# OUR CHANGING PLANET

## THE FY2000
## U.S. GLOBAL CHANGE RESEARCH PROGRAM

*Implementation Plan and Budget Overview*

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 2000 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, C. Chesters (NASA/GSFC) and T. Nielsen (University of Hawaii).

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THE FY2000
U.S. GLOBAL CHANGE RESEARCH PROGRAM

*The Nation's Research Investments*
*To Understand the Complexity of Global Environmental Change*

## Implementation Plan and Budget Overview

*Perspectives for the USGCRP for the Decade Ahead*
*Preparing the Agenda for the 21st Century*

A Report by the Subcommittee on Global Change Research,
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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
**OFFICE OF SCIENCE AND TECHNOLOGY POLICY**
WASHINGTON D.C. 20502

March 1999

Members of Congress:

I am pleased to forward a copy of *Our Changing Planet: The FY 2000 U.S. Global Change Research Program*. This annual report was prepared under the auspices of the President's National Science and Technology Council (NSTC).

The first edition of *Our Changing Planet* was transmitted to Congress as a supplement to the FY 1990 budget. Over the last decade, this program has brought about a fundamental improvement in our knowledge of global-scale environmental change. We have a much better understanding of the causes and consequences of ozone depletion, land cover change, patterns of climate variability (such as El Niño/Southern Oscillation phenomena in the tropical Pacific Ocean), and the longer-term climate change that stands as one of our greatest environmental challenges as we enter the 21st century.

These research successes have led to a series of new investigations of climate change, ecological impacts, atmospheric chemistry, human dimensions of change, the global water cycle, and, most prominently, the global carbon cycle. A focused initiative in carbon cycle science, highlighted in the FY 2000 budget, is designed to provide the information needed for more effective management of carbon held in U.S. agricultural and forest lands. It will also examine the opportunities for enhancing carbon uptake, which holds promise of reducing greenhouse gas emissions while providing environmental and economic benefits in the years ahead. The application of science to creating useful information for decision makers in the public and private sector is an increasingly important aspect of the USGCRP. The program is in the midst of its first National Assessment of the potential consequences of climate change for the United States. Nineteen workshops have been held around the country, and analyses of the impacts of climate change on our Nation's agriculture, forests, water resources, coastal areas, and human health are underway. A National Assessment Report, scheduled for publication in early 2000, will bring together regional and sectoral analyses to create a national picture, identify adaptation and resource management options, and define further research needs.

The USGCRP has been strongly backed by each Administration and Congress since its inception. The FY 2000 Budget Request demonstrates President Clinton's continuing commitment to supporting the research that provides the knowledge we need to preserve environmental quality for future generations. The Administration looks forward to working with you as we carry on this bipartisan tradition of support for sound science.

I commend all the public and private sector participants in this program, and particularly the members of the Subcommittee on Global Change Research who manage this effort for the participating agencies, for their contributions to this important research endeavor.

Neal Lane

Neal Lane
Director

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# EXECUTIVE SUMMARY

The U.S. Global Change Research Program (USGCRP) stands at the threshold of a major transition. Over the next several years, in addition to continuing to improve our understanding of the Earth's environment and how it is changing, the program will greatly advance our knowledge about the implications of such change for society. The research successes of the last decade have laid the foundation for a global environmental change information service that will allow global change research results to be applied more effectively to national needs.

Since its establishment a decade ago, the USGCRP has supported a comprehensive program of scientific research on the multiple issues presented by climatic and other changes in the Earth system. USGCRP-supported research has produced substantial increases in knowledge, predictive understanding, and documented evidence of global environmental change, including major scientific advances in the understanding of stratospheric ozone depletion, the El Niño-Southern Oscillation phenomenon, global climate change, tropical deforestation, and other issues.

These interlinked problems of global environmental change present long-term challenges at local and regional scales as well. Science has much to contribute to the management of these challenges. In the next decade, the USGCRP will focus on understanding the Earth system as a whole, on the dynamics of environmental change, and on connecting that knowledge to societal needs, including the provision of information on regional implications of change. A series of five broad objectives are guiding the program as it pursues these goals:

1. Determine the origins, rates, and likely future course of natural and anthropogenic changes.
2. Increase understanding of the combined effects of multiple stresses on ecosystems.
3. Understand and model global environmental change and its processes on finer spatial scales and across a wide range of timescales.
4. Address the potential for surprises and abrupt changes in the global environment.
5. Understand and assess the impacts of global environmental change and their consequences for the United States.

## Organization of the Program

A recent National Research Council report, *Global Environmental Change: Research Pathways for the Next Decade*, which was commissioned by the USGCRP, has influenced the definition of the near-term research challenges identified in this report, and is important input to developing a new long-term research strategy for the USGCRP, which will be completed in FY 2000.

To respond to the scientific challenges described in the Pathways report, the USGCRP will be organized and managed as a series of closely-linked Program Elements. This FY 2000 Implementation Plan and Budget Overview contains detailed descriptions of a series of research challenges and FY 2000 objectives for each Program Element.

## USGCRP Program Elements

USGCRP Program Elements include:

1. Understanding the Earth's Climate System, with a focus on improving our understanding of the climate system as a whole, rather than focusing on its individual components, and thus improving our ability to predict climate change and variability.
2. Biology and Biogeochemistry of Ecosystems, with a focus on improving understanding of the relationship between a changing biosphere and a changing climate and the impacts of global change on managed and natural ecosystems.
3. Composition and Chemistry of the Atmosphere, with a focus on improving our understanding of the global-scale impacts of natural and human processes on the chemical composition of the atmosphere and determining the effect of such changes on air quality and human health.
4. Paleoenvironment and Paleoclimate, with a focus on providing a quantitative understanding of the envelope of natural environmental variability, on timescales from centuries to millennia, within which the effects of human activities on the planet's biosphere, geosphere, and atmosphere can be assessed.
5. Human Dimensions of Global Change, with a focus on explaining how humans intervene in the Earth system and are themselves affected by the interactions between natural and social processes.
6. The Global Water Cycle, with a focus on improving our understanding of the movement of water through the land, atmosphere, and ocean, and on how global change may increase or decrease regional water availability.

Finally, Carbon Cycle Science is receiving heightened emphasis within the USGCRP. The need to understand how carbon cycles through the Earth system is critically important to the ability to predict future climate change. The USGCRP is establishing a Carbon Cycle Science Initiative, with significant new investments proposed in the FY 2000 budget. This effort will provide critical scientific information on the fate of carbon dioxide in the environment, the sources and sinks of carbon dioxide on continental and regional scales, and how sinks might change naturally over time or be enhanced by agricultural or forestry practices. A new level of interagency coordination is being put in place to pursue this important objective. The program will be guided in this task by a science plan that has been drafted with extensive participation by many of the leading scientists in this field.

# SUMMARY OF KEY USGCRP ACCOMPLISHMENTS IN 1998

**National Assessment:** The U.S. National Assessment of the Potential Consequences of Climate Variability and Change was initiated in 1997 to define potential vulnerabilities and coping strategies for the United States in the context of future climate variability and change. The USGCRP coordinates the assessment, which involves geographical regions, socioeconomic and natural resource sectors, and a national synthesis. The Global Change Research Act of 1990 requires an assessment, and it has been used to emphasize broad stakeholder participation that extends beyond the research community.

In early 1998, the USGCRP appointed a National Assessment Synthesis Team, with members broadly representing the public and private sectors, to provide intellectual leadership to the National Assessment and to manage the overall synthesis of regional and sectoral information. Twelve additional regional scoping workshops took place in 1998, bringing the total number held in 1997-1998 to 19. Many of the regions initiated their analyses of key issues and preparation of reports in a common format, and continued stakeholder engagement. In addition, the Synthesis Team selected five sectors — agriculture, coastal areas and marine resources, forests, human health, and water resources—for assessment. For each sector, the Synthesis Team appointed a team that is conducting an assessment of key issues and vulnerabilities, with reports to be published in a common format.

**El Niño-Southern Oscillation (ENSO) forecasting:** Substantial improvements in the field of short-term climate prediction and the application of these developing capabilities to problems of social and economic consequence continued in 1998. Over the last year, USGCRP-supported scientists developed new products and methodologies based on insights generated by the 1997-1998 ENSO event, including climate information tailored for regions such as the Pacific Northwest and California, and the implementation of a series of regional Climate Outlook Fora throughout the world. In addition, scientists anticipated the current La Niña conditions in mid-1998.

**Global temperature record:** Based on observations of global average surface temperature, scientists from both NASA's Goddard Institute of Space Studies and NOAA's National Climatic Data Center found that 1998 was, by a good margin, the warmest year on record since widespread instrumental measurements began in the 1860s. The record warming also showed up in the microwave satellite temperature record of tropospheric temperatures compiled by NASA's Marshall Space Flight Center. This continues the recent pattern of very warm conditions during the 1980s and 1990s.

**Warmest period in at least 1000 years:** Paleoclimatic reconstructions of pre-instrumental temperatures in the Northern Hemisphere indicate that the late 20th century is the warmest period in at least the last 1000 years. While the Medieval Warm Period in Europe was somewhat warmer for that region, that warming, unlike the current one, did not affect the entire hemisphere. These reconstructions

also show that the cold period of the 16th to 18th centuries that is often labeled the Little Ice Age was also mainly a regional climatic cooling covering the North Atlantic region and did not involve the whole Northern Hemisphere. The key implication of these findings is that the very warm, hemispheric conditions during the latter part of the 20th century are even less likely than previously believed to be due to a natural fluctuation and are more likely to be significantly affected by anthropogenic influences.

**North America carbon sink:** Analyses of the gradients and fluxes of carbon dioxide concentrations over North America during a recent five-year period indicate that the forests, soils, and sediments of North America may be sequestering surprisingly large amounts of carbon, thereby somewhat limiting the rise being caused by the increasing use of fossil fuels. While the regrowth of forests in the Northeast may be one contributor to the uptake (and so may become limited as forests mature), other processes, such as changes in land use and agricultural practices, also may be contributing to the uptake. Although a number of studies suggest that North America is a carbon sink, the findings on the size of the sink vary. Further research is needed to better understand the location and mechanisms of sources and sinks and to narrow the uncertainty of the estimates.

**Greenhouse gas increase and ozone depletion:** The rise in the atmospheric concentration of greenhouse gases that causes warming at the surface tends to cause cooling in the lower stratosphere, and may affect the propagation of waves and transport of trace substances from the troposphere to the stratosphere. Any cooling of the stratosphere is likely to enhance ozone depletion, potentially delaying the recovery of the ozone layer that is expected due to the reduction in stratospheric halogen concentrations resulting from emission reductions associated with the Montreal Protocol on Substances that Deplete the Ozone Layer.

**Assessment of Ozone Depletion:** USGCRP results were prominent in the Scientific Assessment of Ozone Depletion, released in June by the United Nations Environmental Programme and the World Meteorological Organization. The total combined abundance of ozone-depleting compounds in the lower atmosphere peaked in about 1994 and is now slowly declining. In the stratosphere, combined abundance of chlorine is expected to peak before the year 2000, but direct evidence for the recovery of the ozone layer still lies well into the future. Detailed analysis has provided conclusive evidence of statistically significant reductions of ozone over northern mid-latitudes for the time period 1980-1996. This depletion is largest in the lower and upper stratosphere (~7.5%/decade) and smallest in the middle stratosphere (~2%/decade near 30 km).

**Long-range transport of air pollution:** Data from ground- and space-based instruments have shown clear evidence for long-range transport of pollutants over relatively unpolluted areas. In some cases, plumes of polluted air originally from South and East Asia have been shown to reach the West Coast of the United States; transport of mineral desert dust from Africa to the southeastern U.S. and of smoke and ash from Mexican forest fires into the northeastern U.S. also has been demonstrated.

**Ocean analysis:** The Joint Global Ocean Flux Studies (JGOFS) program, in cooperation with the World Ocean Circulation Experiment (WOCE), has logged a decade of observations of the surface waters at two mid-ocean subtropical sites off Hawaii and Bermuda. The suite of data gathered on ocean climate, nutrient cycling, biological production, ecological community composition, particulate sedimentation, and carbon dioxide from ships and moored buoys is unique in the history of oceanography. These data are providing invaluable insights into the biocomplexity of the central ocean. Time series observations have shown that nitrogen fixation plays a major role in supporting new production. A comparison of the two sites indicates very different nutrient and primary production dynamics.

**Tropical Rainfall Measuring Mission (TRMM):** One year after its successful launch, TRMM has proven to be valuable for both scientific research and development of new weather forecasting capabilities. The scientific understanding resulting from this mission will greatly enhance our knowledge of how storms and hurricanes form and dissipate.

**Radarsat:** The U.S.-Canadian Radarsat provided the first detailed radar map of Antarctica. Nearly 70 percent of the Earth's fresh water is contained in the Antarctic region, and changes in this reservoir directly influence world sea levels and climate.

**Fire monitoring:** In an effort to improve the monitoring of the fires in Central America and Mexico, the NASA Earth Science Enterprise worked with NOAA to develop a new Internet site to provide information to study fires. Other fires worldwide have been monitored, including those in Indonesia and Russia, and the results are available via the Internet.

**SeaWiFS:** One year after its successful launch, the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) is providing important data on coastal upwelling in the U.S. Northwest, Argentina, and South Africa. Upwelling fosters dramatic plankton blooms, a critical food source for fish. These SeaWiFS data are used to understand the role of oceans in removing carbon dioxide from the atmosphere, and the ocean's productivity. The spacecraft is also providing valuable images of the land.

# GLOBAL ENVIRONMENTAL CHANGE INFORMATION SERVICE

During the last decade, USGCRP-supported research has increased the world's scientific knowledge of global environmental change. Research supported by the USGCRP is laying the foundation for a viable, fully functioning U.S. Global Environmental Change Information Service supported by a multidisciplinary scientific research community. This service would assist society by providing information on how a changing global environment (i.e., physical, biological, and human systems) affects regions within the United States.

For example, in the last five years, USGCRP-supported research has assisted in the production and distribution of rainfall and temperature forecasts on timescales ranging from three to five days up to seasonal and interannual timescales. The challenge for the next decade is to expand global environmental change information to all timescales—days, seasonal, interannual, decadal, centennial, and millennial forecasts—and to include information on climate, ecosystems, carbon, water, and so forth.

The U.S. Global Environmental Change Information Service will integrate research, assessment, and prediction activities with the more traditional distribution of scientific information to provide:

1. Interface between producers of scientific information and decisionmakers/clients (e.g., Federal agencies, national security offices at the State Department, the intelligence community, the National Security Council, state and local governments, and the public) to ensure useful information is developed and distributed for the benefit of all.
2. Creation of environmental change information products for use by decisionmakers in affected sectors, including agriculture, human health, water resources, and energy.
3. Integration of currently existing elements of an environmental information service, including: national assessment programs; global change management applications and information activities; global change data and information activities; and the Global Change Research Information Office (GCRIO).

# A VISION AND PERSPECTIVE FOR THE DECADE AHEAD

## Setting the Stage for Global Change Research in the 21st Century

The U.S. Global Change Research Program stands at the threshold of a major transition. Over the next several years, in addition to continuing to improve our understanding of the Earth's environment and how it is changing, the program will advance greatly our understanding of the implications of such change for society. The research successes of the last decade have laid the foundation for establishment of a global environmental change information service that will allow global change research results to be applied more effectively to national needs.

In the early 1980s, when climate research began in earnest on a global scale, the problem of understanding the entire Earth system seemed in many ways intractable. Climate system behavior, excepting a few well-known features such as the ice ages and the annual march of the seasons, seemed chaotic. Accurate prediction of the future course of change thus appeared very unlikely. Although it was apparent that scientific research was required to increase understanding of a set of newly identified global-scale environmental changes, it was by no means clear where progress was most likely to be achieved.

In response to this challenge, the establishment of the U.S. Global Change Research Program led to a comprehensive program of support for research across a broad range of Earth system science issues. The result has been a remarkable change in perspective. Scientists discovered the ozone hole, in part through routine surveillance; determined its spatial extent, temporal behavior, and chemical origins; and showed it was caused by human activities. Observations demonstrated a long-term, statistically significant decline in ozone amounts over most of the Earth's lower atmosphere, much of which is attributable to changes in atmospheric chemistry associated with human activities. A rapid increase in scientific understanding supported a global consensus on steps to ameliorate the problem. Ongoing research and monitoring have shown that the emissions controls on chlorofluorocarbons (CFCs) and related molecules implemented under the Montreal Protocol on Substances That Deplete the Ozone Layer have begun to have an effect, as the concentration of chlorine-containing source gases at the Earth's surface has begun to decrease. Field experiments, long-term global observations, and computational modeling all played key roles in advancing our scientific understanding of ozone depletion.

As these events took place, another group of scientists began to pursue studies of El Niño, leading to equally remarkable scientific developments. These studies have

shown beyond any doubt that the El Niño-Southern Oscillation process, in which the actions of the ocean and the atmosphere are closely coupled, has some degree of predictability in its behavior. The scientific community, working in the context of the USGCRP, successfully predicted the onset of the 1997-1998 El Niño and some of the resulting climate anomalies around the world. Societies made limited but significant advance preparations; in some cases economic consequences were minimized and loss of lives and property was reduced.

Coincident with these and other research successes, a large fraction of the research community was achieving an even more visible and significant result. USGCRP-supported observations and analyses played a prominent role in demonstrating that emissions of carbon dioxide and other trace gases resulting from human activities are changing the composition of the atmosphere. Projections indicate that the changes over the next century will increase atmospheric concentrations of greenhouse gases to levels not seen in tens of millions of years—periods when the climate was substantially different than today. Observations suggest that the human-induced changes in atmospheric composition are already starting to change the climate. Careful measurements of surface temperatures around the world indicate that the global average temperature has risen substantially in the latter half of this century, compared both to observed temperatures since the 19th century and to estimated temperatures reconstructed from tree rings and other evidence back as far as a thousand years. Substantial improvements in climate models have been achieved and these models project increases over the next century in global average temperatures of from $2^{o}$ to $7^{o}$ F, as well as shifts in precipitation and a significant acceleration in the rate of sea-level rise.

Observations and monitoring from space of changing land cover, along with the production and distribution of global land cover data, 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 and quantified changes in tropical and subtropical land cover, such as the loss of tropical forest in Brazil. Changes in land cover and land use are occurring around the world at an increasingly rapid rate, driven largely by human activities. Research has documented that changes in land cover such as the conversion of forest to pasture in the tropics, and changes in land use such as increases in fertilizer applications to cropland worldwide, are contributing to changes in atmospheric composition and may also contribute to climate change on both regional and global scales.

The real significance of all these scientific developments is seen most clearly when they are taken together. Several major environmental processes are now understood and there is some degree of predictability in their behaviors. A deeper appreciation of how the Earth's oceans, atmosphere, and land surface function together as a dynamic system is being gained. Over the next decade, the causes and consequences of an entire suite of interacting large-scale environmental changes will be better understood. The future course of such changes, and the limitations of prediction, will become clearer. Scientific knowledge will improve the preservation and enhancement of environmental quality and the management of environmental change.

Achieving this vision requires new science findings and better assessment and interpretation of scientific information. The full spectrum of public and private-sector decisionmakers also need routine, reliable, and readily understood scientific insight.

The United States and other nations face an emerging group of environmental problems that are relatively new to public and private-sector institutions. The global reach of such problems means that collective actions are necessary. Yet the interlinked issues of climate change, loss of biodiversity, and land-use and land-cover changes are not only global issues; they present long-term challenges at local and regional scales as well.

Science has much to contribute to the management of these issues. Longstanding climate-related problems (e.g., droughts, floods, reduced agricultural production, and pest infestations) now can be anticipated to some extent. Better understanding of the complexity of changes on planet Earth, such as temperature and precipitation patterns, creates opportunities to reduce exposure and enhance resiliency in socioeconomic systems.

Estimating in advance the magnitude of these problems or the value of opportunities to respond is extremely difficult. One thing is already clear, however—current economic measurements alone do not suffice to explain or judge the severity of such problems. The importance of some issues far outstrips any purely economic measurement. Some representative examples:

### ◆ Societal Costs and Impacts of the El Niño

In any given year, the effects of weather and climate result in societal costs. Climate anomalies of the past two years, most directly related to El Niño, have accounted for worldwide impacts exceeding $30 billion. Inclusion of impacts related to the recent flooding in China, which is believed to be partially attributable to the 1997-98 El Niño, could push these direct losses to $60 billion. This most recent El Niño also claimed 21,000 lives, displaced 4.5 million people, and affected 82 million acres of land through severe flood, drought, and fire. Costs from the El Niño in terms of slowed development and lost opportunities have yet to be measured, but surely involve economic losses even higher than the direct costs. Early estimates of the value of preparedness in areas such as California and Peru suggest that perhaps one-half of the likely cost in the absence of any advance warning was avoided in 1997-98. These limited successes were based on experimental predictions that can be further improved. When regional summer climate perturbations are better understood and projected, the severe impacts of events like 1998's multi-billion-dollar U.S. drought or the tenfold-more-expensive floods in China might be ameliorated—any reduction in their impacts would be a noteworthy improvement. The knowledge of how to avert disaster through forecasting, make advance preparations, and use early warning systems effectively now appear to be within reach scientifically.

### ◆ Patterns of Change in the Frequencies of Hurricanes

Over the next decade, it will likely become known whether the recent epoch (nearly 30 years) of infrequent hurricane landfalls along the East Coast of the United States—during which time we have greatly increased our vulnerability by building in coastal regions—has been supplanted by a return to conditions similar to those of the 1930s, 1940s, and 1950s. In that event, it is much more likely that the long-

feared "category 4" (132-155 mph, such as the unnamed 1947 storm that hit southeast Florida and Louisiana) or "category 5" hurricane (156+ mph, such as the 1935 Florida Keys storm) will make landfall in a densely populated area by 2010. The losses to the insurance industry from such an event, or the cumulative impact of more frequent category 2 and 3 events, could render privately funded insurance unavailable, perhaps even bankrupting a large portion of the industry. Studies of a category 4 hurricane that passed through Florida and Alabama in 1926 indicate that the same hurricane today would cause an estimated $77 billion in damage. The economic and societal value of supplying constantly improving information that could enable the industry to remain viable is still unknown. This value could be substantial; that the industry itself is investing in some research on this subject indicates its high level of concern. Such information will allow U.S. Government decisionmakers to assess more reliably whether or not to become the default insurer. Some, but not much, of the needed information is available now. Again, much more relevant information is believed to be within reach scientifically with a sufficient research effort.

