process Study data
  - U.S. GLOBEC Northwest Atlantic Program data.

APPENDIX F

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Notes

NOTES

Our Changing Planet FY99 Edition

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Departments and agencies, through their representatives to the Subcommittee on Global Change Research, provided FY99 program highlights.

Abstract

Our Changing Planet: The FY 1999 Global Change Research Program is a report to Congress supplementing the President's FY99 budget, pursuant to the Global Change Research Act of 1990. The report describes the U.S. Global Change Research Program (USGCRP); presents highlights of recent and ongoing scientific research on key global change issues; presents highlights of current developments in integrating activities supported by the USGCRP; outlines a National Assessment of the Consequences of Climate Change for the United States, initiated as a core USGCRP activity; and provides a detailed view of the FY99 USGCRP budget, including FY99 program components and program highlights by agency. Achieving the goals of this program will require continued strong support for the scientific research needed to improve understanding of how human activities are affecting the global environment, and of how natural and human-induced change is affecting society.

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On the Back Cover

Deviations of the Observed Sea Surface Temperature from Normal (°C), Comparing Warm Episodes from December 1982 and December 1997. The maps of the deviations from normal sea surface temperatures in the Pacific Ocean show areas of extreme warmth in December 1982 and December 1997. These periods represent the peak of the previous "El Niño of the century" (1982–83) and what appears to be the peak of the even larger 1997–98 event. However, because the temperature-cooling effect of stratospheric aerosols resulting from the El Chichon volcanic eruption in 1982 probably led to a slight reduction in the observed deviation from normal temperature at that time, the two El Niño events are probably very close in size.

The El Niño Southern Oscillation (ENSO) Observing System used to gather the data needed for these maps is a composite system of ocean and atmosphere observations in the tropical Pacific Ocean. The system is made up of four complementary networks: The Tropical Atmosphere/Ocean (TAO) array of deep-ocean moorings; surface drifting buoys; tide gauges; and measurements made from Volunteer Observing Ships (VOS). These measurements of oceanic and atmospheric variables are used in conjunction with remotely sensed measurements from satellites to document what is happening at and below the ocean's surface. These networks provide the data that form the basis for early warnings of impending ENSO events and for monitoring the events as they progress.

Source: Ants Leetmaa/NOAA Climate Prediction Center.

The U.S. Global Change Research Program