### ◆ Issues of Fresh Water Availability

Social scientists commonly identify limited availability of fresh water, a resource many of us take for granted in the United States, as potentially one of the most pervasive crises of the coming century. Setting aside the question of whether certain countries may have gone to war over water by 2010, how will things look politically and economically in the American West? Tension between states and localities will have reached acute levels if the climate system continues to exacerbate problems such as the diminished Colorado River runoff. (The Ogallala Aquifer in the Texas High Plains offers an example of affected populations already having to adjust to changes in the water balance.) Is the West's water supply sufficient to meet future needs? In the fastest growing areas of the West the demand for water for all uses already exceeds supply. What, then, will a knowledge of nature's tendency to sustain or hinder development in the West ultimately be worth? Insights provided by studies of the historical impacts of climate on water and agricultural resources, and emerging from current research efforts, indicate that this problem could prove to be extremely costly. For example, under current conditions, it is estimated that droughts cost, on the average, $6 billion to $8 billion annually within the United States. Thus, advances in current understanding of these and recent multi-billion-dollar droughts (such as the 1987-1992 events in the West and the 1995-1996 event in Texas) may lead to improvements worth up to a billion dollars annually.

### ◆ Influences of Sources and Sinks for Carbon on the Earth's Climate

By 2010, scientists throughout the world will be producing regional maps of large carbon sources and sinks. In all likelihood, managed terrestrial ecosystems (e.g., replanted forests) will have been shown to be an important multi-decadal sink. By 2010, the United States may well have been confirmed and shown conclusively to possess such a sink and to have the capacity to augment it, again subject to major social forces pro and con. The gradual realization by governments of the full implications of these regional maps of carbon sources and sinks cannot help but alter the

terms of the debate about emission controls. If the scientific effort is integrated across ocean, land, and air and managed effectively, it can demonstrate to the world that an adequate monitoring effort is feasible and that regional mitigation and sequestration can be made a serious part of the international negotiations. This invaluable information seems well within reach of the research effort which is already organizing to do the job.

### ◆ The Influence of Climate Change on the Salmon Fishery

In the United States, renewal licensing of major dams constructed decades ago has become a serious issue, in part because of the ecological consequences of their presence. The USGCRP has helped to clarify the relationship of climate-related regional variations in salmon productivity on timescales of a few decades to overall observed decline in the Columbia River and other Pacific Northwest river ecosystems. Many other insights about the coupling of the Earth's major ecological systems to climate variability and change will result from the proposed research effort. The availability and timeliness of these insights will rest very much on the kind of research program assembled. This program can provide relevant information not only about the freshwater resource on which the dams and the fish depend, but a far more complete picture of the true natural background against which the effects of the dams can be judged.

### ◆ Changes in Air Quality

The combination of population growth and industrialization of developing countries, notably in South and East Asia, is leading to dramatically reduced air quality in these regions on a large spatial scale. Plumes of polluted air are being transported out into previously unpolluted regions and at some times reach the coastal regions of the United States (in particular the West Coast), affecting the background concentrations of ozone and other species important for air quality in some regions. New satellite instruments for measuring tropospheric ozone will show clearly the spatial extent of these plumes and their day-to-day variation. Governments in these developing countries will begin to realize that they must take steps to control local pollution, including reduction of fossil fuel combustion, switching to less polluting fuels (e.g., from high-sulfur coal to petroleum products containing less sulfur), and importing of emissions control technologies. Such steps offer the potential to reduce greenhouse gas emissions and emissions of air pollutants at the same time. Results obtained from the USGCRP on global tropospheric chemistry will allow U.S. policymakers to understand better the sources of polluted air and the regional and global impact of these emissions and their changes.

### ◆ Changes in Ozone Concentrations in the Atmosphere

The Montreal Protocol will continue to lead to reductions in concentrations of some ozone-destroying gases in the atmosphere in the early part of the 21st century. Many of the "quick fixes" called for under the Protocol (e.g., reduction of methyl chloroform) already will have taken place, and halogen concentrations will have begun to decrease very slowly, based on the natural lifetimes for CFCs, which are more than 100 years for some compounds. Monitoring by the USGCRP of surface-level con-

centrations of CFCs, their replacements, and related halogenated hydrocarbons is helping to assess international compliance with the Protocol, and may help provide information on the regional distribution of emissions of any regulated compounds. The response of the ozone layer to these reduced levels of CFCs and related compounds is studied routinely by USGCRP agencies with a combination of ground-, balloon-, and space-based instruments. These measurements and associated modeling efforts will continue to help demonstrate whether the "replenishment" of the ozone layer is occurring, as is expected, as anthropogenically amplified stratospheric chlorine levels decrease--or, alternatively, whether other processes (such as stratospheric cooling associated with increased greenhouse gas concentrations or increasing levels of stratospheric bromine) are interfering with the expected recovery by creating conditions under which lower amounts of chlorine can still deplete stratospheric ozone.

The economic value of the understanding gained through the USGCRP cannot be accurately calculated, both because of limitations in current economic methodology and lack of accurate data. It is clear, however, that the total value is significant (on the order of tens of billions of dollars annually). Part of the USGCRP research plan is to improve the ability to document the economic values of USGCRP research and applications, and thus to be able to include such estimates as an input in the research planning process.

# CHANGING VISION FOR THE RESEARCH AGENDA FOR THE 21ST CENTURY

## Creating a New Partnership Between Science and Public Policy

The growing relevance of Earth system science to policy concerns was central to the establishment of the USGCRP as a Presidential Initiative in 1988. In 1990 Congress passed The Global Change Research Act, which called for:

*"...the 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;" and "...increasing the overall effectiveness and productivity of Federal global change research efforts."*

Other nations similarly increased their emphasis on research designed to address these issues. Further, international research programs were established to provide a venue for coordinating the scientific research. Thousands of projects have been established, and many thousands of scientists have committed their professional careers to addressing this new challenge to human understanding. A new era of scientific collaboration was established as Earth system science matured as a field of knowledge during the 1990s.

## The First Decade of Research Focused on Understanding the Components of the Earth System and Modeling at the Global Scale

The first decade of global change research, including the USGCRP, was necessarily a broad attack on the multiple problems presented by climatic and other changes in the Earth system. Problems such as a potential human influence on the stratospheric ozone layer, the perplexing issue of the timing and magnitude of greenhouse warming, the degree of predictability in El Niño events, and the coupling of ecological systems to climate on the one hand and to human land-use practices on the other all demanded scientific attention. The need for greater understanding led to the creation of a range of individual projects, each focused on a seemingly quite distinct problem.

This strategy of addressing tractable parts of the Earth system was complemented by research that addressed broad global-scale Earth system processes, characteristics, and change, and sought to integrate those across the whole planet. This approach produced substantial increases in knowledge, predictive understanding, and documented evidence of changes on the global scale, including major scientific advances in the understanding of stratospheric ozone depletion, the El Niño-Southern Oscillation phenomenon, global climate change, tropical deforestation, and other issues. However, this initial strategy, more often than not, emphasized scientific understanding at spatial or temporal scales that were either of limited significance to societal interests or of limited relevance to assessing socioeconomic impacts.

## Critical Unanswered Questions and Societally Relevant Issues Remain

By the end of the 1990s it was becoming much clearer how many component parts of the Earth system are interrelated. This improved understanding of the systemic nature of the environment has resulted in the identification of a set of intriguing—and socially-relevant—scientific questions: Could global warming be influencing the timing and duration of El Niño events? Have human land-use practices, known to be a factor in carbon cycling, been influencing managed and natural ecosystems sufficiently to create large-scale, transient carbon sinks? How can the large, global-scale, but very rapid changes in the paleoclimate record be explained.

*Global Environmental Change: Research Pathways for the Next Decade*, a major report recently issued by the National Research Council of the National Academy of Sciences, concludes, in its review of the USGCRP:

> During the past decade, the USGCRP has realized an impressive array of scientific accomplishments. Progress has been made in understanding the loss of stratospheric ozone, and amendments and adjustments to the Montreal Protocol have benefited from research flowing from the USGCRP. Ice cores have provided evidence of past changes in the Earth's environment, and human-induced environmental changes have been documented. There is a much better understanding, including the development of large-scale models, of the important roles of terrestrial and marine ecosystems in the overall carbon cycle, including knowledge of how such systems might shift under a changing climate. The success in providing predictive, useful information about El Niño-Southern Oscillation (ENSO) phenomena is a significant step in providing scientific information for natural resource management and for improving human welfare, and it offers encouragement that the broader issues of climate variability and human-induced climate change can also be successfully attacked.
>
> The inherent challenges in achieving the central purposes of the USGCRP, however, will be ongoing; to ensure our well-being for the foreseeable future, it is essential to meet these challenges. They also set a difficult agenda for science....Fortunately, with 10 years of experience of successes and setbacks, we are in a far better position to meet the scientific challenges in the coming decade.

The National Research Council report, which was commissioned by the USGCRP, outlines the central issues that should characterize global environmental research in the coming decade:

> We do not understand the climate system well enough to clarify the causes and likelihood of rapid or abrupt climate changes. What does the record from the past reveal in detail about environmental changes? What will be the patterns and modes of human-forced climate changes? What will be the impacts

of multiple stresses upon systems; in other words, what are the effects on terrestrial ecosystems of changes in the chemistry of the atmosphere, changes in the patterns and intensities of land use, and changes in temperature and rainfall patterns? How will the chemistry of the atmosphere be affected by continuing patterns of human-induced forcing, and how will climate variability and change affect these changes? What is the geographical distribution of the sources and sinks of greenhouse gases, and how might they change? How will institutions respond to climate and other environmental changes? These are the types of scientific unknowns that require clarification if we are to make sound policy decisions; they are also the questions that must be answered if we are to have a sound foundation for mitigation science.

Questions such as these require a new level of intellectual and program integration in the international global environment research effort, including the USGCRP.

## Goals and Objectives for the USGCRP in the Decade Ahead

In the next decade the USGCRP will focus on understanding the Earth system as a whole, on the dynamics of environmental change, and on connecting that knowledge to societal needs. Our Nation's investment in global environmental change research is heavily driven by our need to understand the societal implications of change, because environmental changes will influence the trends and patterns of social and economic development in the United States and around the world. The research and assessment activities of the USGCRP will address, to the maximum extent possible, the needs for relevant scientific understanding and predictive skill across a range of global environmental change issues.

To provide an integrative perspective and overall direction to the program, the USGCRP will be guided by a comprehensive Overall Goal:

- Observe, understand, predict, and assess the critical natural and human-induced dynamic states and trends of the Earth's global environmental system across a wide range of time and spatial scales;
- Address those uncertainties and gaps in scientific knowledge central to the Nation's global environmental change policy interests; and
- Deliver timely information and data products essential to informed decision making that protects the environment, enhances socioeconomic development, and ensures a sustainable future for the Nation and the world.

To achieve this goal and to guide the Federal investments in global environmental change research, a series of **Research and Program Objectives** will guide the program.

**OBJECTIVE 1 – Determine the Origins, Rates, and Likely Future Course of Natural and Anthropogenic Changes:** The USGCRP should continue to refine our understanding of both natural and human-induced changes in the Earth's environment and project future changes.

**OBJECTIVE 2 – Increase Understanding of the Combined Effects of Multiple Stresses on Ecosystems:** Numerous environmental stresses are influencing the dynamics of the Earth's major ecosystems. The consequences of stresses, individually and in concert, need to be better understood.

**OBJECTIVE 3 – Understand and Model Global Environmental Change and its Processes on Finer Spatial Scales and Across a Wide Range of Timescales:** Climate change manifests itself on a regional scale, and the magnitude of change and impacts varies by region. Providing decisionmakers with the information they need requires research and modeling of global environmental change on much finer spatial scales and across a wider range of timescales than is being done today.

**OBJECTIVE 4 – Address the Potential for Surprises and Abrupt Changes in the Global Environment:** Historically the planet has experienced wide ranges of environmental and climate conditions, from ice ages to tropical-like climates in the polar regions, with dramatic changes in patterns of temperature and precipitation. The transitions between these various conditions are not always smooth and gradual, but rather can be abrupt and very rapid. Climate change resulting from greenhouse gas emissions poses the potential for abrupt change. USGCRP research, particularly in the modeling programs, must increasingly account for these potential surprises that may result from nonlinear behavior and abrupt changes in the Earth system.

**OBJECTIVE 5 – Understand and Assess the Impacts of Global Environmental Change and Their Consequences for the United States:** The USGCRP should continue its involvement in and sponsorship of regional and national-scale assessment activities, as well as the international assessments of global issues such as climate, ozone, biodiversity, forests, and so forth. Such assessments are essential for making scientific information useful for decisionmakers. The scientific questions derived from assessing how climate change affects the environment and natural resources and how these impacts lead to societal consequences are very important for the continued development of the research and programmatic agenda of the USGCRP.

The real significance of these objectives is seen most clearly when they are taken together. How several major Earth subsystems work is relatively well understood, and there is some degree of predictability in their behaviors. Researchers are poised to take a giant step toward a whole-system understanding of the Earth's environment and application of this understanding to societal needs.

**A Broad Measure of Success:** The broad suite of program elements within the USGCRP is now being modified in ways that should enable the program to achieve its objectives. This process, although it is not yet complete, has guided the creation of this implementation plan. Among the most pressing tasks ahead is the completion of a revised long-term research plan, which will more thoroughly map out the course of the USGCRP for the next decade and provide the context for annual implementation plans. The USGCRP will produce such a long-term research plan and seek endorsement of the plan by the National Academy of Sciences before the end of FY 2000.

# IMPLEMENTATION OF THE USGCRP IN FY 2000

To pursue effectively the goals and objectives described above, we have organized the USGCRP as a series of closely-linked program elements. We discuss these program elements in more detail in the sections below. The recommendations contained in the recent National Research Council report, *Global Environmental Change: Research Pathways for the Next Decade*, have significantly influenced the key issues and near-term focus areas.

Significantly enhanced interagency collaboration will be featured in the implementation of the USGCRP. By FY 2000, joint announcements of opportunity will be issued in the area of climate research in which representative agencies: 1) share overarching research goals; 2) participate in one collaborative merit-review process; 3) coordinate funding support; and 4) convene regular interagency workshops to document progress and propose changes in the integrated climate research agenda, with workshop outputs to be reflected in future budget requests. Such joint funding arrangements follow successful joint announcements in areas such as terrestrial ecosystems and paleoclimate research. In the development of new programs, such as carbon cycle research, agencies are collaborating in seeking scientific guidance in common from a single scientific advisory panel. In this way, programs are integrated at their inception.

## Program Elements

### Understanding the Earth's Climate System

The Earth's climate system is an important influence on the social and economic well-being of our societies, affecting water resources, ecosystems, and temperature patterns that enable—and in some cases restrain—a diverse array of activities. Fluctuations in climate occur naturally over time scales ranging from seasons to centuries and beyond. There is emerging evidence that humans may be influencing the climate by increasing the concentration of greenhouse gases in the atmosphere.

As evidenced by the 1997-1998 El Niño-Southern Oscillation event, climatic variations can seriously disrupt the world's socioeconomic activity, resulting in the loss of human lives and billions of dollars worldwide. However, these same fluctuations in climate can provide opportunities in some areas by, for example, bringing increased rainfall to a semi-arid region, resulting in an increase in agricultural productivity. The key to mitigating the damage and taking advantage of the opportunities presented by climate variability lies in large part in achieving a predictive understanding of the climate system as a whole, including its multiple modes of variability across timescales and its interaction with human systems. Unraveling the complexities of the climate system offers opportunities to make optimal use of this knowledge in the pursuit of economic development and social benefits in the coming century.

Throughout the past decade of climate research, the USGCRP has focused on

# La Niña Forecast January - March 1999

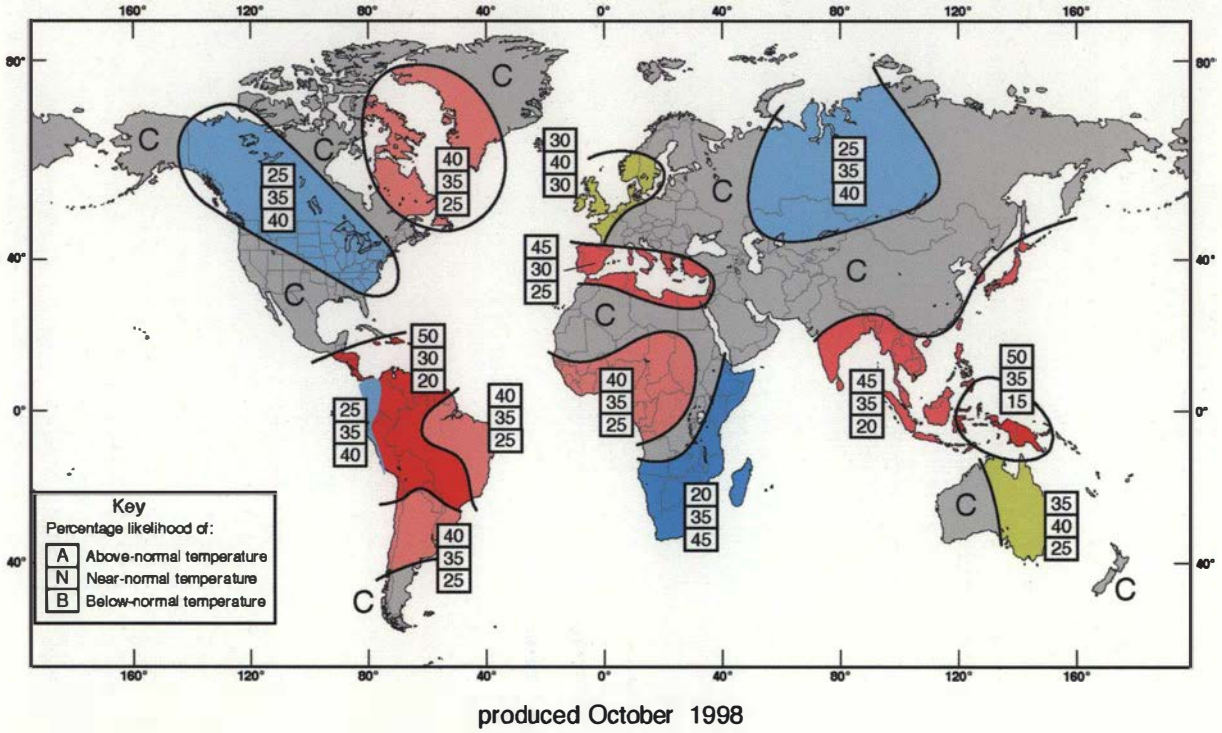



Figure 1. La Niña experimental climate forecast: Global temperature forecast for January-March 1999. (See page 93 for additional information)

understanding and predicting the variability within the Earth's various subsystems. This approach has enabled predictions of the behavior of individual subsystems, such as the El Niño-Southern Oscillation (ENSO), with some degree of confidence and has also revealed the many linkages among these subsystems (for example, the connection between ENSO and the Atlantic Ocean). Future success in climate prediction depends on tapping the current wealth of knowledge to develop an integrated understanding of the climate system as a whole, rather than focusing on its individual components.

This holistic approach will be advanced through unprecedented levels of interagency collaboration in a combination of modeling, observations, and process studies that will be conducted within the framework of the international Program on Climate Variability and Predictability (CLIVAR). The program's emphasis on both intellectual and interagency integration will lead to an improved predictive understanding of the climate system across virtually all timescales.

## Key research challenges include:

1. **ENSO:** Maintaining and improving the capability to make El Niño-Southern Oscillation predictions.
2. **Global Monsoon:** Defining global seasonal to interannual variability, especially that affecting the global monsoon system, and understanding the extent to which it is predictable.
3. **Land Surface Exchanges:** Understanding the roles of land-surface energy and water exchanges and their correct representation in models for seasonal to interannual prediction.
4. **Downscaling:** Improving the ability to interpret the effects of large-scale climate variability on a local scale.
5. **Impacts on Weather:** Understanding how seasonal to interannual climate variability is manifested in storms, floods, and other extreme weather events.
6. **Natural Climate Patterns:**
   —Improving knowledge of decadal to century-scale natural climate patterns, including their distributions in time and space.
   —Improving the optimal characterization of climate patterns, their mechanistic controls, and feedbacks.
   —Improving knowledge of the sensitivities of climate patterns to changes in forcing, including their interactions with, and responses to, anthropogenic forcing.
7. **Climate System Components:** Addressing those issues whose resolution will most efficiently and significantly advance our understanding of decadal to century-scale climate variability for specific components of the climate system.
8. **Anthropogenic Perturbations:** Improving understanding of the long-term responses of the climate system to the anthropogenic addition of radiatively active constituents to the atmosphere, and devising methods of detecting anthropogenic influences against the background of natural climate variability.

## Focus for FY 2000:

- The USGCRP will develop and publish a summary that synthesizes the state of knowledge of the relationship between El Niño cycles and longer-term anthropogenic climate change. This summary will provide input to the international assess-

ment of climate change being conducted by the Intergovernmental Panel on Climate Change for its Third Assessment Report, to be completed in 2001.

- The USGCRP will develop improved El Niño/La Niña forecasts based on models that incorporate other important multiple-time scale phenomena, particularly: 1) the longer-term anthropogenic component of the climate system; 2) the decadal variability within the ENSO cycle; and 3) the influence of subseasonal phenomena such as the Madden- Julian Oscillation on the development of ENSO events. Forecasts will improve both in terms of accuracy and in terms of regional specificity.
- The USGCRP will produce a Land Data Assimilation System that incorporates both atmospheric and land surface data (e.g., soil moisture), to provide analyzed fields for future climate studies. The program will develop at least one land surface module that contains a full suite of cold season processes (e.g., snow distribution, snow melt, and frozen ground) and will integrate it into operational models to improve the land surface exchange component of seasonal to interannual prediction.
- The USGCRP will analyze and model how climate variability associated with the ENSO phenomenon is manifested in localized extreme weather events, such as storms and floods.
- The USGCRP will document quantitative and qualitative savings/gains resulting from the use of integrated regional weather and climate forecasts.

## Biology and Biogeochemistry of Ecosystems

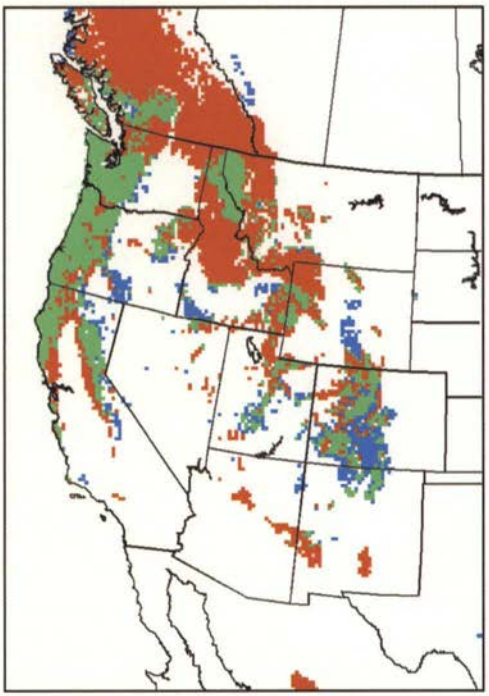
USGCRP agencies are continuing efforts to build a strong interagency focus on global change impacts on managed and natural ecosystems, and to understand the relationship between a changing biosphere and a changing climate. The primary goal of the ecosystems program element is to provide a stronger scientific basis for understanding, predicting, and responding to the consequences of global environmental changes, of both natural and human origin, in terrestrial, aquatic, coastal, and marine ecosystems. Also under study is how these changes affect ecosystems' ability to provide goods and services and support sustained use. USGCRP ecosystems research activities will be closely coordinated with the research that is being undertaken by the CENR Subcommittee on Ecological Systems, including the newly emerging efforts under the Administration's Integrated Science for Ecosystem Challenges (ISEC) initiative. Cooperation in the development and implementation of USGCRP and ISEC research strategies is particularly important for investigating the effects of multiple stresses on U.S. ecosystems, which is a priority for each.

The biosphere consists of diverse ecosystems that vary widely in complexity and productivity, in the extent to which they are managed, and in their value to society. Ecosystems directly provide forage, timber, fish, food, and fiber, as well as other services such as water cycling, climate regulation, recreational opportunities, and wildlife habitat. The proper functioning of ecosystems and sustained use of natural resources may be threatened by a number of global environmental changes. Some of the stresses or disturbances that have the greatest immediate potential to affect ecosystems adversely and alter their capability to support humanity include: changing land use and land cover; direct effects of rising $CO_2$; changes in global nitrogen cycles; and species invasions. Moreover, subjecting ecosystems to one or more of these stresses simultaneously may have a significant negative impact on ecosystem function.

# Potential Changes in Distribution of Douglas Fir

**Present-day observed species distribution**

**Change in species distribution between present-day simulated distribution and simulated distribution under 2x$CO_2$ climate**



**No change**

**Contraction**

**Extension**

Figure 2. Western North America under 2x$CO_2$ conditions. (See page 93 for additional information)

## Key research challenges include:

1. **Changing Land Use and Land Cover:** Greater understanding is needed of the relationships among land cover, land use, climate, and weather, particularly how changing land use and land cover affect local and regional climate, and how changing temperatures, altered patterns and amounts of precipitation, and increased variability in weather affect major terrestrial and marine ecosystems. The effects of changes in land use on land cover, ecosystem services, hydrologic cycles, species distribution, biodiversity, and human social and economic systems also need study.
2. **Multiple Stresses in Ecosystems:** Ecosystems subjected to more than one stress—either simultaneously or sequentially—may respond in ways qualitatively different from that which would be expected from an examination of single stresses. The dynamics of multiple stresses, and the possibility of, and indicators for, "threshold" responses in ecosystems that lead to sudden and dramatic change in ecosystem structure and function, must be better understood. Improvements also are needed in the capability to observe and develop a predictive understanding of effects of multiple, interacting environmental changes, such as combined effects of elevated $CO_2$ and reduced availability of water in terrestrial ecosystems.
3. **Changes in the Global Nitrogen Cycle.** Humans have significantly impacted the global nitrogen cycle, doubling the rate at which atmospheric nitrogen (which most organisms cannot use directly) is converted into a nutrient form that can be used by many organisms. These amounts of nitrogen in terrestrial ecosystems can affect the productivity of plants and cause shifts in the types of species present in the ecosystems, and may also, in some cases, stimulate carbon storage.

While key challenges can be readily described, the ecosystems program does not easily lend itself to the development and implementation of a focused strategy for research on ecosystem impacts. In addition, limited resources constrain the number and diversity of important ecosystems that can be analyzed; data bases from representative ecosystems are often lacking, yet crucial to modeling and predicting ecosystem responses to multiple global environmental changes; and experimental facilities for investigating the combined effects of multiple factors on intact ecosystems need to be strengthened.

## Focus in FY 2000:

- The USGCRP will continue developing and publishing inventories and models of terrestrial ecosystems that will be used to better predict how ecosystems are affected by multiple environmental stressors.
- The USGCRP will document land-use and land-cover change in regions where rapid change could potentially alter the sensitivities/vulnerabilities of the region to climate change.
- The USGCRP will examine how climate change, vegetation management practices, and disturbance affect the spread of exotic plants and the regeneration of native plants at high elevations.
- The USGCRP will understand the influence of changing precipitation and nutrient cycling patterns on species regeneration and composition, and the resulting consequences for forest growth, decomposition processes, carbon sequestration, and sustainability.

- The USGCRP will develop and apply, using tools of molecular biology, gene probes for key enzymes linking the carbon and nitrogen cycles in marine microbes.
- The USGCRP will develop methods that assess the invasiveness of nonindigenous species by combining the science of landscape ecology with the principles of risk assessment. The program will use these methods to identify those areas in the U.S. that may be vulnerable to nonindigenous species invasion due to climate change and variability.
- Using ecosystem-scale experiments involving increased $CO_2$ and other environmental factors, the USGCRP will determine how atmospheric change and potential climatic change may affect forest productivity, forest health, and species distributions.

## Composition and Chemistry of the Atmosphere

A combination of human and natural processes can affect the chemical composition of the global atmosphere. These changes can have important implications for life on Earth, including such factors as biologically damaging ultraviolet (UV) radiation, radiative forcing of the Earth/atmosphere system (which in turn affects climate), and the global composition of the atmosphere, which can affect air quality in regions. Human activity that can affect atmospheric composition on a global scale includes the use of chlorofluorocarbons and other halogenated hydrocarbons, fossil fuel combustion and the associated release of air pollutants, and changes in agricultural practices that affect the concentration of gases such as nitrous oxide and methane, as well as that of smoke. Changes in climate driven largely by increases in greenhouse gases can also be expected to affect atmospheric chemistry in complex ways that are difficult to predict. Natural processes affecting global atmospheric composition include volcanic eruptions, variations in solar radiation, and normal weather. Particular questions addressed by this element of USGCRP include:

- How are global ozone levels and surface UV fluxes changing, and how are they likely to change in the future, given expected changes in both human industrial activity and the underlying climate in which ozone chemistry takes place?
- What changes may take place in the concentrations of ozone, aerosols, and other chemically and radiatively active atmospheric constituents that may contribute to climate change, and what changes may take place in the background concentrations of trace gases that affect regional atmospheric chemistry?
- How will global changes in surface UV flux and surface-level concentrations of ozone and other gases and particulate matter affect human health and the productivity of ecosystems?

Current USGCRP activity in these areas builds on the accomplishments of previous research. For example, significant reductions in the total amount of stratospheric ozone over most of the Earth have been demonstrated over the past 20 years. A combination of airborne-, ground-, balloon-, and space-based instruments have all shown that industrially-produced chlorine- and bromine-containing chemical species contribute significantly to the observed ozone depletion. Observations have shown that the surface concentrations of several of the compounds regulated under the Montreal Protocol on Substances that Deplete the Ozone Layer have been reduced significantly, while those of the longer-

# Continental Scale Impact of Mexican Forest Fires

## Earth Probe TOMS - Absorbing Aerosols, May 16, 1998

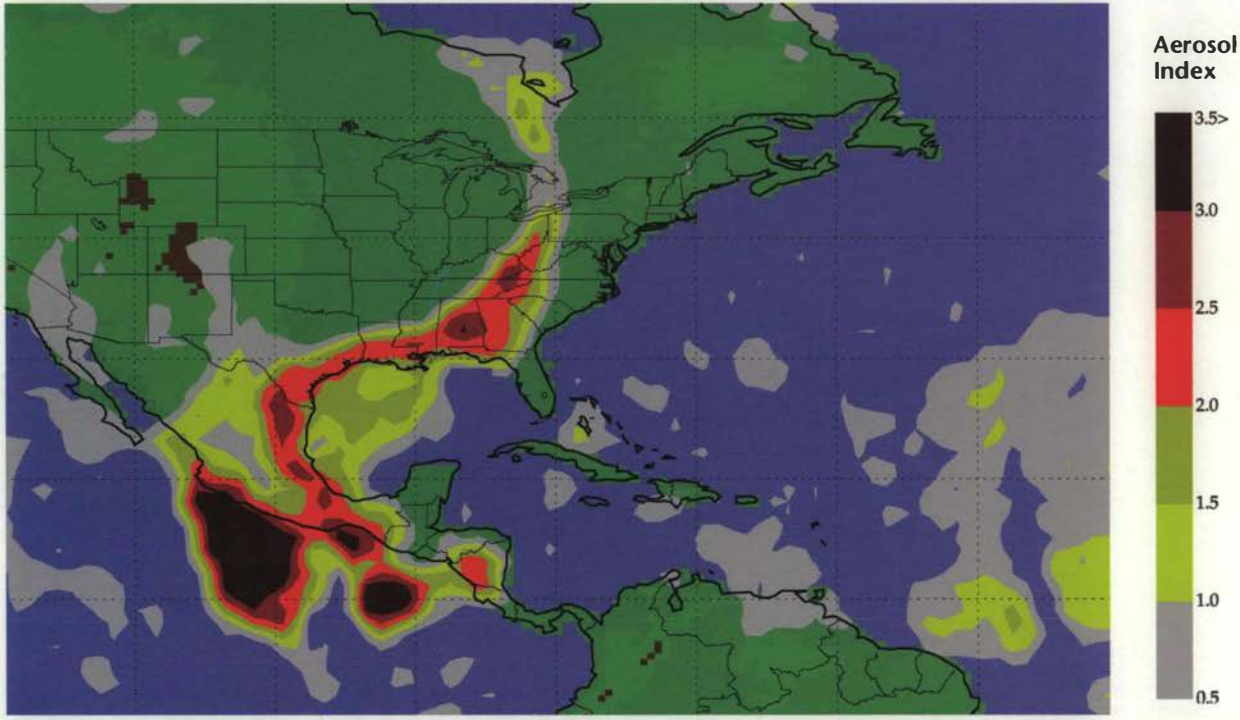



**Figure 3.** Long-range transport of smoke and dust from Mexican forest fires to the central and northeastern United States and Canada. (See page 94 for more information)

lived chlorofluorocarbons have essentially reached a maximum and will soon begin to decline. It is expected that maximum levels of stratospheric chlorine will be reached around the turn of the century. The stratosphere should be most susceptible to ozone depletion at that time; recovery of the ozone layer could, in principle, begin shortly thereafter. It is possible, however, that global climate change (which is projected to cool the stratosphere as the lower atmosphere warms), or a large volcanic eruption, could delay the projected recovery.

## Key research challenges include:

1. **Stratospheric Ozone and UV Radiation:** Defining and predicting trends in the intensity of ultraviolet exposure the Earth receives by documenting the distribution of stratospheric ozone and surface UV flux, the chemical species that control the destruction of ozone, and the meteorological variables that define the physical environment of the stratosphere; and describing the coupling between chemistry, dynamics, and radiation in the stratosphere and upper troposphere.
2. **Photochemical Oxidants:** Defining the global processes that control ozone precursor species, tropospheric ozone, and the oxidizing capacity of the global atmosphere; and developing better understanding of what determines the ability of the atmosphere to cleanse itself of pollutants, both now and in the coming decades.
3. **Atmospheric Modeling:** Improving atmospheric models to better represent the trace gas and aerosol composition of the global atmosphere, as well as its transport properties, and predicting the atmosphere's response to future levels of pollutants and to changes in climate at both global and regional scales.
4. **Atmospheric Aerosols and Radiation:** Documenting the chemical and physical properties of aerosols; and elucidating the chemical, microphysical, and transport processes that determine their size, concentration, and chemical characteristics.
5. **Toxics and Nutrients:** Documenting the rates of chemical exchange between the global atmosphere and ecosystems; and elucidating the extent to which interactions between the atmosphere and biosphere are influenced by changing concentrations and depositions of harmful and beneficial compounds.
6. **Clouds:** Documenting the role of clouds in the partitioning of trace gases in the global atmosphere between different chemical forms and in their removal from the atmosphere, as well as their contribution to surface deposition.

The USGCRP work in several of these areas, notably photochemical oxidants and toxics and nutrients, will be carried out in close collaboration with the more regionally focused work on air pollution, acid deposition, and airborne toxics carried out through other Federal research programs organized under the auspices of the Air Quality Research Subcommittee of the Committee on Environment and Natural Resources.

## Focus for FY 2000:

- The USGCRP will examine the chemistry of the stratosphere at high northern latitudes in winter, to determine the potential for an Arctic ozone hole. The study will use combined balloon and airborne measurements together with observations from an instrument currently planned for launch in late 1999 aboard a Russian satellite.

- The USGCRP will carry out significant modeling work in support of the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report, to be completed in 2001. These modeling efforts will help to simulate prior evolution of atmospheric trace constituents and aerosol composition and to forecast its future evolution. The output from these model runs will be used by climate modeling groups in their simulations of the future climate.
- The USGCRP will examine the atmospheric chemistry over Southern Africa using a combination of ground-based, airborne, and satellite-based measurements. This will help establish the influence of land-cover and land-use change on regional atmospheric composition, and the role of trace gases and aerosols in atmospheric warming.
- The USGCRP will increase knowledge of the distribution of ozone in the troposphere and southern sub-tropics using an enhanced network of balloon-based measurements. The data should provide a unique capability for the validation of tropical ozone columns derived from satellite data.
- The USGCRP will have obtained the first full year of global carbon monoxide vertical profiles. These data, obtained by an instrument scheduled for launch in mid-1999 as part of the Earth Observing System, should provide a significantly improved picture of carbon monoxide distributions. When analyzed together with data on smoke and aerosols obtained from other EOS instruments, these measurements should lead to new insights about the role of biomass burning and industrial emissions in global pollution.
- The USGCRP will have obtained surface UV flux data from the fully-implemented USGCRP ground-based UV monitoring network. These data, making use of some 60 instruments at some 50 locations, will be provided to researchers investigating biological response to ultraviolet radiation. UV flux data for other regions of the earth will be available from satellite-based techniques.
- The USGCRP will provide extended and updated data sets on the global methane budget, using a combination of long-term surface-based measurements showing unexplained interannual variations in growth rate and newly-obtained total column methane observations made from a space-based instrument launched in 1999 as part of the Earth Observing System.
- The USGCRP will carry out detailed studies of new data on the distribution and composition of aerosols in the global troposphere, based on a combination of ground-, ship- , airborne- , and space-based data; and the program will integrate these data into global numerical models designed to simulate aerosol formation, transport, and interaction with surrounding meteorology.

## Paleoenvironment/Paleoclimate

The Earth's climate and environmental history has been long, amazingly complex,and marked by enormous changes. The challenge to this element of the USGCRP is to provide a quantitative understanding of the Earth's past environment and to define the envelope of natural environmental variability within which the effects of human activities on the planet's biosphere, geosphere, and atmosphere can be assessed.

# Notable Past Droughts Reconstructed from Tree Rings

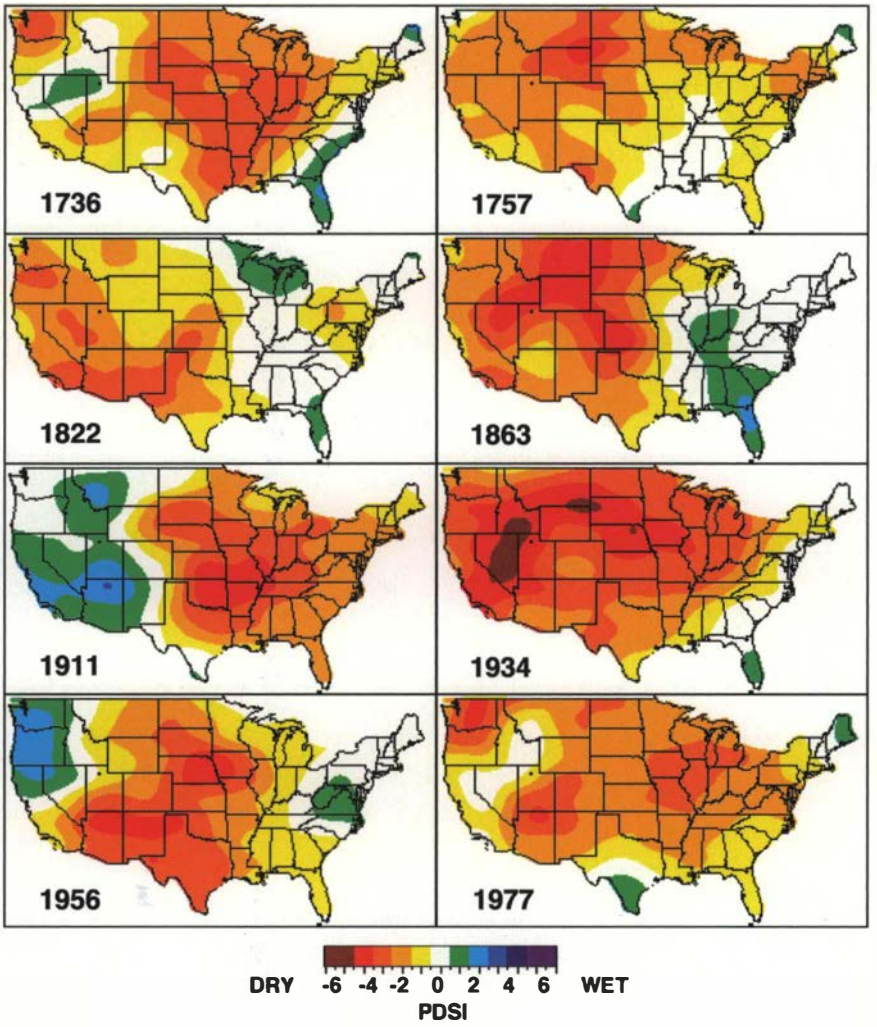



**Figure 4.** (See page 94 for additional information)

Paleoenvironmental records are derived from a wide variety of natural archives, such as: lake and ocean sediments, tree rings, wind-blown deposits, coral, and ice cores, as well as historical documents. Chemical, isotopic, and ecological analyses of these records have demonstrated that the natural climate system has varied locally and globally over a far greater range than can be inferred from relatively short-term instrumental records. In most locations, instrumental records might provide 100 years of climate data, whereas an ice core might provide an annual climate record of 10,000 to 30,000 years.

Understanding the natural environmental changes of our planet on long timescales (years to millennia) provides the context for understanding today's climate dynamics and for elucidating the impacts of natural versus anthropogenic influences. Reconstructing the historical climate record offers an enhanced understanding of the mechanisms controlling the Earth's climate system and, together with insight obtained from numerical modeling exercises, anticipates how the planet might respond to future environmental perturbations.

## Key research challenges include:

1. **Global Climate and Earth's Environment:** Documenting how the global climate and Earth's environment have changed in the past and determining the factors that caused these changes; exploring how this knowledge can be applied to understand future climate and environmental change; and establishing the natural (baseline) environment prior to human intervention.
2. **The Natural Limits of Global Environmental Variability:** Exploring the natural limits and variability of our global environment and determining how changes in the boundary conditions of the environment are manifested.
3. **Forcing Factors:** Documenting the important forcing factors that have controlled past climate and examining how these forcing factors interact and have varied in significance over time; and investigating the causes of the rapid climate change events and rapid transitions in climate state observed in the paleo record and evaluating the potential for environmental "surprises" in the near- and long-term future.

## Focus for FY 2000:

- The USGCRP will have completed the first global synthesis of paleoclimate within the context of global change research. This synthesis will be fashioned within the time frame of the last 100,000 years. The international research community will focus on establishing and understanding the temporal and spatial range of natural climate variability during the period prior to significant anthropogenic impact, and initiate the use of the paleorecord for improving the predictive ability of climate and environmental system models.
- The international paleoenvironmental data system, the World Data Center for Paleoclimate (Boulder, CO), will be in place and functioning. This will serve as the global data coordination, access, and archive point for the international research community and will include easy-access links to specialized national, regional and project databases.
- The USGCRP will have established a global network long-term paleoclimate records from corals, tree rings, ice cores, and other sources (some of which are up to 1,000 years long), and will develop statistical methodologies to link these disparate sources of climate data.
- Researchers will focus on calibrating the relatively short instrumental climate record to paleoclimate proxies, in order to assess climate change over decadal to centennial timescales.
- The USGCRP will have evaluated the hypothesis that the Arctic is one of the most sensitive regions for climate and environmental change, has undergone large changes over the last 1000 years, and, in magnitude and extent, is currently undergo-

ing an unprecedented warming. Further, the program will have begun the development and evaluation of coupled atmospheric/oceanic/sea-ice climate models and high-resolution regional models to advance our understanding of the dynamic Arctic environment and its climatic linkages to the lower latitudes.

- The USGCRP will have a much clearer understanding of natural climatic variability within quasi-stable climatic states (i.e., glacial and interglacial times). Although climatic variation occurs within all periods, research will focus on establishing the predictability of abrupt and extreme climatic events and their spatial and environmental impact.
- Research will focus on characterizing the history of the warm pool in the tropical Pacific Ocean over the last 200-300 years. Researchers will establish the history of significant changes in surface temperature and/or areal extent of this water mass under varying climatic states. This information will be essential for understanding global climate dynamics and testing models under different boundary conditions.
- Paleoenvironmental research will initiate a special emphasis on the closely interlinked relationship between human societal evolution and climatic and environmental change, with special emphasis on the last 500,000 years. Researchers will aim for a clearer understanding of both the impact of a changing environment on human development (migration, adaptation) and human impact on the environment (burning, megafauna and vegetation change).
- The USGCRP will have a much clearer understanding of climate-induced vegetation and ecosystem change over the last 20,000 years, particularly in North America. This knowledge will allow us to improve estimates of future climate-induced vegetation and ecosystem change, as well as possible biophysical and biogeochemical feedbacks to the climate.

## Human Dimensions of Global Change

For almost a decade the USGCRP has invested in research on the human dimensions of global change because it is essential to the program's ability to realize its central goals of understanding the planet and the implications of social and environmental change. This research has helped explain how humans drive important interventions in the Earth system, are affected by the interactions between natural and social processes, and are part of the solution. The USGCRP looks to the Human Dimensions Program to study response options in the face of change—what can we anticipate, how should we handle uncertainty, how might we better prepare?

The challenge of the next decade is to more meaningfully embed Human Dimensions research questions within the other elements of the USGCRP. Humans are a part of the climate system, the drivers of land cover change, increasingly significant contributors to the chemical composition of the atmosphere, and utterly dependent upon the global water cycle. But a separate focus on Human Dimensions is also required, both to capture the socially driven aspects of environmental change and to shape our understanding of the context within which we experience the impacts of natural system fluctuations.

# Land Cover Change in the Tensas River Basin

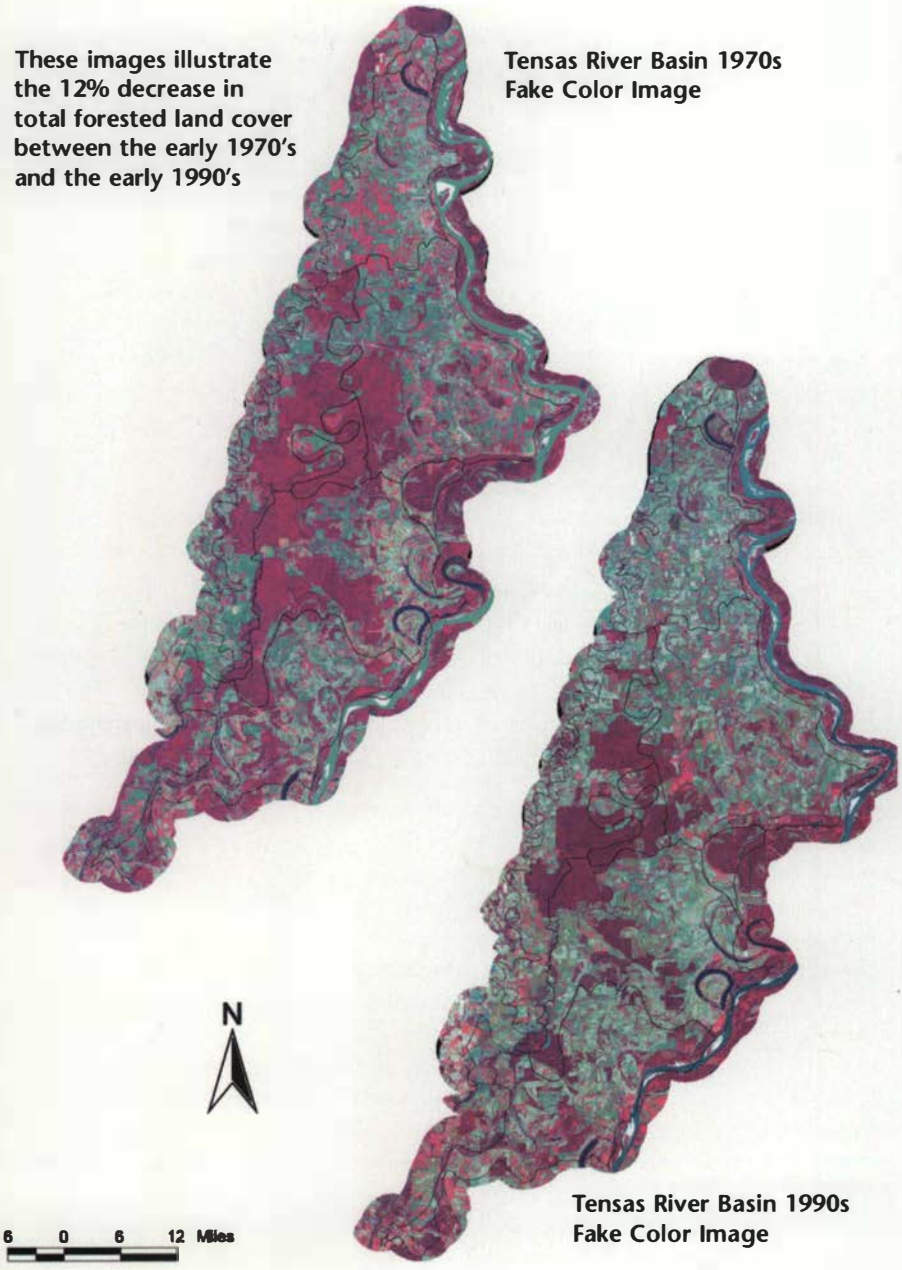



Figure 5. See page 95 for additional information

### Key research challenges include:

1. **Determining the human sensitivities to the consequences of global environmental change** for key life support systems (such as water, health, energy, natural ecosystems, and agriculture), including the economic and social dynamics of these systems.
2. **Determining a scientific foundation for analyzing the potential human responses to global change,** their effectiveness and cost, and the range of response options.
3. **Understanding the underlying social processes or driving forces behind the human relationship to the global environment,** such as human attitudes and behavior, population dynamics, institutions, and economic and technological transformations.
4. **Understanding the major human causes of change in the global environment,** and how they vary over time, across space, and between economic sectors and social groups.

### Focus for FY 2000:

- The USGCRP will demonstrate the importance of assessments research to the analysis of options for coping with the risks posed by climate variability and change. Regional-scale investigations will serve as a means for studying global to local influences in an integrated framework, understanding human and ecosystem vulnerability, developing innovative methods for assessing regional consequences, and integrating global change research.
- The USGCRP will develop integrated assessment models that include representation of greenhouse gases other than $CO_2$, carbon dioxide sinks, and carbon leakage (moving carbon emissions from countries with stringent controls to countries with little or no control).
- The USGCRP will provide improved information and analysis supporting efforts to foresee disaster and identify opportunities associated with climate through joint sponsorship of new research in Human Vulnerability to Climate Risk and Environmental Surprise.
- The USGCRP will issue a joint announcement in Human Activity and Changes in Land Use, to support research on the social, economic, and cultural processes associated with land-use change and on how land-use changes affect ecosystems and biogeochemical cycles, including the modeling of sinks.
- The USGCRP will improve our capability to model the relationship of heat-related mortality and illnesses due to anticipated increases in the intensity and duration of heat waves.

## The Global Water Cycle

The movement of water through the land, atmosphere, and ocean is termed the global water cycle. The water cycle is intimately tied to the climate of the planet through processes including latent heat exchange and the radiative effects of water vapor. Similarly, climate influences the water resources of the planet through changes in evaporation and precipitation. In examining these processes, long-distance atmospheric

transport of water, along with evaporation and precipitation, are the principal inputs in hydrological process and water-resource models. The study of the global water cycle is the unifying theme that can bridge the gap in the spatial-scale spectrum between atmospheric and hydrological sciences. This issue is in its first year and will be implemented through coordinated U.S. and international programs. Planning is underway to develop joint interagency programs in the U.S. and coordination with international programs [e.g., the Global Energy and Water Cycle Experiment (GEWEX), the Program on Climate Variability and Predictability (CLIVAR), Biological Aspects of the Hydrologic Cycle (BAHC), and potentially a more fully coordinated international Hydrology and Water Cycle Program].

The primary goal of this research is a greater understanding of the seasonal, annual, and interannual mean state and variability of water and energy cycles at continental-to-global scales, and thus a greater understanding of the interactions among the terrestrial, atmospheric, and oceanic hydrosphere in the Earth's climate system.

This understanding will be achieved through a combination of observations, modeling, and analysis at a range of spatial and temporal scales, and will provide the foundations for understanding the relationship between weather (the manifestation of fast atmospheric hydrologic processes) and climate (the long-term statistical measures of these hydrological processes.) The research program aims at furthering our understanding of these relationships---especially the relationship between the physical representation of fast hydrologic processes and climatic statistics; the relative roles of land, atmosphere, and ocean hydrologic processes in weather and climate at continental-to-global scales, from daily to interannual timescales; and a determination of how these relationships and roles vary globally and seasonally. Such advances should lead to improved inferences about the occurrence of severe weather events, such as floods and drought, that directly affect property and human safety, and permit the downscaling of hydrological variables (precipitation, surface meteorology, etc.) that can lead to improved water and environmental management.

An important element of the research program is a quantitative assessment of the improved understanding for weather prediction and for water and environmental management. In addition, advances in understanding the relationships between hydrologic processes and climate will lead directly to better inferences regarding climate change and its subsequent hydrologic impacts at regional-to-global scales. Improving this understanding is hampered by the complexity of the nonlinear hydrologic processes, and in the heterogeneity related to both process forcings and process parameters that exists at all spatial and temporal scales. Understanding is also hampered by a lack of consistent, systematic observations, making it difficult to develop and test new theories and hypotheses regarding the global water cycle.

## Key research challenges include:

1. **Land Surface Interactions:** Developing a better understanding of the coupling of land surface hydrologic processes to atmospheric processes over a range of spatial and temporal scales; the role of the land surface in climate variability and climatic extremes; and the role of the land surface in climate change and terrestrial productivity.
2. **Atmospheric Processes:** Developing a better understanding of the role of clouds

# Tropical Rainfall Measuring Mission

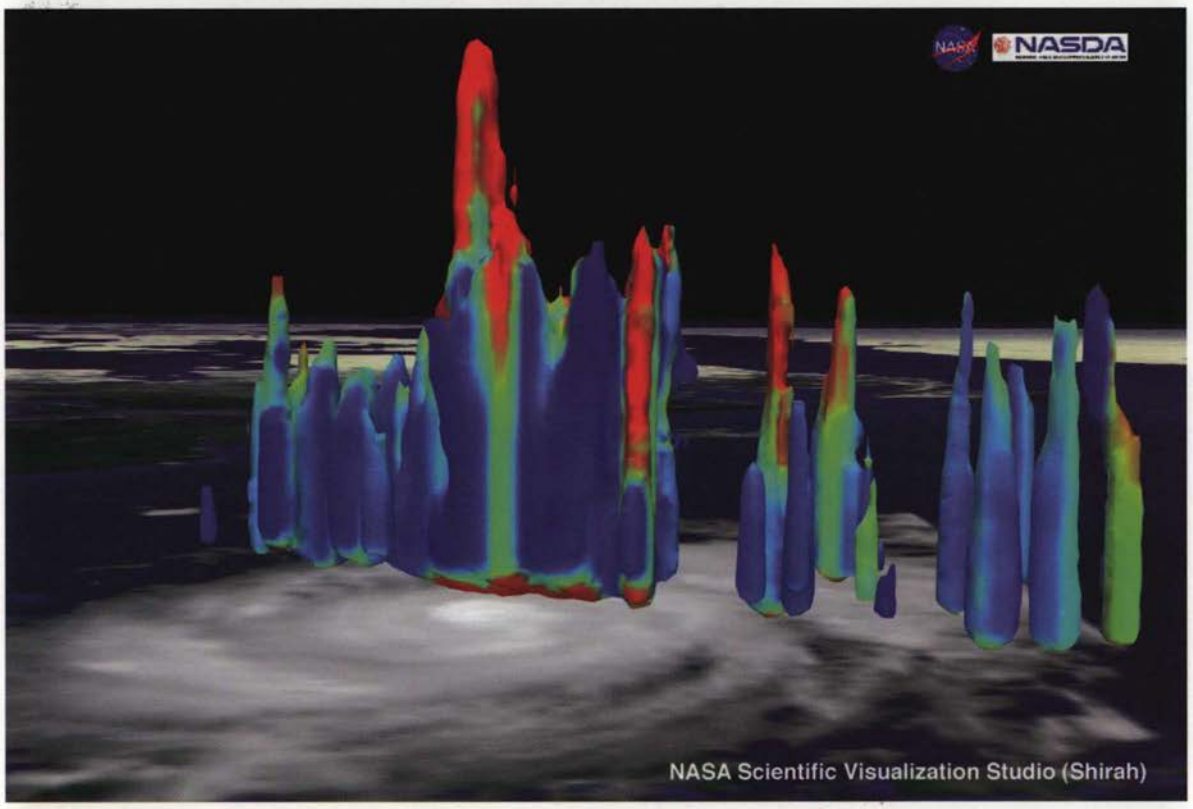



**Figure 6.** Hurricane Bonnie storm cloud, August 22, 1998. (See page 96 for additional information)

and their influence in the coupling of the atmospheric water and energy cycles, and of the vertical transport and mixing of water vapor on scales ranging from the local boundary layer to regional weather systems.

## Focus for FY 2000:

- The USGCRP will demonstrate skill in predicting changes in water resources and soil moisture on timescales up to seasonal and annual as an integral part of the climate system. As a first step, the program will quantify evaporation, precipitation, and other hydrological processes as required to improve prediction of regional precipitation over periods of one to several months
- The USGCRP will demonstrate the ability to determine radiative fluxes and diabatic heating within the atmosphere and at the surface with the precision needed to predict transient climate variations and to understand natural and anthropogenically-forced climate trends.
- The USGCRP will combine Tropical Rainfall Measuring Mission (TRMM) measurements with rainfall measurements from other sources to set a benchmark for rainfall in the tropics. We will obtain maps of the diurnal cycle of precipitation (which cannot be obtained from sun-synchronous sensors). The insight gained from this exercise will be used to reprocess 10 years of SSM/I data for climate record. This 10-year data set and ongoing TRMM measurements will be used to validate climate models as well as demonstrate the impact of rainfall in assimilation and weather forecast schemes.
- The USGCRP will establish a climatologically valid database of 60 months of rainfall data from various ground validation radar sites. The program will achieve 10% agreement among the various TRMM-related sensors for zonally averaged monthly rainfall accumulations. This will establish our confidence in how well tropical rainfall, a central component of the global water cycle, can be measured from space.
- The USGCRP will complete cloud model simulations of major storm systems in the Brazilian Amazon and at the Kwajalein atoll oceanic site for the purpose of testing latent heating estimates from TRMM.
- The USGCRP will assess the accuracy of remote and in-situ humidity measurements, and improve understanding of the climate consequences of water vapor radiation feedback. The program will conduct a field experiment at the DOE radiation testbed facility in Oklahoma, under joint NASA and DOE sponsorship.
- The USGCRP will conduct data comparison workshops, establish validation sites, and expand and improve global water vapor data sets toward the goal of quantifying and understanding the role of water vapor in meteorological, hydrological, and climatological processes.
- The USGCRP will examine linkages between land-atmosphere processes, their relationship to anthropogenic and other emissions, and the consequences of their deposition to the functioning of the biogeophysical and biogeochemical systems of southern Africa. This initiative is being built around a number of ongoing activities supported by the U.S., the international community, and African nations in the southern African region.

## Carbon Cycle Science: An FY 2000 Initiative

Rising atmospheric carbon dioxide concentration and its potential impact on future climate is an issue of global economic and political significance. The need to understand how carbon cycles through the Earth system is therefore critically important to our ability to predict any future climate change. Recent policy debates have demonstrated the need for a comprehensive, unbiased scientific understanding of sources and sinks of carbon dioxide on continental and regional scales, and how sinks might change naturally over time or be enhanced by human activities. The National Research Council's report, *Global Environmental Change: Research Pathways for the Next Decade*, specifically emphasizes the need for a comprehensive carbon cycle research strategy.

The USGCRP is answering this call by establishing the Carbon Cycle Science Initiative. USDA, DOE, DOI, NASA, NSF, DOC/NOAA, and the Smithsonian will take part in this initiative. The new program is poised to provide critical unbiased scientific information on the fate of carbon dioxide in the environment to contribute to the ongoing public dialogue. The program will:

- take advantage of ongoing breakthrough advances in innovative scientific techniques to measure, monitor, observe, and model the carbon cycle, making it possible to examine the carbon cycle comprehensively as an integrated system;
- provide the scientific foundation for estimating the capacity of land ecosystems and the ocean to sequester and store carbon dioxide released as a result of human activities;
- integrate modeling, observational, and process research to identify and quantify regional- to global-scale sources and sinks for carbon dioxide and other greenhouse gases;
- seek to understand how these sources and sinks will function in the future and provide this essential information for future climate predictions; and
- evaluate potential management strategies for enhancing carbon sequestration in the environment and in capture and disposal strategies.

Achieving these objectives will provide information to policymakers and assist with the planning of future climate research activities. It will also provide valuable information to land and forest managers in the public and private sectors, and contribute to the natural resource management missions of agencies such as USDA and DOI.

Full implementation of the new program will require a significant investment of resources and a new level of interagency coordination to ensure integration. Implementation of this program will be closely coordinated with international programs (e.g., the International Geosphere-Biosphere Programme and the World Climate Research Programme) to ensure a comprehensive international research strategy.

### Background

Carbon dioxide is exchanged naturally between three active reservoirs: the atmosphere, the ocean, and land ecosystems. Human activity has increased the amount of carbon dioxide now being exchanged between these reservoirs. Carbon dioxide is initially added to the atmosphere as a product of combustion of fossil fuel and as emissions from conversion of forested land to agriculture. About half of what is added remains in the

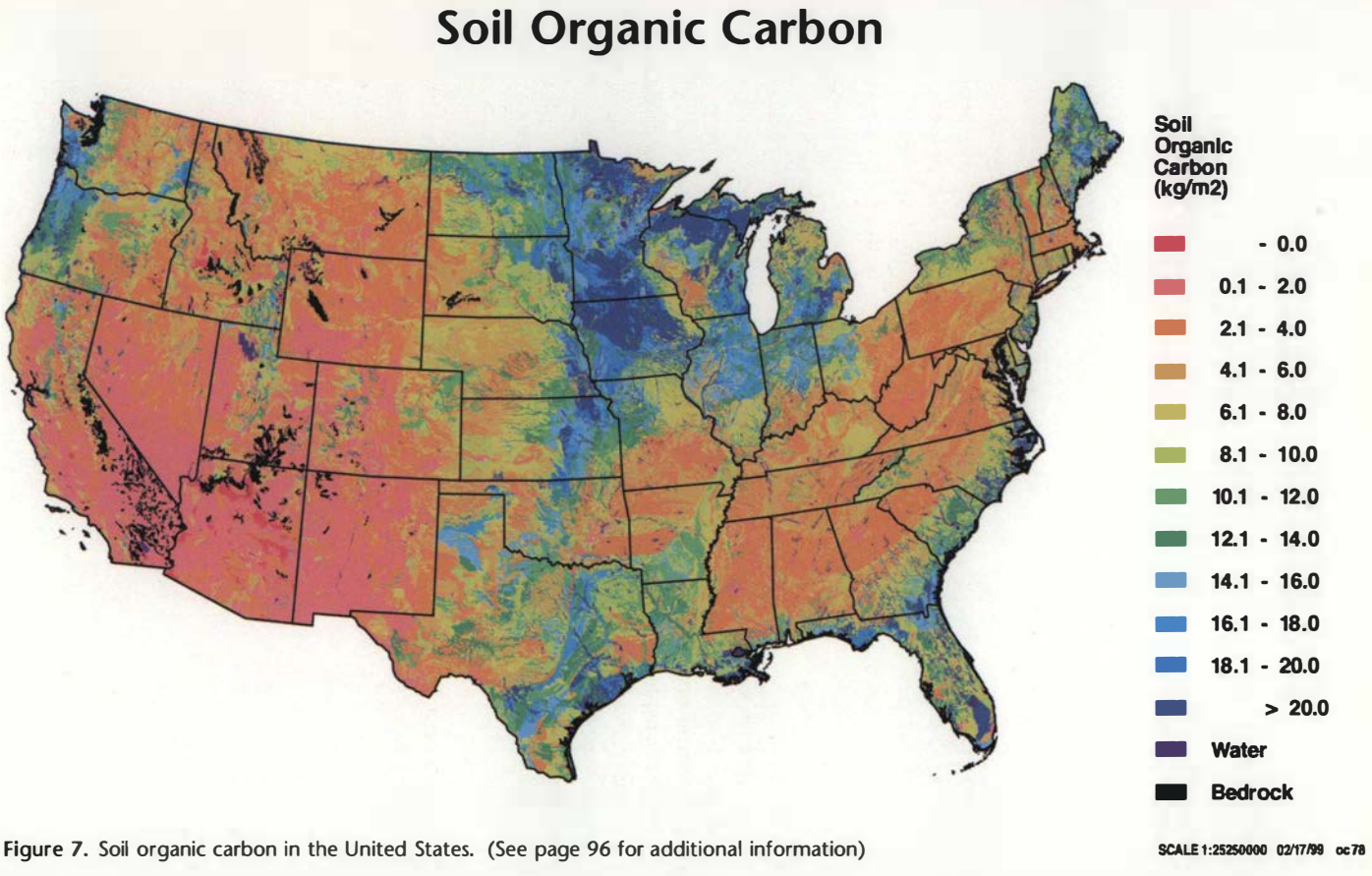



**Figure 7.** Soil organic carbon in the United States. (See page 96 for additional information)

atmosphere, and the rest is taken up by the other two reservoirs—the ocean and land and freshwater ecosystems. Uptake of carbon dioxide by these reservoirs is commonly referred to as a "sink." While we can measure the concentration of carbon dioxide in the atmosphere quite accurately, measurements of storage of carbon in the ocean and land ecosystems are still considerably uncertain.

For the past decade or more, independent approaches and innovative tools have greatly increased our understanding of how carbon dioxide is transported and stored in the Earth system. Most past research has tended to focus, appropriately, on each component of the carbon cycle separately. However, the carbon system is fundamentally integrated, and understanding of each component is now reaching the point where answers are available for how the carbon cycle operates as an integrated whole. This information is essential for use in designing and optimizing any potential carbon mitigation strategies envisioned in the next two decades.

The storage reservoir, or sink, for carbon that we know the least about is the land ecosystem. Estimates from atmospheric and oceanic data and models have predicted that the terrestrial sink is larger in the Northern Hemisphere than in the Southern Hemisphere. Recent studies have attempted to refine the location of the Northern Hemisphere sink to a continental-scale region. While there is considerable debate about the magnitude and location of the terrestrial sink, there is strong evidence that it may be very significant.

The ocean provides a long-term sink for carbon dioxide as a result of physical and biological processes that are largely independent of human control. However, humans may have inadvertently both created and destroyed terrestrial carbon sinks in the past from their manipulation of the land surface for settlement, food and energy production, and water management, for example. Climate also likely influences the magnitude of both the terrestrial and the oceanic sink. We have now reached a state of knowledge in the carbon cycle research arena where we can begin to tackle these questions and provide unbiased, scientific information to society about the location, magnitude, and cause of carbon sinks.

## Program Goal

The overarching goal of the Carbon Cycle Science Program (CCS) is to answer the following fundamental questions:

1. What has happened to the carbon dioxide that has already been emitted by human activities (anthropogenic carbon dioxide)?
2. What will be the future atmospheric carbon dioxide concentration resulting from past and future emissions?

## FY 2000 Program Highlights

The major focus of the initiative in FY 2000 will be on determining the location, magnitude, and cause of carbon sinks in North America, and how North America compares to other key regions, such as South America. Estimates of the Northern Hemisphere sink range widely; a program of integrated observations, process research, and modeling will narrow this range and provide a more accurate estimate of the North American terrestrial sink and its variability. The strategy will be to combine appropriate research approaches from the atmosphere, oceanic, terrestrial, and human dimensions aspects of

the carbon cycle, providing information on various temporal and spatial scales, necessary to providing an accurate picture of the current state of the terrestrial carbon sink over North America.

To accomplish these objectives, carbon cycle science research activities will include:

- Atmospheric and oceanographic sampling field campaigns over the continent and adjacent ocean basins, combined with atmospheric transport models to develop more robust estimates of the continental and subcontinental-scale magnitude and location of the sink (includes DOE, NOAA, and NSF).
- Local-scale experiments conducted in various regions that will begin to identify the mechanisms involved in the operation of carbon sinks on land, the quantities of carbon assimilated by ecosystems, and how quantities might change or be enhanced in the future (includes DOE, NSF, Smithsonian, and USDA).
- Evaluation of information from past and current land-use changes, both from remotely-sensed and historical records, to assess how human activity has affected carbon storage on land (includes NSF, NASA, USDA, NOAA, DOI, and DOE).
- Enhanced long-term monitoring of the atmosphere, ocean, forests, agricultural lands, and rangelands, using improved inventory techniques and new remote sensing, to determine long-term changes in carbon stocks (includes USDA, NASA, NOAA, DOE, and DOI).
- Evaluation of potential management strategies for maximizing carbon storage, including evaluation of the variability, sustainability, lifetime, and related uncertainties of different managed sequestration approaches (includes USDA and DOE).
- Integration of new observations and understanding of carbon cycle processes in regional and global carbon system models to improve projections of future atmospheric concentrations of carbon dioxide and other greenhouse gases (includes DOE, NOAA, NSF, NASA, DOI, USDA, and Smithsonian).

Understanding from each of these areas will be synthesized to represent our current state of knowledge of the carbon system, as well as incorporated into carbon system models, to provide a best estimate of how carbon sources and sinks may change in the future. This integrated approach will be the most efficient and effective way to understand the carbon sink and to provide the most accurate information on the current state of the sink over North America.

Achieving this task will require new technologies for measuring the atmosphere-land-ocean carbon system. In addition, the existing observational networks and monitoring programs will be maintained and enhanced, especially observations of undersampled aspects of the global $CO_2$ cycle, such as spatial distributions in the atmosphere, ocean temporal variations, changes of net ecosystem production (e.g., carbon gain), soil carbon transformations, and land use/vegetation changes in the tropics. Large-scale observations will be tested with locally-derived process models and hypotheses about spatial and temporal variability of $CO_2$ exchange among the major Earth system reservoirs. Models to predict carbon sources and sinks and their interannual/decadal variability (ocean and land) will be refined, incorporating the most important mechanisms and providing predictions with enhanced credibility.

**Carbon Cycle Science Initiative**
**FY 2000 Budget by Agency**
(Dollars in Millions)

| | |
|---|---|
| 7.0 | DOC/NOAA |
| 14.8 | DOE |
| 3.4 | DOI |
| 81.1 | NASA Space-Based Observations |
| 37.5 | NASA Scientific Research |
| 13.1 | NSF |
| 0.3 | Smithsonian |
| 31.5 | USDA |
| 188.7 | Total |

Carbon cycle science has a unique opportunity. Exciting techniques and a new threshold of understanding have paved the way for the next stage of carbon cycle science in the United States: developing an integrated, whole system predictive capability for the carbon system. The ultimate goal is to provide integrated estimates of carbon sources and sinks, with a focus in FY 2000 on implementing activities to determine the magnitude, location, and cause of the North American terrestrial sink. The knowledge base will then be available to provide input on how sinks might be enhanced and how they might change in the future—information of critical importance to potential decisions to manage the carbon system.

In FY 2000, activities in the Carbon Cycle Science program will provide the following results:

- A state-of-the-science report assessing the magnitude, location, and cause of the North American terrestrial sink from available data, and a research strategy for addressing uncertainties in the terrestrial sink estimates that are not reconcilable with current data;
- Implementation of integrated observation, research, and modeling activities to provide more accurate information on the location, magnitude, and cause of the North American terrestrial sink based on these identified uncertainties;
- A synthesis of global ocean carbon dioxide data, enabling the design of a research strategy for monitoring changes and identifying variability in the oceanic sink;
- Improved parameterization of key processes controlling carbon storage, such as air-sea gas exchange, a major uncertainty in ocean sink estimates;
- An improved, long-term, integrated monitoring strategy for carbon measurements in the atmosphere, ocean, and land ecosystems.

# OBSERVATION, MONITORING, AND DATA MANAGEMENT

Achieving the goals of the USGCRP program elements requires, in many cases, the documentation of change and the existence of long-term data records. The USGCRP agencies, through space-based and ground-based activities, provide many of the required long-term observations. The program also directs particular attention to the development and implementation of research observing systems to address new requirements arising from improved scientific understanding and from operational resource managers and policy imperatives.

Space-based systems have the unique advantage of obtaining global spatial coverage, particularly over the vast expanses of the oceans, sparsely populated land areas (deserts, mountains, forests, and polar regions), and the mid- and upper troposphere and stratosphere. They provide unique measurements of the Earth's radiation budget; solar output; vegetation cover; atmospheric ozone; stratospheric water vapor and aerosols; greenhouse gas distributions; sea level and ocean state; ocean surface state, level, and winds; weather; and tropical precipitation, among others.

But satellite observations alone are not sufficient; they require in-situ measurements for calibration and validation. In-situ observations are required for the measurement of parameters that cannot be estimated from space platforms (e.g., biodiversity, groundwater, carbon sequestration at the root zone, and subsurface ocean parameters). They also provide long time series of observations required for the detection and diagnosis of global change, such as surface temperature, precipitation and water resources, weather and other natural hazards, the emission or discharge of pollutants, and the impacts of multiple stresses on the environment due to human and natural causes.

To meet the need for the documentation of global changes on a long-term basis, the USGCRP integrates observations from both research and operational systems, such as NOAA's operational weather satellites and surface-based stations. The latter are essential for the USGCRP but are not included within the USGCRP programs or budget presentation.

Following are some of the specific observation and monitoring activities that support the various program elements.

**Understanding the Earth's Climate System**

- Data collection from the EOS-AM satellite will provide observations of cloud structure, water vapor distribution, aerosol particles, trace gases, and terrestrial and ocean properties. These data are required for improved monitoring and modeling of air-land and air-sea interaction and of the exchanges of carbon, energy, and water.
- Launch of JASON-1 will provide altimetry measurements for ocean circulation and sea-level change required for the monitoring and prediction of El Niño events.

# Ocean Circulation Profiling Floats

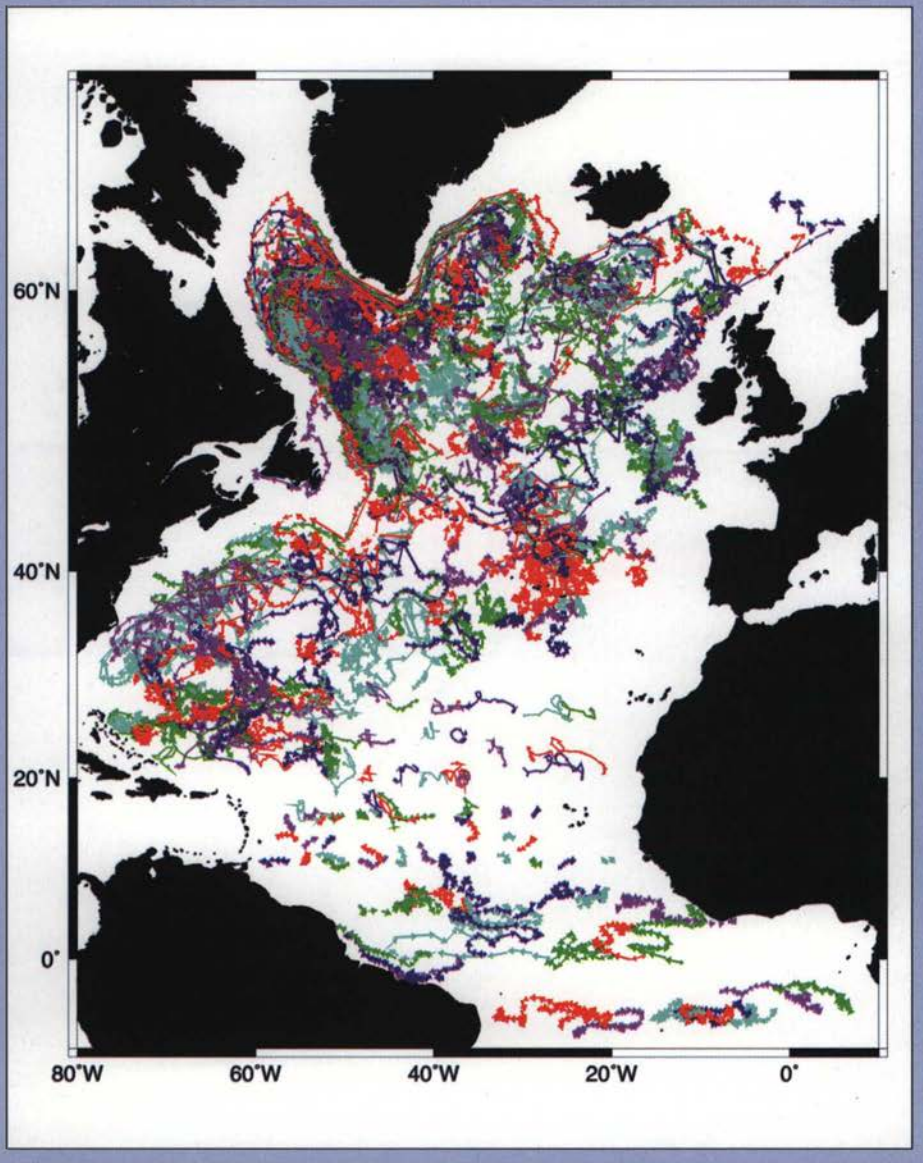



**Figure 8.** See page 97 for additional information.

- Launch of ACRIMSAT will provide accurate data to monitor solar irradiance, and for studies of solar-terrestrial/atmosphere interaction.
- Launch of the Seawinds satellite will provide more accurate measurements of ocean surface winds and wind stress required to run ocean models for El Niño prediction. The data are also required to improve weather forecasting.
- Further development of a Climate Reference Network, consisting of several hundred stations from the network of 7000 sites that measure temperature and precipitation daily, will provide stable measurements of climate change with the requisite continuity over the instrumental record.
- Deployment of a pilot climate monitoring array in the tropical Atlantic, including moorings, surface drifting buoys, and autonomous profiling floats, will complement similar platforms in the tropical Pacific and expand the global domain of ocean surface and subsurface observations. Similar deployments will be carried out in the North Pacific and the Indian Ocean.
- A third Atmospheric Radiation Measurement Station in the western Pacific will provide data on the effects of clouds on the Earth's radiative energy balance, a major source of uncertainty in climate models.

**Biology and Biogeochemistry of Ecosystems**

- Launch of the Vegetation Canopy Lidar (VCL) satellite will provide detailed measurements of the vertical structure of the vegetation canopy. These data are required to improve the mapping and categorization of vegetation/biosphere, the monitoring of change, and the parameterization in models of atmosphere-land surface processes involving the exchange of heat, momentum, moisture, and gases. The data will also contribute to distinguishing between deforestation and reforestation.
- Data from the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument on the EOS-AM satellite will provide measurements of land and ocean surface temperatures, chlorophyll fluorescence, and land surface vegetation---key elements of land and ocean biology and ecosystems.
- Ongoing data collection from the Landsat satellites will provide continued monitoring and mapping of land surface characteristics, vegetation, soils, and minerals.
- The addition of several coastal sites to the existing Long-Term Ecological Research (LTER) network will provide data on the response of a broader distribution of ecosystems to short- and long-term climate changes, as well as data on the response to other stresses.

**Composition and Chemistry of the Atmosphere**

- Continued development of the EOS Chemistry satellite, scheduled for launch in December 2002, will provide: three-dimensional profiles on a global scale of all infrared active trace gas species from the surface to the lower stratosphere and measurements of greenhouse gas concentrations, tropospheric ozone, acid rain precursors, and gas exchange leading to stratospheric ozone depletion. Data will also be

obtained on water vapor, aerosols, atmospheric temperature, polar stratospheric clouds, and cloud tops.

- Continued measurements of surface concentrations of ozone/UV radiation, and of CFCs and their replacement compounds, halons, and other chemicals regulated under the Montreal Protocol and its amendments, will be made by NOAA's Climate Monitoring and Diagnostics Laboratory network (a part of the ground-based Advanced Global Atmospheric Gas Experiment).
- Launch of the Total Ozone Mapping Spectrometer (TOMS) will lead to continued measurements of atmospheric ozone.
- Completion of the deployment of ultraviolet radiation spectrophotometers will provide data from a UV monitoring network at 14 national parks and 8 urban sites.

**Paleoenvironment/Paleoclimate**

- Improved technology to delineate more accurately the timing of pre-historical climatic events will provide data on the temporal and spatial character of natural climate variability and abrupt climate changes during the period prior to significant anthropogenic impact.
- Establishment of a global network of centuries-long paleoclimatic time series will help create links to sedimentological, paleobiological, and geochemical data.
- Continued extraction of paleoenvironmental data from North America will provide a clearer evaluation of climate-induced vegetation and ecosystem change over the last 20,000 years.

**Human Dimensions of Climate Change**

- Data from the ongoing Landsat program will provide monitoring and categorization data on land cover and land use, urban expansion, and agricultural practices.
- Integration of climate data with human health statistics will provide information on the occurrence and spread of vector-borne diseases, heat-related mortality, and vulnerabilities of social systems to climate variability and global change processes.
- Measures of the health effects of CFC replacement chemicals (HCFCs and halogenated hydrocarbons) and UV radiation will provide information to decisionmakers.
- LTER sites, which continue to provide information on the response of ecosystems to changes due to climate and other multiple stresses, will assist in distinguishing between direct and indirect human-induced impacts.

**The Global Water Cycle**

- Continued measurements from rainfall radar on board the Tropical Rainfall Measuring Mission (TRMM) satellite, together with surface radars and rainfall stations, will provide a benchmark for rainfall in the tropics. The data will be used to develop a rainfall climatology, validate climate models, and demonstrate the impact of rainfall in assimilation and weather forecast schemes. These data will provide

key information for the improved understanding, monitoring, and modeling of the global water cycle, and assessment of water resources.

- The North American Rain Gauge Network will provide detailed information on the regional and local impact of El Niño and climate change on rainfall, water supply, and water resources.
- Data collection from the EOS-AM satellite will provide data on clouds and on the exchanges of water and energy between the atmosphere, land, and oceans. These data will also contribute to improved parameterizations in models of water/moisture transports and budgets, improved weather forecasting, and the prediction of the impacts of climate change on water resources.

**Carbon Cycle Science**

- The operation of 25 AmeriFlux sites, representing major ecosystem types in North and Central America (including forests, croplands, grasslands, rangelands, and tundra), will provide data for comparative (across ecosystem types) assessments of atmosphere/terrestrial-biosphere exchanges of energy and water, net sequestration of carbon dioxide, and the effects of environmental factors (including climate variations) on the net exchange of carbon and the role of biophysical processes controlling this exchange
- Landsat, MODIS, and VCL, along with the Advanced Very High-Resolution Radiometer (AVHRR) will provide improved global measurements of vegetation cover and changes, key components in the carbon budget and carbon cycle of the Earth system. Ocean color data from MODIS will include global ocean productivity maps at weekly time intervals for assimilation into carbon cycle models.
- Continued data collection from SeaWifs will provide global and more accurate measures of ocean biology and land surface vegetation, which are key elements in the global carbon cycle.

Data and information management from these activities are critical to the success of the USGCRP, supporting not only scientists but also a broader range of users including teachers and educators, land use managers, and the public at large. Information on the availability of data sets will be widely disseminated through the Global Change Data and Information System (GCDIS). In FY 2000, the system will provide the following data products to the broad range of users:

- Integrated global data sets from both research and operational space- and ground-based platforms supporting all the research programs of the USGCRP.
- El Niño monitoring and prediction information.
- Warning of natural hazards.
- The analysis and assessment of:
- ozone depletion and associated chemistry;
- greenhouse gas concentrations;
- global and regional land and ocean surface temperature;

- global tropical precipitation;
- global vegetation cover;
- global ocean productivity;
- global and regional carbon sources and sinks;
- global and regional ecosystems;
- natural climate changes of the past;
- global and regional water resources;
- solar-climate relations; and
- global change and vector borne diseases.

Over the longer term, USGCRP agencies are exploring ways to maintain the long-term data records necessary for documenting and understanding global change. NASA, NOAA, and DOD, the partners in the National Polar-orbiting Operational Environmental Satellite System (NPOESS), are exploring ways to extend the long-term measurements of key global change parameters beyond the EOS AM-1 and PM-1 time frame to provide a bridge into the post-2008 NPOESS era. Internationally, the United States participates with other nations in the Committee on Earth Observation Satellites, which has called for developing an Integrated Global Observing Strategy (IGOS) to link space and in-situ observations in a common strategic framework. The United States also participates in the international coordination of the Global Climate Observing System (GCOS), the Global Ocean Observing System (GOOS), and the Global Terrestrial Observing System (GTOS). The broader objective of IGOS is to develop a comprehensive strategy for integrated space-based and in-situ observations to monitor the interactive Earth system holistically, addressing the needs of scientific research and those of the broad community of users involved in operational resource management, international assessments, and policy development.

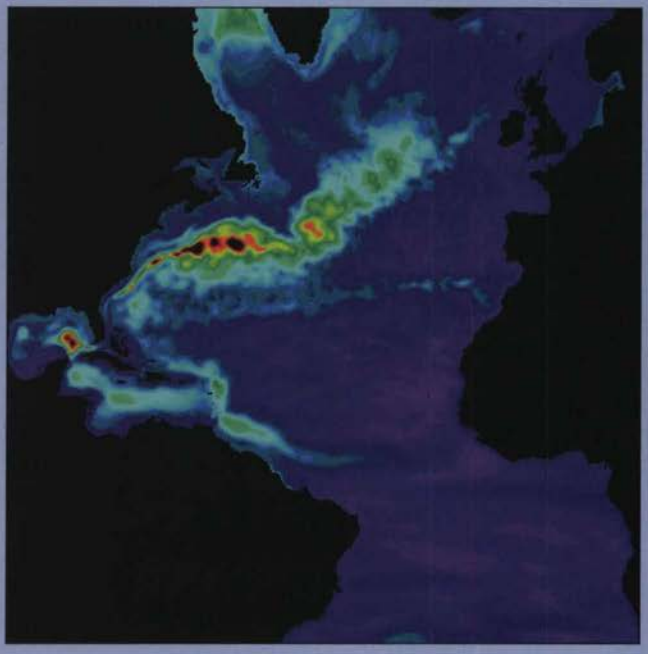
# EARTH SYSTEM MODELING AND SIMULATION

Computer simulation models are the primary tools by which knowledge of the workings of the Earth System can be integrated, and the results of these models are, in many ways, one of the major payoffs of the USGCRP. Only through Earth system models can we, for example, predict future climate variability and change, including the possible effects of human activities on the global climate system. The long-term objective of Earth system modeling and simulation is to create and apply models that provide credible predictions (including levels of certainty and uncertainty) of changes and variations in climate on regional-to-global scales, along with useful projections of potential environmental and societal consequences. Gaining scientific understanding and predictive capability for variability and change in our

## Ocean Circulation: Comparison of Modeling and Observation

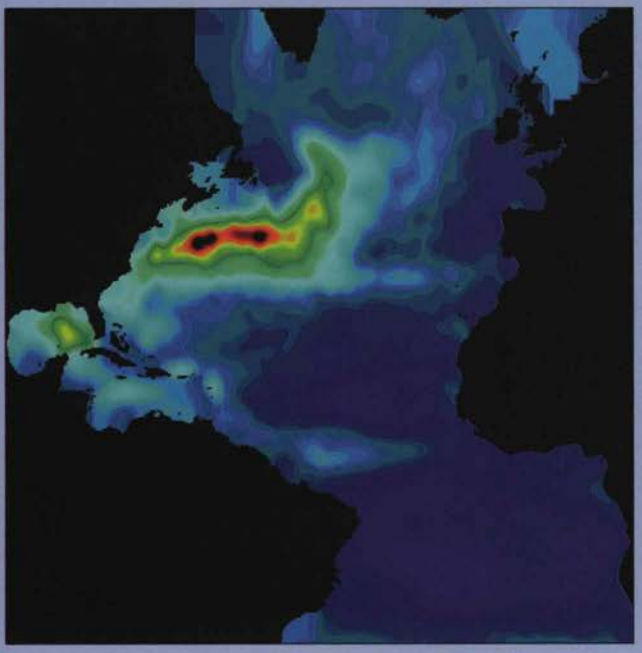
### MODELING

**MICOM**
**Sea surface height variability (3-year average)**



planet's environment requires the study of the dynamic interactions among the major components of the Earth system, including the oceans, atmosphere, land surface, and sea ice.

Over the past several years, a number of internal and external analyses have identified significant problems with the U.S. climate modeling effort. The most recent of these is a study by the National Research Council, *Capability of U.S. Climate Modeling to Support Climate Change Assessment Activities*, which states that while the U.S. community is "a world leader in intermediate and smaller climate modeling efforts, it has been less prominent in producing high-end climate modeling results, which have been featured in recent international assessments of the impact of climate change." In the modeling community, the U.S. has been falling behind many other nations in its ability to perform long-term climate simulations. Modeling centers in Australia, Canada, England, Germany, and elsewhere have computational abilities that far exceed those of



## OBSERVATION

**TOPEX (from NASA/JPL, courtesy of G. Goni**

**Figure 9.** See page 97 for additional information.

U.S. centers. The U.S. is now relying heavily on these foreign modeling centers in producing scenarios of how climate will evolve in the future. The NRC report went on to state that

> . . .insufficient human and computational resources are being devoted to high-end, computer intensive, comprehensive modeling, perhaps, in part, because of the absence of a nationally coordinated modeling strategy. . .In order to optimally use existing scientific capabilities, adequate resources, including greatly improved supercomputing capabilities, need to be provided to the climate modeling community. The reliance of the United States upon other countries for high-end climate modeling must be redressed.

The USGCRP agencies are working to provide short-term relief to the current computing capacity shortfall in the Nation's leading climate modeling centers. However, incremental changes to current capability and program structure will not be adequate to the long-term task. A more substantial response to this need is underway.

With DOE and NSF taking the lead, the USGCRP has been developing a long-range, Accelerated Climate Prediction Initiative (ACPI). The ACPI takes an integrated view of the improvements required to accelerate progress in climate simulation and projection of climate change. Interrelated activities in model development and evaluation, simulations, and projections, and analysis and assessment will be addressed by concurrent improvements in the models themselves, data availability and usefulness, computer speed and memory, collaboration and data management capabilities, and widespread institutional interaction. The USGCRP agencies will develop a more integrated modeling strategy, including improved program integration and development of overall USGCRP climate modeling priorities that are closely linked to overall USGCRP climate system research objectives.

Major steps forward in large-scale U.S. climate modeling will require major increases in computational resources and a coupling of increased computational capability with increased scientific knowledge of climatological phenomena. Indeed, the specifically articulated goals of the ACPI are to: (1) accelerate progress in general circulation model development and application; (2) reduce substantially the uncertainties in model-based projections of global environmental change on the full range of relevant timescales; and (3) increase the availability and usability of global change projections to the broader environmental research and environmental assessment communities.

It is estimated that these goals will require, from the hardware side, horizontal model resolutions of 30 km in the atmosphere, 1 km of the land surface, and 5-10 km in the ocean. These needs, added to the requirements of multiple ensemble runs for statistical confidence, dictate the imperative for teraflop (trillions of operations per second) computational capability.

To achieve this enhancement of the Nation's climate modeling capabilities,

many of the USGCRP agencies are participating in the Administration's Information Technology for the 21st Century initiative. The information technology focus for the USGCRP is on developing computational tools that will support climate modeling using the teraflop-scale computational resources created and made available through the overall Information Technology Initiative. This will be a key aspect of implementing the integrated strategy that is being developed through the ACPI.

In FY2000, USGCRP Earth system modeling and simulation activities will include:

- Providing improved modeling capability to support national and international assessments, including the 2002 WMO/UNEP Ozone Assessment and the 2001 and 2005 climate change assessments of the Intergovernmental Panel on Climate Change.
- Improving the ability to simulate regional patterns of natural climate variability and climate change, including improved predictions of climate change resulting from various potential greenhouse gas emission scenarios, through increasing the regional geographic resolution of models and incorporating more realistic representations of land-surface/atmosphere interactions and biogeochemical cycling.
- Providing to impacts and consequences researchers data sets of statistics for the probability of occurrence of extreme weather events (frequencies and magnitudes), under both natural climate variability and climate change scenarios, through analysis of ensembles of climate simulation runs to produce the statistics, means, and extremes of the predictions.

# INTERNATIONAL CONNECTIONS

USGCRP scientists coordinate many of their programs with those of their counterparts in other countries to aggregate the scientific and financial resources needed for the study of global processes on a cohesive and comprehensive basis. This coordination is achieved through a series of global and regional programs. Some of the most important of these at present are:

**World Climate Research Programme.** The purpose of the WCRP is to develop the fundamental scientific understanding of the climate system and climate processes that is needed in order to determine the extent to which climate can be predicted, and the extent of human influence on climate. The U.S. Climate Variability and Predictability Program and Global Energy and Water Cycle Experiment are coordinated through WCRP.

**International Geosphere-Biosphere Programme.** The goal of the IGBP is to describe and understand the interactive physical, chemical, and biological processes that regulate the total Earth system, the unique environment that this system provides for life, the changes that are occurring in this system, and the manner in which these changes are influenced by human actions. U.S. programs coordinated through IGBP include the Joint Global Ocean Flux Study, the Global Ocean Ecosystem Dynamics project, and the Past Global Changes project.

**International Human Dimensions Programme on Global Environmental Change.** How humans interact with the environment, how individuals and societies can mitigate or adapt to environmental change, and how policy responses to such changes influence economic and social conditions are at the center of research on the human dimensions of global environmental change within the IHDP. Key IHDP programs underway address Land Use and Land Cover Change and the Institutional Dimensions of Global Environmental Change.

**The Intergovernmental Panel on Climate Change** was established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) to assess the available scientific, technical, and socioeconomic information in the field of climate change. The U.S. scientific community participates extensively in IPCC assessments, and the U.S. hosts the Technical Support Unit for IPCC Working Group II on Impacts, Adaptation, and Vulnerability.

**The Inter-American Institute for Global Change Research** is an intergovernmental organization with U.S. participation dedicated to global change research, to augmenting the scientific capacity of the the Americas, and to providing information in a useful and timely manner to policymakers. The primary objectives of the IAI are to encourage comparative research and focused global change research important to the region as a whole and beyond the scope of individual national programs.

**The International Research Institute for Climate Prediction** issues season-

al to interannual climate forecasts based on global and regional coupled ocean/atmosphere models. The IRI disseminates this forecast guidance to nations and groups vulnerable to such climate variability phenomena as El Niño and La Niña so that they might prepare for and respond to impacts on climate-sensitive sectors such as agriculture, health, and water resources. The IRI is a USGCRP initiative led by NOAA and housed at the Columbia University/Lamont-Doherty Earth Observatory and the University of California, San Diego/Scripps Institution of Oceanography. The IRI is forging international partnerships for multilateral sponsorship and management of its programs.

**The Integrated Global Observing Strategy Partnership** brings together a wide range of international, intergovernmental, and nongovernmental organizations to develop a global observing strategy to meet the needs of global change research and of operational science programs. Key partners include the WCRP, IGBP, and potentially the IHDP; the WMO/UNEP, Intergovernmental Oceanographic Commission, and the Food and Agriculture Organization; the International Group of Funding Agencies for Global Change Research (IGFA) and the Committee on Earth Observation Satellites; and the International Council of Scientific Unions.

**Development of Two New Integrated International Programs.** The USGCRP, beginning in FY 1999, will work with the WCRP, IGBP, IHDP, IGFA, and individual international partners to develop integrated modeling, observational, and process research programs and activities to: (1) identify and quantify regional- to global-scale sources and sinks for carbon dioxide and other greenhouse gases and understand how these sources and sinks will function in the future; and (2) identify and quantify regional- to global-scale atmospheric transport and precipitation of water (which control the principal input of hydrological process and water-resource models) and study the global water cycle as a unifying theme that can bridge the gap in the spatial-scale spectrum between atmospheric and hydrological sciences. The latter effort will be coordinated nationally through planning underway to develop joint interagency programs and internationally through international programs that address water cycle research (e.g., the Climate Variability and Predictability Program, the Global Energy and Water Cycle Experiment, and the Biospheric Aspects of the Hydrological Cycle program). Both of the above-cited new international efforts are critical to development of climate databases and the prediction systems that utilize them.

# ASSESSMENT OF GLOBAL ENVIRONMENTAL ISSUES

Assessments and their related research play an integrative role across the USGCRP programmatic areas. They assemble and synthesize scientific results, increasing communication between scientists, the scientific communities, and the public and private sectors of our Nation, and identify gaps in knowledge, helping to incorporate user needs into the research agenda. Assessments are increasingly being viewed as an important vehicle for disseminating information to public policy and decisionmaking communities. The assessments of specific global environmental change issues, and related research, are designed to obtain the best possible understanding of such matters as:

1. How global environment change is the result of natural and/or human events.
2. How these changes potentially lead to consequences for societies and nations in such areas as food and agricultural production, water resources, human health, communities, or critical natural systems such as forests, grasslands, and fisheries.
3. How environmental, ecological, and resource changes will affect society and how, in turn, society will affect these systems.

The USGCRP participates in both international and national assessments.

**International:** The U.S. participates in a number of international assessments of the impacts and consequences of global environmental change, such as the Intergovernmental Panel on Climate Change (IPCC) assessments and the scientific assessments of ozone depletion, biodiversity, forests, and desertification. The USGCRP facilitates U.S. scientific participation in most of these assessments. The third IPCC assessment, scheduled to be completed early in FY 2001, will be a major international focus for the USGCRP well into the year 2000. USGCRP research programs and USGCRP-supported scientists provide scientific and technical input to these assessments. For example, a U.S. scientist serves as co-chair of the IPCC Working Group II on Impacts, Adaptation, and Vulnerability. Further, the USGCRP provides the venue, resources, and scientific and technical personnel to support this international Working Group. Most importantly, a substantial number of U.S. scientists will serve as lead authors, co-authors, contributors, and reviewers for the many chapters of the Third Assessment Report. The U.S. Government's scientific and technical review of the products of this international assessment process are coordinated by the USGCRP, and in so doing, the program invites input from a wide variety of sources, including many nongovernmental organiza-

tions and entities. While other international assessments will command some U.S. participation and resources, the IPCC Third Assessment Report will be the major effort well into FY 2000.

**National:** What are the risks and opportunities for the United States—its people, its environment, and its economy—associated with climate variability and climate change? This and related questions are being addressed in a National Assessment of the Potential Consequences of Climate Variability and Change for the United States being conducted by the USGCRP, as mandated by the Global Change Research Act of 1990. This assessment involves a broad spectrum of stakeholders in the Nation from government, business, academia, and other interested parties. This first national assessment includes a set of regional assessments (20 regions throughout the U.S.), assessments of the consequences of climate change on five important societal and economic sectors of our nation (water resources and availability, agriculture and food production, human health, forests, and coastal areas), and a synthesis that draws together the regional and sectoral assessments in a summary for policymakers. The National Assessment will be completed and documented early in FY 2000.

Assessment-related research, while a new component of the USGCRP still in its early stage, has the potential to link research results to the needs identified by the assessment process, and focuses on users' needs (e.g., applications of El Niño predictions to societal needs in such areas as agriculture, forest management, water resources, public health, etc.). During coming years, this type of research will likely be an increasingly important part of the USGCRP. Applications-oriented research efforts are being developed by several agencies and will be integrated into the ongoing USGCRP efforts in FY 2000 and beyond.

# APPENDIX A

## The Proposed USGCRP Budget for FY 2000

The proposed FY 2000 USGCRP budget totals $1.787 billion, a 6.1% increase above the FY 1999 budget level. As outlined in this edition of *Our Changing Planet*, the USGCRP budget supports scientific research on key global change issues, including Understanding the Earth's Climate System, the Biology and Biogeochemistry of Ecosystems, the Composition and Chemistry of the Atmsophere, Paleoenvironment/Paleoclimate, the Human Dimensions of Global Change, the Global Water Cycle, and Carbon Cycle Science.

The figure and tables in Appendix A provide the following:

- USGCRP budget for FY 1998–FY 2000 by department and agency
- USGCRP budget for FY 1998–FY 2000 by budget function
- USGCRP budget for FY 2000 by program element

The table below showing the USGCRP budget for FY 1998–FY 2000 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. It is important to recognize that the national system of operational environmental satellites and ground-based networks, while vital to the collection of atmospheric and ocean-surface data for global change research, is not included in the USGCRP budget.

Of the total USGCRP FY 2000 budget request, 54% supports Space-Based Observation Programs while 46% supports Scientific Research. The FY 2000 request for $829 million for Scientific Research is an 11.0 % increase above the FY 1999 budget level. The $958 million request for Space-Based Observation Programs is a 2.2% increase above the FY 1999 budget level.

# FY 1998 - 2000 U.S. Global Change Research Program
# Budget by Agency
## (Dollars in Millions)

| AGENCY | FY1998 | FY1999 | FY2000 Request |
|---|---|---|---|
| Scientific Research | | | |
| Department of Agriculture (USDA)* | 53 | 55 | 89 |
| Department of Commerce (DOC/NOAA) | 60 | 63 | 70 |
| Department of Energy (DOE) | 106 | 114 | 125 |
| Department of Health and Human Services (HHS/NIH) | 35 | 40 | 40 |
| Department of the Interior (DOI) | 26 | 27 | 27 |
| Environmental Protection Agency (EPA) | 13 | 17 | 23 |
| National Aeronautics and Space Administration (NASA) | 212 | 240 | 261 |
| National Science Foundation (NSF) | 167 | 182 | 187 |
| Smithsonian Institution (SI) | 7 | 7 | 7 |
| **Scientific Research Subtotal** | **679** | **745** | **829** |
| **Space-Based Observation Programs** | | | |
| National Aeronautics and Space Administration (NASA) | 998 | 937 | 958 |
| **U.S. Global Change Research Program Total** | **1,677** | **1,682** | **1,787** |

*USDA budget for USGCRP revised from FY 2000 President's Budget (see Chapter 7. Promoting Research, p.112)

# FY 1998 - 2000 U.S. Global Change Research Program
# Budget by Budget Function
## (Dollars in Millions)

| Budget Function | Budget Function Number | FY 1998 | FY1999 | FY 2000 Request |
|---|---|---|---|---|
| General Science, Space & Technology | 250 | | | |
| National Aeronautics and Space Administration (NASA) | | 1210 | 1177 | 1219 |
| National Science Foundation (NSF) | | 167 | 182 | 187 |
| Energy | 270 | | | |
| Department of Energy (DOE) | | 106 | 114 | 125 |
| Natural Resources & Environment | 300 | | | |
| Department of Commerce (DOC/NOAA) | | 60 | 63 | 70 |
| Department of the Interior (DOI) | | 26 | 27 | 27 |
| Environmental Protection Agency (EPA) | | 13 | 17 | 23 |
| Department of Agriculture (USDA/FS & NRCS) | | 18 | 18 | 37 |
| Agriculture | 350 | | | |
| Department of Agriculture (USDA/ARS, ERS & CSREES) | | 35 | 37 | 52 |
| Smithsonian Institution (SI) | 503 | 7 | 7 | 7 |
| Health | | | | |
| Department of Health and Human Services (HHS/NIH) | 550 | 35 | 40 | 40 |
| **TOTAL** | | **1,677** | **1,682** | **1,787** |

# FY 2000 U.S. Global Change Research Program by Program Element

## (Dollars in Millions)

| Program Element | DOC/ NOAA | DOE | DOI | EPA | HHS/ NIH | NASA Observ. | NASA Science | NSF | SI | USDA | Element Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Understanding the Earth's Climate System | 41.3 | 70.4 | 6.7 | 0.0 | 0.0 | 348.0 | 56.1 | 83.7 | 0.4 | 0.0 | 606.6 |
| Composition & Chemistry of the Atmosphere | 8.8 | 15.6 | 0.0 | 0.0 | 0.0 | 240.3 | 74.3 | 18.7 | 0.3 | 16.2 | 374.2 |
| Global Water Cycle | 5.0 | 4.0 | 0.0 | 0.0 | 0.0 | 207.8 | 65.2 | 9.7 | 0.0 | 0.0 | 291.7 |
| Carbon Cycle Science | 7.0 | 14.8 | 3.4 | 0.0 | 0.0 | 81.1 | 37.5 | 13.1 | 0.3 | 31.5 | 188.7 |
| Biology and Biochemistry of Ecosystems | 0.0 | 12.0 | 12.7 | 3.0 | 0.0 | 81.0 | 27.6 | 29.0 | 3.8 | 41.1 | 210.2 |
| Human Dimensions of Global Change | 5.2 | 4.8 | 0.0 | 20.0 | 40.2 | 0.0 | 0.0 | 14.0 | 0.6 | 0.0 | 84.8 |
| Paleoenvironment/Paleoclimate | 2.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 19.3 | 1.6 | 0.0 | 23.3 |
| Agency Total | 69.7 | 121.6 | 22.8 | 23.0 | 40.2 | 958.2 | 260.7 | 187.5 | 7.0 | 88.8 | 1,779.5 |

| | |
|---|---|
| DOC/NOAA | Department of Commerce/National Oceanic and Atmospheric Administration |
| DOE | Department of Energy |
| DOI | Department of the Interior |
| EPA | Environmental Protection Agency |
| HHS/NIH | Department of Health and Human Services |
| NASA Observ. | National Aeronautics and Space Administration Space-Based Observations |
| NASA Science | National Aeronautics and Space Administration Scientific Research |
| NSF | National Science Foundation |
| SI | Smithsonian Institution |
| USDA | Department of Agriculture |

Notes:

DOE $3.2m classified as Small Business Innovative Research not included

DOI $4.4 m classified as Data Management not included.

# APPENDIX B

## The FY 1998-2000 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 "FY 2000 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 FY 1999 appropriated funds and the FY 2000 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 several different Appropriations bills. Thus, the relationship between the USGCRP budget and the Appropriations process is complex and not easily summarized.

# Department of Agriculture

| USDA | Program Title | FY98 | FY99 Estimate | FY00 Request |
|---|---|---|---|---|
| ARS | Agriculture and Rangeland Global Change | 12.1 | 11.3 | 19.3 |
| ARS | Methyl Bromide Research | 14.6 | 14.6 | 14.6 |
| CSREES | Improved Response Models | 6.4 | 8.6 | 14.6 |
| CSREES | UV-B Monitoring Network | 1.0 | 1.0 | 1.6 |
| ERS | Economic Incentives Carbon Sequestration | 0.0 | 0.0 | 0.7 |
| ERS | Economics of Global Change and Agriculture | 0.8 | 0.8 | 0.8 |
| FS | Forest Global Change | 16.9 | 16.9 | 22.9 |
| NRCS | Soil Carbon Studies | 1.2 | 1.5 | 13.5 |
| USDA | USGCRP National Assessments of Climate Change Impacts | 0.0 | 0.0 | 0.8 |
| | **USDA Total** | **53.0** | **54.7** | |
| | **President's Request** | | | **88.8** |

*USDA budget for USGCRP revised from FY 2000 President's Budget (see Chapter 7. Promoting Research, p.112)

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

**Areas of Global Change Research.** USDA-sponsored research focuses on understanding terrestrial systems and the effects of global change (including water balance, atmospheric deposition, vegetative quality, and UV-B radiation) on food, fiber, and forestry production in agricultural, forest, and range ecosystems, and examines how agricultural and forestry activities can contribute to a reduction in greenhouse gases. USDA research provides policymakers and agricultural producers with useful scientific information. Research areas include: interactions between terrestrial ecosystems and the atmosphere; methane generation and nitrous oxide release; soil properties, including moisture, erosion, organic matter, nutrient fluxes, and microbes; the relationship of global change to forest and range fires, insects, and plant pathogens; global change and agricultural management systems; and the contributions of agricultural sources of methyl bromide to stratospheric ozone depletion, and possible alternatives and substitutes for this fumigant.

In FY 2000, USDA will increase its carbon cycle research program. As part of the interagency Carbon Cycle Science Program, USDA will collaborate with other Federal agencies to conduct research to better understand how agricultural practices affect the net carbon balance and develop methods that will assist farmers, ranchers, and forest

landowners to increase carbon sequestration. Special emphasis will be given to measurement of the effects of management and conservation practices on carbon storage in cropland and grazing lands. Basic research will define the mechanism by which soil carbon is lost to the atmosphere or transferred to stable carbon pools. USDA will also identify and quantify carbon sources, sinks, and fluxes for all U.S. forest land, including marginal agricultural land and other potential conversion land-use types. USDA will expand and digitize its cooperative soil survey data bases that provides information necessary to assess the impact of policies directed at increasing the terrestrial carbon stock. Additional research will be directed at estimating the economic feasibility of carbon sequestration strategies.

**FY 2000 Program Highlights.** ARS will continue to focus on four broad research 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 affect water quality, efficiency of use by crops, and availability for industry, urban use, and irrigated agriculture; and 4) the development of simulation models with required inputs for predicting responses of crops, watersheds, and managed ecosystems to global change.

CSREES will continue to support the USDA UV-B Monitoring Network. Information from this research network is combined with satellite-based measurements to provide an accurate climatological UV-B irradiance database. This database documents long-term trends and supports research on plant effects on the factors controlling UV-B irradiance; radiation transfer model development; and assessment of the potential for damage to ecosystems. Global Change research in CREES's National Research Initiative (NRI) Competitive Grants Program aims to increase 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 on crop productivity, natural resources, hydrological processes, and water availability. The NRI Programs that solicit global change research are: 1) Plant Responses to the Environment; 2) Ecosystems Science; 3) Soils and Soil Biology; and 4) the NSF/DOE/NASA/USDA/NOAA Joint Program on Terrestrial Ecology and Global change (TECO).

ERS will continue its analysis of the 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. Research also will assess the potential farm sector impacts of changing weather variability and farmer adaptation to changing environmental conditions. In FY 2000, ERS will initiate a new research program to assess the economic feasibility of various climate change mitigation efforts in U.S. agriculture, focusing on the economic potential for domestic carbon sequestration and control of trace gases in agriculture, the use of economic incentives to encourage carbon sequestration on agricultural lands, and the potential to target existing USDA conservation programs toward promoting greenhouse gas mitigation activities in the

farm sector.

FS global change research focuses on determining 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 are describing 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. Forest and grassland ecosystems are major factors in understanding and enhancing global and regional carbon cycles. In FY 2000 the Forest Service will enhance its long-term research on forest and grassland carbon cycles, with particular emphasis on the soil component. This enhanced carbon research effort will result in better information for use by forest resource managers to improve carbon cycle management on their lands.

NRCS will collect data necessary to build validated, verified baseline soil carbon inventories and assess policy-driven impacts on soil carbon stocks at national, regional, and field-level scales. NRCS goals include establishing baseline soil carbon levels under various covers/management systems; developing a "use-dependent" soil carbon database integrated with national soils databases; collecting soil carbon data on a sample-based inventory frame for national and regional level inventory estimation; and testing the use of models and field collection of soil carbon data. In conjunction with ARS, NRCS will test soil carbon prediction/planning tools.

**Related Research.** In addition to focused USGCRP research, the USDA sponsors 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 United States 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 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

| DOC | Program Title | FY98 | FY99 | FY00 Request |
|---|---|---|---|---|
| NOAA | Aerosols Project | 1.1 | 1.1 | 1.1 |
| NOAA | Applications of Regional Forecasts | 2.9 | 3.5 | 3.5 |
| NOAA | Atmospheric Chemistry Project | 6.5 | 6.6 | 7.0 |
| NOAA | Carbon Cycle Science | 3.9 | 3.9 | 7.0 |
| NOAA | Climate Change Data and Detection | 4.6 | 4.6 | 4.8 |
| NOAA | Climate Dynamics and Experimental Prediction | 14.4 | 16.5 | 17.0 |
| NOAA | Climate Variability (CLIVAR) | 16.8 | 17.0 | 19.5 |
| NOAA | Economics and Human Dimensions of Climate Fluctuations | 1.7 | 1.7 | 1.7 |
| NOAA | Global Energy and Water Cycle Experiment (GEWEX) | 5.0 | 5.0 | 5.0 |
| NOAA | Health of the Atmosphere* | 0.8 | 0.8 | 0.8 |
| NOAA | Paleoclimatology | 2.3 | 2.3 | 2.3 |
| | **DOC TOTAL** | **60.0** | **63.0** | |
| | **President's Request** | | | **69.7** |

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

**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, and the role of global transfers of carbon dioxide among the atmosphere, ocean and terrestrial biosphere in climate change; improvements in climate modeling, prediction, and information management capabilities; the projection and assessment of variability across multiple timescales; the study of the relationship between the natural climate system and society and the development of methodologies for applying climate information to real problems of social and economic consequences; and archiving, management, and dissemination of data and information useful for global change research.

**FY 2000 Program Highlights.** In FY 2000, NOAA will continue to advance understanding of 1) whole-system dynamics and modes of climate variability, for exam-

ple the El Niño Southern Oscillation (ENSO) and the Northern 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. FY 2000 program highlights include the following:

- Improving regional-scale modeling and the prediction of seasonal to interannual variability over North America.
- Increasing understanding of the role of the Atlantic Ocean in climate changes, with an initial focus on the relationship between tropical Atlantic variability and the North Atlantic Oscillation.
- Continuing the advancement of a sustained Atlantic observing system to support CLIVAR research.
- Advancing the improvement of models and modeling systems for seasonal to interannual climate prediction and the ability to provide regional-scale forecasts and predicted probabilities of extreme.
- Developing a comprehensive understanding of the effects of land surface forcing on climate during the full annual cycle and the effects of orography on precipitation and water supply in the western and central parts of the Missouri River Basin, and concluding several demonstration projects with water resources agencies in the eastern part of the Mississippi River Basin.
- Advancing detailed studies of past climate variability on seasonal to centennial time scales using century to millennia-long paleoenvironmental proxy records in order to improve the current understanding of seasonal to interannual.
- Increasing our understanding of the global transfers of $CO_2$ between the atmosphere, ocean, and terrestrial biosphere, thereby helping to constrain predictions of the uptake of anthropogenically-released $CO_2$ within these reservoirs; the initial focus will be on the sinks of carbon in the North American continental region.
- Supporting focused data set development and research activities contributing to the IPCC Third Assessment Report and the U.S. National Climate Assessment, and providing support for World Climate Research Program and International Geosphere-Biosphere Program objectives; and working with Global Climate Observing Systems and others to prevent degradation of long-term data sets.
- Advancing efforts to reduce uncertainties in the understanding of direct radiative forcing by tropospheric aerosols through an integrated program focused on targeted, in-situ measurements of aerosols chemical, physical, and radiative properties, integrated with model analyses of the distributions and radiative forcing of key aerosol types.
- Characterizing the "ozone-friendliness" of substitutes for ozone-depleting gases, developing methods for the detection of the recovery of the ozone layer, assessing new airborne measurement methods for key chemicals species like nitric acid (the "missing sink"?), characterizing the regional variance of tropospheric ozone and its role in the heat budget, and quantifying the absorption of radiation in clouds by lightning-produced chemical species in selected locations.
- Advancing our understanding of societal vulnerability and current coping mechanisms related to climate variability on seasonal up to decadal timescales (including climate extremes and surprises), and the potential use of climate information for

planning purposes.

- Advancing existing efforts to foster the application of forecast information in climate-sensitive regions and sectors such as agriculture, water management, energy, human health, and transportation infrastructure through 1) continuing the process of integrating basic science and human dimension program outputs into regional assessments efforts; 2) developing one or two new projects; and 3) exploring opportunities for scientific and programmatic learning within the context of these pilots.

**Related Research.** In addition to focused USGCRP research, related NOAA activities include advance short-term weather forecasting and warning services; marine ecosystem research; 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.

**Mapping of Budget Request to Appropriations Legislation:** In the Departments of Commerce, Justice, and State, the Judiciary, and Related Agencies Appropriations Bill, NOAA activities are funded under Title II–Department of Commerce and Related Agencies, within the NOAA Operations, Research, and Facilities account. In Appropriations Committee reports, funding for NOAA's USGCRP activities is included as part of the Climate and Global Change budget within Oceanic and Atmospheric Research.

# Department of Defense

**Areas of Global Change Research.** The Department of Defense does not support dedicated global change research, but continues a history of participation in the USGCRP through sponsored research that concurrently satisfies National Security requirements and stated goals of the USGCRP. A non-inclusive summary of related Defense research that highlights collaborative opportunities with other agencies is described below.

**FY 2000 Program Highlights.** Defense research associated with the USGCRP keys on data collection and research to enhance seasonal to interannual prediction. Under the aegis of the Navy-led, multi-agency, National Oceanographic Partnership Program (NOPP), several data collection efforts are underway and/or planned: an Ocean Drifting Buoy Program with NSF, DOE, and NOAA partners will continue; several projects based on a FY 1999 NOPP solicitation for (1) Data Assimilation and Modeling and (2) High Resolution Ocean Measurement technology will be in place; and a NOPP-sponsored report on National Ocean Observation needs will be available pursuant to a FY 1999 Congressional request.

DOD investments in new and novel sensors include the third generation Polar Ozone and Aerosol Measurement (POAM III) sensor system aboard the SPOT satellite, which is providing high-resolution stratospheric ozone measurements to complement data from NOAA and NASA satellite sensors (TOMS/SBUV). WINDSAT, a passive, polarimetric, radiometer designed for high-resolution measurement of ocean waves is sponsored by DOD and NOAA and scheduled for a 2002 launch. High-resolution hyperspectral space-borne sensors are scheduled for launch in the 2000-2002 timeframe.

The Defense Modeling and Simulation Office (DMSO) World Wide Web site http://mel.dmso.mil provides access to a variety of environmental and geospatial data and models. The multiagency MEDEA group will continue to bridge the national security and civil community for access to classified environmental data.

In the high latitudes, reduction and analyses of data from the Surface Heat Budget of the Arctic (SHEBA) project will continue to provide insights into mass and energy balances between the atmosphere, ocean, and Arctic ice pack. Data analysis from the final scheduled SCICEX cruise in CY 1999 on a specifically configured Navy nuclear submarine will include detailed studies of bathymetric, gravimetric, and oceanographic measurements under the Arctic ice canopy. Work on the Nation's only operational Arctic sea ice model, the Navy's Polar Ice Prediction System model (PIPS 3.0), will focus on developing a more robust ocean circulation module and improved ice morphology to more accurately represent the complex dynamic regime in the high Arctic. A new U.S.-Russia program, the Arctic Climate Observations using Underwater Sound (ACOUS), is an acoustic thermometry investigation along specific mode paths. ACOUS will provide near-continuous temperature profiles along transects in the Arctic ocean—information vital for thermodynamic investigations. This unique Navy program is included in the framework of the Gore-Primakov Joint Commission on Economic and

Technological Cooperation.

Navy and NSF-sponsored researchers will partner with colleagues from Korea and Japan in a Sea of Japan Physical Oceanography science program in 2000. The DOD Marine Boundary Layer research in air-sea gas transfer mechanisms is closely coordinated with related NSF and DOE carbon cycle research.

The Navy Ocean Modeling Program (NOMP) continues work on nested high-spatial-resolution, coupled air-sea-terrestrial regional models. Current versions are demonstrating 9-km resolution operating on UNIX and PC host machines.

All data and research results are routinely made available to the civil science community.

**Related Research and Infrastructure.** DOD-sponsored research and supporting infrastructure, not describe 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; terrestrial and marine environmental quality research, and energy conservation measures. DOD's continued investments in environmental infrastructure, such as the university Oceanographic Research Fleet, the Cold Regions Research and Engineering Laboratory, and the various services' globally-operational oceanographic and meteorological support structures, will continue to provide data and services of benefit to USGCRP efforts.

# Department of Energy

| DOE | | FY98 | FY99 | FY00 Request |
|---|---|---|---|---|
| BER | Atmospheric Chemistry & Carbon Cycle | 20.7 | 27.1 | 26.1 |
| BER | Climate & Hydrology | 63.1 | 64.1 | 74.4 |
| BER | Ecological Processes | 13.1 | 12.3 | 12.0 |
| BER | Human Interactions | 8.9 | 7.5 | 9.1 |
| BER | Small Business Innovative Research/ Technology Transfer | 0.0 | 3.0 | 3.2 |
| | **DOE Total** | **105.8** | **114.0** | |
| | **President's Request** | | | **124.8** |

BER Biological and Environmental Research Program

**Areas of Global Change Research.** Research by DOE's Office of Biological 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.

**FY 2000 Program Highlights.** The DOE Biological and Environmental Research (BER) program utilizes the unique multidisciplinary facilities of the DOE National Laboratories and supports research and infrastructure at these Laboratories, universities, and other research institutions. With the other USGCRP agencies, a new focus in FY 2000 is the Accelerated Climate Prediction Initiative (ACPI), which will integrate the frontiers of computational science and climate science to accelerate progress in climate simulation model development and application; to substantially reduce the uncertainties in decade-to-century model-based projections of climate change; and to increase the availability and utility of climate change projections to the broader climate change research and assessment communities. Additional new resources are requested by DOE for new research to advance understanding of the global carbon cycle, particularly how natural processes control the exchange of carbon between the atmosphere and terrestrial and marine ecosystems. In support of the USGCRP, the BER program includes activities in the following four key areas:

**1) Climate and Hydrology:** The Atmospheric Radiation Measurement (ARM) program focuses on the improvement of parameters for climate prediction. In FY 2000,

ARM will deploy the third research station in the Tropical Western Pacific and continue activities at the Southern Great Plains and on the North Slope of Alaska. The Unmanned Aerial Vehicle program will complete additional experiments and data analysis to resolve the excess absorption uncertainty.

In FY 2000, the Program on Climate Model Diagnosis and Intercomparison (PCMDI) will focus on phase 2 of the international Coupled Model Intercomparison Project, and the Computer Hardware, Advanced Mathematics and Model Physics (CHAMMP) program will provide results of the first set of new Parallel Climate Model climate simulations. The ACPI will focus on the analysis and downscaling of GCMs for regional studies, on multi-institutional model development research for long time simulation at regional resolution, and improved predictability and parameterization of GCMs.

**2) Atmospheric Chemistry and Carbon Cycle:** In FY 2000, new resources will be invested in new carbon cycling research that will seek to reduce the uncertainties in the estimated net exchange of anthropogenic carbon dioxide between the atmosphere and terrestrial and ocean systems and to explore the biophysical processes controlling the net exchange. In FY 2000, the Terrestrial Carbon Processes (TCP) will focus on regional-scale calibration of calculated net primary productivity using NASA satellite-derived estimates. With the Program on Ecosystem Research (PER) and the National Institute for Global Environmental Change (NIGEC), the AmeriFlux $CO_2$ measurement network will analyze model-derived estimates and experimental results.

In FY 2000, Environmental Meteorology research will focus on vertical transport and mixing and on studies of the transitions between stable and convective conditions. The Atmospheric Chemistry program will focus on aerosols and research in support of NARSTO.

In FY 2000, BER and NOAA will enter the final phase of joint activities to synthesize data from the ocean carbon dioxide surveys. The Biological Investigations - Ocean Margins Program (BI-OMP) will be recompeted, focusing on linkages between carbon and nitrogen cycles in marine microbes and on developing collaborative partnerships between institutions with strong traditions in marine biology with those with emerging capabilities.

**3) Ecological Processes:** In FY 2000, PER, TCP, and the NIGEC programs will continue to support experimental and modeling studies to assess the consequences of human-induced climate changes and of 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 to elevated concentrations of atmospheric $CO_2$ and will include approaches for conducting multi-factor experiments on intact ecosystems. PER will continue Throughfall Displacement Experiment studies on hardwood forest ecosystems.

**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 presents the results of the USGCRP to the policy process. FY 2000 will focus on supply curves for gases other than carbon dioxide and on the development of supply curves for land use and carbon sinks.

The three components of the Global Change Education Program are: (1) the Summer Undergraduate Research Experience, involving students at the end of their

sophomore or junior years and including mentored research experience at national laboratories; (2) the Graduate Research Environmental Fellowships; and (3) a continued partnership in the multi-agency Significant Opportunities in Atmospheric Research and Science (SOARS) undergraduate and graduate program.

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. FY 2000 will focus on management of data from the FACE experiments, NARSTO, and AmeriFlux.

The National Institute for Global Environmental Change (NIGEC) supports research at universities and in FY 2000 will emphasize research at AmeriFlux sites and on implementing scientifically-based assessments of the consequences of climate change.

**Related Research.** DOE plays a major role in the President's Climate Change Action Plan to reduce greenhouse gas emissions through changes in energy supply and improvements in energy efficiency and conservation. Building on global change research, activities in carbon management are part of the Climate Change Technology Initiative.

**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 Institutes of Health

| HHS | Program Title | FY98 Actual | FY99 Estimate | FY00 Request |
|---|---|---|---|---|
| NIEHS | Human Health Effects of Exposure to UV Radiation & CFC Replacement Chemicals | 4.2 | 4.4 | 4.5 |
| NEI | Health Effects of UV Radiation | 9.3 | 10.4 | 10.7 |
| NCI | Health Effects of UV Radiation | 21.4 | 24.6 | 24.7 |
| NIAMS | Health Effects of UV Radiation | 0.3 | 0.3 | 0.3 |
| | **HHS Total** | **35.2** | **39.7** | |
| | **President's Request** | | | **40.2** |

| | |
|---|---|
| NCI | National Cancer Institute |
| NEI | National Eye Institute |
| NIAMS | National Institute of Arthritis and Musculoskeletal and Skin Diseases |
| NIEHS | National Institute of Environmental Health Sciences |

**Areas of Global Change Research.** Four NIH institutes support research on the health effects of UV and near UV radiation: the National Institute of Environmental Health Sciences (NIEHS), National Eye Institute (NEI), National Cancer Institute (NCI), and National Institute of Arthritis and Musculoskeletal and Skin Diseases (NIAMS). Their principal objectives include an increased understanding of the effects of UV and near UV radiation exposure on target organs (e.g., eyes, skin, immune system) and of the molecular changes that lead to these effects, and the development of strategies to prevent the initiation or promotion of disease before it is clinically defined. In addition, NIEHS supports research on the health effects of CFC replacement chemicals, including studies on the metabolism and toxicity of HCFCs and halogenated hydrocarbons.

**FY 2000 Program Highlights.** The NIEHS program supports grants and intramural projects that investigate the effects of UV exposure on the immune system, aging process, sensitive tissues such as the retina and skin, and methods to reduce these harmful effects. Other projects involve the comparison of mutagenic potential in bacteria of UV and near UV radiation at levels found in natural sunlight and at levels anticipated with a 15 percent depletion of stratospheric ozone. Several projects supported by NIEHS are investigating molecular changes in DNA that lead to aberrations and mutations in human tissue, rodents, fruit flies, and bacteria. In addition, these studies are investigating the variety of ways these organisms repair damage to DNA resulting from UV exposure. Other studies include research on the photobiological mechanisms involved in aging caused by chronic UV damage, antimalarial drugs to determine whether the cutaneous and ocular side effects associated with their use are light-induced, and the photochemistry of all light-absorbing components of the eye to determine whether long-term exposure to light contributes to the deterioration of clarity of the lens and functioning of the retina.

A major NEI initiative is underway to determine how and why eye cataract develops and to search for ways to prevent or slow the progression of cataract, an age-related eye disease that affects 17-20 million people globally. Since UVB radiation has been implicated as a specific risk factor in cataract, this project is investigating its role in cataract development. Another important area of NEI research is the understanding of certain enzymatic and nonenzymatic detoxification systems in the eye and how they combat damage from UVB radiation. The goal of this effort is to identify drugs that might have therapeutic or preventative applications. UVB radiation has been implicated in the production of singlet oxygen and other active species of oxygen by photodynamic action of the photosensitizers present in the normal eye. One of the long-term goals of NEI research is to define a molecular mechanism for the changes in the vitreous fluid and lens components (such as hyaluronic acid, collagen, and the crystallin proteins) and determine whether there is a link between photooxidation and certain eye diseases.

The NCI is supporting a wide range of studies to characterize the etiology, biology, immunology, and pathology of a variety of changes in the skin, including photoaging, non-melanoma skin cancers, and melanoma caused by exposure to UV radiation. For example, the role of reactive oxygen molecules in development of melanoma is being studied, as well as evaluation of antioxidants such as beta-carotene to prevent deleterious effects. Other research is exploring UV-induced immunosuppression, which is critical to the development of UV-induced skin tumors, and the cellular and molecular basis for the genetic predisposition to UVB-induced skin cancer in people with Basal Cell Nevus Syndrome.

NIAMS supports basic and clinical research on the effect of UVA and UVB radiation on skin. This includes direct toxic effects, drug-induced photosensitivity, photoaging, effects on the skin's immune functions, mutagenesis, and carcinogenesis. The effect of UV on the skin's pigment-forming system and therapeutic uses of UV in the treatment of skin diseases are also topics of interest to NIAMS.

**Related Research.** In addition to research areas that are 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 technologies to mitigate or adapt to climate change. Exposures of special concern for FY 2000 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 the prevention of and treatment for water-, food- and vector-borne diseases, such as cholera, salmonella, 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.

# Department of the Interior

| DOI | Program Title | FY98 | FY99 | FY00 Request |
|---|---|---|---|---|
| USGS | Biogeochemical Cycling | 2.5 | 2.5 | 2.5 |
| USGS | Climate History | 4.4 | 4.3 | 4.2 |
| USGS | Hydroclimatology | 2.5 | 2.5 | 2.5 |
| USGS | Impacts on Terrestrial and Coastal Ecosystems | 5.3 | 5.3 | 5.3 |
| USGS | Land Surface Characterization | 2.6 | 2.6 | 2.6 |
| USGS | Mississippi Basin Carbon Project | 1.6 | 1.6 | 1.6 |
| USGS | Satellite Data Management and Dissemination | 3.8 | 3.8 | 3.8 |
| USGS | Terrestrial Earth Surface Processes | 3.7 | 4.0 | 4.1 |
| | **DOI TOTAL** | **26.4** | **26.6** | |
| | **President's Request** | | | **26.6** |

USGS U.S. Geological Survey

**Areas of Global Change Research.** Research at the Department of the Interior's U.S. Geological Survey (USGS) contributes directly to the USGCRP's intellectual framework of a whole-system understanding of global change (i.e., the interrelationships among climate, ecological systems, and human behavior). The USGS examines terrestrial and marine processes and the natural history of global change, including the interactions between climate and the hydrologic system. The character of past and present environments and the geological, biological, hydrological, and geochemical processes involved in environmental change are documented. The USGS is an international source for ground-based and remotely sensed Earth science data, information, and applications, which contributes to assessments of the potential effects of global change on society.

**FY 2000 Program Highlights.** In FY 2000, the USGS will continue to support ongoing efforts across a broad area of global change research that includes a focus which increases emphasis on understanding the sensitivity of natural systems and impacts of climate change and variability, surficial processes, and other global change phenomena on the Nation's lands and environments at the regional scale. Specific goals of the program are: to improve the utility of global change research results to land management agencies; to emphasize monitoring the landscape and developing technical approaches to identifying and analyzing changes that will take advantage of a burgeoning archive of remotely sensed and in situ data; and to emphasize biogeographic regions and features particularly montane, coastal and inland wetland ecosystems. There is also an increasing emphasis on the carbon cycle, with integrated research and modeling of soil dynamics and carbon cycle processes. In direct support of USGCRP, the USGS includes activities in the following areas:

*Biogeochemical Cycling* - Research is developing an understanding of the

exchanges of water, energy, and nutrients between the atmosphere and land surface. The processes that control the cycling and fate of carbon and other nutrients in soils, rivers, lakes, reservoirs, and estuarine systems are critical to understanding issues related to erosion, sediment transport, biogeochemical budgets, snowpack chemistry, surface hydrology, and climate response.

*Climate History* - Climate history research focuses on understanding the rates and magnitudes of decadal to millennial scale natural changes in climate and determining how those changes have affected the environment. These studies contribute to regional and global assessments of climatic change and help evaluate models of regional-scale response to past and likely future changes in global and regional conditions.

*Hydroclimatology* - This research is composed of three major activities: (1) studies to determine the relations between climatic conditions and regional hydrologic variability, including long-term patterns and trends in hydrologic extremes; (2) monitoring trends in the accumulation and dissipation of snow and ice stored in selected U.S. benchmark glaciers; and (3) development of improved procedures for simulating hydrologic processes and conditions in global climate models.

*Impacts on Terrestrial and Coastal Ecosystems, Coastal Wetlands, and Fish and Wildlife* – This research determines the sensitivity and response of natural systems and ecological processes to multiple environmental factors, including existing climate and natural and anthropogenic impacts, at the local, landscape, regional, and continental level. It provides the scientific knowledge and technologies for conservation, rehabilitation, and management of sustainable ecosystems needed by land management agencies of the Federal and state governments.

*Land Surface Characterization* – This area includes research and development of techniques to monitor, analyze, describe, apply, and predict land use, land cover, and other surface characteristics data. Data sets are used to characterize and map the Earth's surface, model land surface processes, detect changes over time, and forecast the response of the land surface to changes in climate, environment, land use, and land cover.

*Mississippi Basin Carbon Project* - Studies are developing a quantitative understanding of the role of land-use change and associated erosion and sedimentation processes on carbon storage and nutrient cycles within the Mississippi Basin. Rates of organic carbon accumulation, erosion, and burial are used to develop whole-basin models of these dynamic relationships.

*Satellite Data Management and Dissemination* - The USGS continues to operate and enhance the capabilities of the EROS Data Center to serve as the National Satellite Land Remote Sensing Data Archive, by maintaining existing datasets, adding new data sets, and converting older data sets from deteriorating media to modern, stable media. The EROS Data Center also maintains and expands the Global Land Information System (GLIS) to provide information about and access to the Center's many land-related data sets.

*Terrestrial Earth Surface Processes* - Research examines the impact of climatic variability and change on earth surface processes, including vegetation change, soil and sediment dynamics and carbon sequestration. A detailed history of vegetation change in the western U.S. and southern Alaska is being constructed. Data sets and techniques are being developed to forecast the effects of possible future regional- and global-scale veg-

etation changes. Alaska soil carbon and fire history studies will be expanded.

**Related Research.** DOI also 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.


# Environmental Protection Agency

| EPA | Program Title | FY98 | FY99 | FY00 Request |
|---|---|---|---|---|
| ORD | Assessment of Consequences of Climate Variability and Change | 2.0 | 16.7 | 20.0 |
| ORD | Biology and Biogeochemistry of Ecosystems | 0.0 | 0.0 | 3.0 |
| ORD | Ecosystem Services | 4.8 | 0.0 | 0.0 |
| ORD | Indicators of Change | 5.2 | 0.0 | 0.0 |
| ORD | Regional Vulnerabilities | 1.0 | 0.0 | 0.0 |
| | **EPA TOTAL** | **13.0** | **16.7** | |
| | **President's Request** | | | **23.0** |

ORD Office of Research and Development

**Areas of Global Change Research.** EPA's Global Change Research Program is currently undergoing a major redirection towards a more assessment-oriented program, with primary emphasis on understanding the potential consequences of climate variability and change on human health, ecosystems, and socioeconomic systems in the United States. The above table reflects the fundamental change in the program over the three-year period. Assessments will also be made of potential opportunities to adapt to climate change in order to reduce the risks, or take advantage of the opportunities, presented by climate variability and change. All of ORD's program in FY 1999 falls within the "Human Dimensions of Global Change" program element.

**FY 2000 Program Highlights.** The increase requested in FY 2000 will be added to the base program in order to conduct research and assessment activities that examine the potential effects of climate variability and change. Most of the program ($20.0 million) falls within the "Human Dimensions of Global Change" program and includes work in the following areas: (1) human health (including the mortality and morbidity effects of heat stress; effects of climate change on air and water quality and the consequent health effects; the potential spread of infectious diseases; the potential health consequences of extreme events such as hurricanes and coastal storm surges; and changes in nutrition due to effects on agriculture and food distribution); (2) air quality (including changes in concentrations of ozone and particulate matter), and the ability of urban areas to attain air quality standards; (3) water quantity and quality; and (4) the frequency, intensity, and socioeconomic impacts of extreme weather events (including floods, droughts and hurricanes). A portion ($3.0 million) of ORD's requested increase in FY 2000 will be applied to the "Biology and Biogeochemistry of Ecosystems" program element and includes research into the: (1) biology of ecosystems (particularly wildlife and biodiversity in both terrestrial and aquatic ecosystems, nonindigenous species, unique ecosystems, National Parks; and effects on ecosystem services of high societal value); and (2)

the effect on coastal zones as a result of sea level rise.

All of these climate-induced changes will be assessed in the context of multiple stressors; that is, climate change will be viewed as one of many stressors, including non-climate-related stressors. For example, the synergistic effects of climate change and UV-B exposure on human health and ecosystems will be assessed. The research and assessment program will also increasingly focus on adaptation to climate change and climate variability.

As part of the USGCRP, the research and assessment program will make significant contributions to the ongoing U.S. National Assessment of the Potential Consequences of Climate Variability and Change. EPA is sponsoring the Mid-Atlantic Regional Assessment, the Great Lakes Regional Assessment, the Gulf Coast Regional Assessment, and the Health Sector Assessment. These assessments will be conducted through a public-private partnership that actively engages researchers from the academic community, decision makers, resource managers, and other affected stakeholders in the assessment process. The first of several National Assessment Reports will be delivered to Congress in January 2000.

The research and assessment activities will also evaluate the potential co-control benefits of greenhouse gas mitigation policies (i.e., the additional changes in criteria air and water pollutants that occur as greenhouse gas emissions are reduced), and the potential co-control benefits of policies to reduce criteria air pollutants (i.e., the additional changes in greenhouse gases that occur as criteria air pollutant emissions are reduced). The resulting health and welfare effects of the changes in criteria air pollutants, water pollutants, and greenhouse gases will be assessed.

**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 ecosystems exposures, responses, and vulnerabilities to high-risk chemicals and non-chemical stressors at multiple scales of biological organization and geographic scales. Relevant research into the global nitrogen cycle, although not funded with USGCRP-based funds, will contribute to our understanding of the nitrogen cycle and the impact of global change on the process of nitrification.

**Mapping of Budget request to Appropriation 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

| NASA | Program Title | FY98 | FY99 | FY00 Request |
|---|---|---|---|---|
| ES | Atmospheric Chemical Modeling | 6.5 | 6.5 | 6.5 |
| ES | Atmospheric Dynamics & Remote Sensing | 5.3 | 5.3 | 5.3 |
| ES | Biological Oceanography | 4.8 | 4.8 | 4.8 |
| ES | Ecological Processes | 16.4 | 16.4 | 16.4 |
| ES | EOS Science | 41.4 | 46.4 | 60.6 |
| ES | Global Data Integration & Validation | 3.8 | 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 | 15.6 | 38.8 | 53.2 |
| ES | Land Cover and Use Change | 6.3 | 6.3 | 6.3 |
| ES | Land Surface Hydrology | 5.1 | 5.1 | 5.1 |
| ES | Mission Analysis Program | 40.0 | 42.1 | 32.7 |
| ES | Ocean Color Data Purchase/Sea WIFS | 2.5 | 2.5 | 2.6 |
| ES | Pathfinder Science Studies | 3.4 | 3.5 | 3.5 |
| ES | Physical Oceanography & Ocean Modeling | 7.5 | 7.5 | 7.5 |
| ES | Polar Programs | 6.5 | 5.5 | 5.5 |
| ES | Radiation Science Program | 9.7 | 7.7 | 7.7 |
| ES | Stratospheric Chemistry | 17.2 | 17.2 | 17.2 |
| ES | Tropical Rainfall Measurement Science | 0.4 | 0.0 | 0.0 |
| ES | Tropospheric Chemistry | 8.8 | 9.8 | 10.8 |
| | **NASA Global Change Science Program** | **212.4** | **240.4** | **260.7** |

| NASA | Program Title | FY98 | FY99 | FY00 Request |
|---|---|---|---|---|
| ES | Advanced Geostationary Studies | 3.0 | 0.0 | 0.0 |
| ES | Earth Systems Science Pathfinder | 22.8 | 62.2 | 75.2 |
| ES | EOS Data and Information Systems (EOSDIS) | 210.1 | 261.7 | 231.5 |
| ES | EOS Flight Development | 491.6 | 403.1 | 432.7 |
| ES | EOS Special Spacecraft | 96.7 | 120.8 | 150.0 |
| ES | Information Systems | 4.3 | 6.1 | 6.4 |
| ES | LANDSAT | 74.3 | 17.0 | 2.9 |
| ES | Launch Services | 39.4 | 4.2 | 0.0 |
| ES | Lewis & Clark Land Imaging Spacecraft | 1.4 | 0.1 | 0.0 |
| ES | Mission Operations | 47.0 | 56.3 | 54.6 |
| ES | Total Ozone Mapping (TOMS) | 6.0 | 4.9 | 4.9 |
| ES | Tropical Rainfall Measurement TRMM | 0.9 | 0.0 | 0.0 |
| | **NASA Global Change Hardware Development** | **997.5** | **936.4** | **958.2** |
| | **NASA Total** | **1209.9** | **1176.8** | |
| | **President's Request** | | | **1218.9** |

ES Earth Science

**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 chemistry and ozone; ocean surface winds and ocean biological productivity; tropical precipitation and the global hydrological cycle; the global carbon cycle and land surface vegetation and ecosystems; and solid Earth geophysics. The space-based activity complements ongoing ground-based research programs in the observation, understanding, and modeling of radiation, climate dynamics, and hydrology and water resources; 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.

**FY 2000 Program Highlights.** The overall goal of NASA's Earth Science Enterprise (ESE) 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 ESE are becoming increasingly important as nations work to meet the demand for economic progress by a growing global population. 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 ESE is utilizing the vantage point of 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 ESE budget into two main components: 1) scientific research, and 2) the budget 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.** The scientific research component of the ESE 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 ESE Science Research Plan are consistent with the newly refined USGCRP Program Elements for FY 2000.

Against the backdrop of the overall ESE effort to better understand the state and health of the Earth's life-support systems, NASA's FY 2000 research will target specific research issues important to national and international environmental and economic security. Through increases in Interdisciplinary Research and Analysis funding and tar-

geted augmentations in the Vegetation Canopy Lidar (VCL) and Sensor Intercomparison and Merger for Biological and Interdisciplinary Ocean Studies (SIMBIOS) components of the Mission Analysis Program, NASA will participate in the new interagency Carbon Cycle Science Program. New research will focus on exploiting data from new satellites (i.e., EOS AM-1, Landsat 7, VCL, EO-1) to document the role of land cover change, ecosystem disturbances, and interannual variability in terrestrial and marine ecosystem productivity in regional and global carbon dynamics. Another 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 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 ESE 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 ESE 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 ESE 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.

*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 1999, with Landsat-7, QuikSCAT, and AM-1.

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.

Continuing the deployment of EOS, FY 2000 will see the launch of the Active

Cavity Radiometer Irradiance Monitor (ACRIM) mission, the SeaWinds scatterometer on Japan's ADEOS II mission, and the US/France Jason-1—a follow-on to the highly successful TOPEX/Poseidon mission. In addition, we will launch the New Millennium Program Earth Observer-1 technology demonstration mission, designed to make future Landsat-type missions possible at vastly reduced size and cost. The New Millennium Program (NMP) provides for the infusion of innovative new technologies into ESE, with an initial focus on the EOS follow-on missions, 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-FY 2000 time frame.

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 systematic, long-term measurements begun with 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. And late in the fiscal year, ESE will fly the Shuttle Radar Topography Mission to use interferometric synthetic aperature radar to produce the first widely available, nearly global, digital-elevation model.

ESE has adopted an evolutionary approach to fulfilling its mission and goals. Future missions needed to achieve continuity for systematic measurements, together with those in the exploratory mode of ESSP, will be implemented according to the "better/faster/cheaper" paradigm. ESE will use commercially available spacecraft in a "catalog" procurement mode to reduce the cost and development time required to prepare a mission for launch. Meanwhile, ESE will invest upfront in instrument technology development, and base its mission selection on both scientific need and technology readiness. In 1998, ESE developed a notional multi-mission scenario for the years 2003-2010, and in 1999 it will be reviewed by the National Academy of Sciences and discussed with prospective interagency and international partners. In FY 2000 the first mission solicitation(s) for EOS follow-on missions will be prepared.

**Related Research.** All NASA global change research is included in the USGCRP 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, as part of the Science, Aeronautics, and Technology account. Within this account, Appropriations Committee reports specify funding for the Earth Science program.

# National Science Foundation

| NSF | Program Title | FY98 | FY99 | FY00 Request |
|---|---|---|---|---|
| | Antarctic Ecosystems | 1.0 | 1.0 | 1.0 |
| | Arctic System Science (ARCSS) | 13.4 | 13.8 | 14.2 |
| | Carbon Cycling | 0.0 | 2.8 | 5.2 |
| | Climate Modeling, Analysis & Prediction (CMAP) | 12.0 | 13.0 | 13.4 |
| | Climate Variability and Predictability (CLIVAR) | 11.0 | 13.6 | 15.9 |
| | Coastal Long-Term Ecological Research (cLTER/LMER) | 2.1 | 3.2 | 3.2 |
| | Earth System History | 13.0 | 18.1 | 19.3 |
| | Ecological Diversity | 5.0 | 6.2 | 6.7 |
| | Ecological Rates of Change (EROC) | 3.2 | 3.2 | 3.2 |
| | Geodata | 1.8 | 2.7 | 2.8 |
| | Global Ocean Ecosystems Dynamics (GLOBEC) | 10.0 | 13.3 | 14.9 |
| | Global Tropospheric Chemistry Program (GTCP) | 12.8 | 13.9 | 14.3 |
| | Greenhouse Gas Dynamics (GGD) | 0.2 | 0.2 | 0.2 |
| | Human Dimensions of Global Change | 12.1 | 13.6 | 14.0 |
| | Joint Global Ocean Flux Study | 17.3 | 10.2 | 7.9 |
| | Methods and Models for Integrated Assessment | 3.4 | 3.4 | 3.4 |
| | Ocean Observation, Data Assimilation, and Modeling (OODAM) | 0.0 | 4.1 | 4.6 |
| | Polar Ozone Depletion/UV Radiation Effects | 4.2 | 4.2 | 4.2 |
| | Regional Research Institutes | 3.2 | 3.2 | 3.2 |
| | Ridge Interdisciplinary Global Experiments (RIDGE) | 3.3 | 3.3 | 3.3 |
| | Sea Level Changes | 5.8 | 6.2 | 6.4 |
| | Solar Influences | 6.8 | 7.2 | 7.4 |
| | Water & Energy: Atmospheric, Vegetative & Earth Interactions | 8.8 | 9.5 | 9.7 |
| | World Ocean Circulation Experiment (WOCE) | 16.8 | 11.8 | 9.1 |
| | **NSF Total** | **167.2** | **181.7** | |
| | **President's Request** | | | **187.5** |

**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, adapta-

tion, and other responses to changing global environmental conditions.

**FY 2000 Program Highlights.** During FY 2000, 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) have entered the analysis and synthesis phase 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. As WOCE and JGOFS complete the synthesis phase resources will be directed to other aspects of climate research (e.g. CLIVAR) and to carbon cycling studies.

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. This activity will hopefully be expanded through the National Oceanographic Partnership Program.

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 develop and apply 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 environ-

mental change. Especially noteworthy are studies of the ways that people and institutions anticipate and respond to risks, because risk assessment and risk management invariably entails 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

| SI | Program Title | FY98 | FY99 | FY00 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 |
| | **SI Total** | **7.0** | **7.0** | |
| | **President's Request** | | | **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 |

**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), National Museum of Natural History (NMNH), Smithsonian Tropical research Institute (STRI) and National Zoological Park (NZP) concentrates on monitoring indicators of natural and anthropogenic environmental change on daily to decadal timescales, 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 in global climate change, provide a long-term repository of climate-relevant research materials for present and future studies, and to bring this knowledge to various audiences, ranging from scholarly to lay public. The unique contribution of the Smithsonian Institution is a long-term perspective, e.g. undertaking investigations that may require extended study before producing useful results and committing to observations on long (i.e. decadal) timescales.

**FY 2000 Program Highlights.** At SAO studies will be performed on 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.

Studies at NMNH and STRI focus on the paleoecology of climate change.

At SERC, measurements will be made of spectral UV-B in Maryland (25-year record), Hawaii, and other sites in the U.S. These studies will be coupled with the efforts of USGCRP agencies to provide long-term as well as spatially extensive records of UV-B exposure. Several parts of the SI programs will examine biological responses to global change and increase public understanding of global change issues. At SERC, research will be conducted on the responses of global ecosystems to increasing $CO_2$, exotic species introductions, and ozone depletion.

The Institute for Conservation Biology will provide a focus for cross-institutional activities in biodiversity education and research which will be performed at STRI, NMNH, and NZP. Tropical biodiversity research programs monitor 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. Other studies on ecosystem response to increasing habitat fragmentation will be conducted at NZP.

The general public and research community will be informed of global change research at the Smithsonian via exhibits, such as the planned "Forces of Change" exhibit at NMNH, educational programs, and a global change information web page.

**Related Research.** Contributing activities include other research conducted by several units within the Smithsonian in a variety of habitats concerning natural and man-induced variations in species, populations-communities and ecosystems. These studies help clarify the relative importance of global change effects as one of several agents of ecological change. 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

## 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 FY 1990 budget as a high-priority research effort, designed to:

1. Address key uncertainties about changes in the Earth system, both natural and human-induced
2. Monitor, understand, and predict global change
3. 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.

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 the efforts in implementing and interpreting systematic and experimental global satellite observations of the Earth, as well as conducting multidisciplinary research aimed at understanding the physical, chemical, and biological processes that control the state of the integrated Earth system and their susceptibility to change; 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 timescales 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.

### Footnotes:

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.

# APPENDIX D

## New 1998 Global Change Related Data Products

This appendix includes a representative listing of global change related research data products made available for the first time in 1998 by USGCRP agencies. In February 1999 a fuller listing of the agencies' data sets with authors, sources, and Web links for each will be on the Global Change Data and Information System Web page (http://www.gcdis.usgcrp.gov).

### DOC/NOAA

- Auroral Activity, Hemispheric Power, and Energetic Particles from NOAA's POES Satellite
- Multistate Atmospheric Pollution from Power Production Study, Precipitation Chemistry Data
- Regional Atmospheric Modeling System Mid-Atlantic Output Archive
- Interannual Climate Prediction
- Circumpolar Active-Layer Permafrost System
- Global Land 1-km Base Elevation
- Geomagnetic Storm Sudden Commencements
- Geomagnetic Kn, Ks, and Km Activity Indices
- Geomagnetic Principal Magnetic Storms
- Ocean Profile Data Base
- Biological and Oceanographic Cruise Data (1948-1975).
- Fish Injury in the Hylebos Waterway of Commencement Bay, Washington.
- New Technologies for Coastal Mapping 1998

### DOE

- Atmospheric Radiation Measurements from the Southern Great Plains
- Greenhouse Gases Database
- Emissions of Greenhouse Gases in the U.S. 1996
- Annual Energy Outlook
- Mitigating Greenhouse Gas Emissions
- Energy Use and Carbon Emissions: Some International Comparisons
- Energy Use and Carbon Emissions: Non-OECD Countries
- An Analysis of the Federal Energy Regulatory Commission's (FERC) Final Environmental Impact Statement for Electricity
- Update on Effects of Title IV of the Clean Air Act Amendments of 1990 on Electric Utilities
- Alternatives to Traditional Transportation Fuels 1994, Volume 2: Greenhouse Gases
- Describing Current and Potential Markets for Alternative-Fuel Vehicles
- Stratospheric Radionuclide and Trace Gas Databases
- Indian Ocean Surface Carbon Data Obtained During the World Ocean Circulation Experiment (WOCE)

- A Coastal Hazards Data Base for the U.S. West Coast
- Global and Hemispheric Temperature Anomalies
- Carbon Dioxide Emission Estimates from Fossil-Fuel Burning, Hydraulic Cement Production, and Gas Flaring for 1995
- Carbon-14 Surface Measurements from the Atlantic, Indian and Pacific Oceans 1965-1994
- Effects of $CO_2$ and Nitrogen Fertilization on Growth and Nutrient Content of Juvenile Ponderosa Pine
- Ice-Core Data from Antarctica
- Carbon Dioxide, Water, and Chemical Data Obtained in the South Pacific Ocean
- Annual Global Methane Emissions Estimates: 1860-1994

## DOI/USGS

- 1995 Global Land 1-km Satellite AVHRR 10-day Vegetation Index Composites
- U.S. Digital Orthophoto Quads (computer-processed aerial photographs having map-like qualities)
- U.S. Digital Raster Graphics (scanned USGS topographic maps)
- Hydrology/Elevation Derivative Database (elevation, slope, aspect, drainage basins, streams, flow direction, flow accumulation, and compound topographic index) for North America, Europe, Africa, and Australasia
- Sediment Yield Simulation Data, Kansas Conservation Reserve Program
- Digital Snow Depth Maps of the Northern Great Plains (1989 and 1997)
- Borehole Temperature Logs from Arctic Alaska (pre-1989)
- Benchmark Glacier Mass-Balance Data, AK and WA (changes in glacier ice volume)
- Data for Devils Hole (NV) Core DH-11 (variations in temperature and other paleo-climatic parameters)
- Long-term Ecological Monitoring Program at Denali National Park and Preserve, AK
- Vegetation Mapping Program (Jewel Cave National Monument, SD; Mount Rushmore National Historic Site, SD; Devils Tower National Monument, WY)
- Forest Ecotone Shift (1935-1975), Bandelier National Monument, NM
- Wetland Data, San Francisco Bay, CA
- Manual of Acute Toxicity: Interpretation and Data Base for 410 Chemicals and 66 Species of Freshwater Animals
- Contaminant Exposure and Effects—Terrestrial Vertebrates
- Raptor Information System
- Bottomland Hardwood Breeding Bird Census Data—Eastern U.S.
- Waterfowl Habitat Data, Russell Lakes (CO) State Wildlife Management Area
- Home Range Data (1971-1991), Black Bear Test Area, MN

## NASA

- Satellite Land 10-day Greenness Index
- Earth Observing System Land Validation Data
- Global Fire Monitoring Satellite Imagery
- Satellite Global Rain Forest Mapping

- Geostationary Satellite Global Infrared Composite of Earth
- Tropical Rainfall Measurements Mission (TRMM) Satellite Lightning Imaging Sensor Data
- Atmospheric Mixing Ratio and Aerosol Scattering Ratio
- Satellite Gridded Oceanic Rainfall
- TRMM Satellite Microwave Imager Hydrometeor Profiles
- TRMM Satellite Microwave Imager Earth Radiance
- Visible and Infrared TRMM Satellite Scanner Earth Radiance
- World Ocean Circulation Experiment Global Data Set (CD)
- Global Cloud Climatology Data Products, 1989-1993 (CD)
- High-Resolution Mean Sea Surface Height from Satellite Altimetry
- TRMM Monthly Averaged Rainfall Rates and Vertical structure
- TRMM Rain Occurrence and Rain Type
- NVAP Global Total Column and Layered Water Vapor, 1988-1994 (CD)
- Global Data Sets for Land-Atmosphere Models, 1987-1988 (CD)
- SeaWiFS Near-Daily Global Ocean Color Time Series – Ocean Surface Chlorophyll Distributions
- Web Site for Fire Monitoring by Satellite at <http://www.modarch.gsfc.gov/fire_atlas/fires.html>
- Historical Data Sets for Key Climate Variables for the Past 100 Years for the U.S. National Assessment on the Potential Consequences of Climate Variability and Change
- Airborne Measurements of Smoke Clouds from Biomass Burning in Brazil
- First High-Resolution Radar Mapping of Antarctica by Radarsat
- Coordinated Satellite, Aircraft and Surface Analysis of the Greenland Ice Sheet
- SHEBA Measurements of Clouds and Radiation in the Arctic
- AGAGE Measurements of Surface Concentrations of CFCs and their Replacement Compounds
- Airborne Measurements of Stratospheric Sulfate Aerosol Levels
- Satellite Data Analysis showing Time-Lag in the Response of Terrestrial Ecosystems to Climate Variability
- PEM Tropics-A Data on Tropical Atmospheric Chemistry
- Upper Tropospheric Water Vapor, Ozone, and Methane Data Set from UARS
- High Thin Cirrus Cloud Data Set from UARS/CLAES
- Lower Stratosphere Nitric Acid Data Set from UARS/MLS
- Data Assimilation Office Global Re-Analysis Products
- Atmospheric Water Vapor Data from the GPS Surface-Based Monitoring system
- Improved Monitoring of Small Variations in the Earth's Gravity field due to Weather and Climate-Related Air and Water Redistribution from Laser Tracking of Satellites
- POLARIS Airborne Campaign Data on Arctic Summertime Photochemistry of Ozone and Related Species
- TOMS Tropospheric Aerosol Index Global Data Set

Note: The primary archive for NASA Earth Science Enterprise data is the network of Distributed Active Archive Centers (DAAC), which can be reached through the ESE Homepage at: http://www.hq.nasa.gov/office/ese/.

## NSF

- Global Scale Atmospheric Wave Model
- Daily Images of the Sun
- Global Atmospheric Reanalysis, 1996-1998
- Comprehensive Ocean Atmosphere Data Set, updates for the 1990s
- Climate Model Products for Assessment Studies, starting 1998
- High Resolution Ocean Climate Model - versions 4B and 4C
- Greenland Summit Ice Cores (CD-ROM)
- Into the Arctic (CD-ROM)
- Ecosystem Carbon Fluxes, Thaw Depth, Canopy Foliage Area, and Soil Temperatures, Toolik Lake, Alaska
- Eddy Flux Data, Methane Flux Data, Borehole Temperatures, and Thaw Depth, Alaska North Slope
- Thaw Depth Data, Alaska, 1995-1996
- Meteorological and Hydrographic Data, and Computed Thaw Depth, Kuparuk River Watershed
- Arctic Global Radiation Data Set
- Northwest Atlantic and Pacific Ocean Flux Data
- Paleoclimatology Program Data
- Chesapeake Bay Land Margin Ecosystem Research
- Columbia River Estaurine Turbidity
- East Pacific Rise Petrology Database
- Geophysical Indices, Hemispheric Power, Equatorward Auroral Boundary at Midnight, and Arecibo (Puerto Rico), Collm (Germany), Goose Bay (Canada), Hankasalmi (Norway), Jicamarca (Peru), Kapuskasing (Canada), Pykkvibaer (Iceland), Saskatoon (Canada), Sondrestrom (Greenland), Stokkseyri (Iceland), and EISCAT Radar Measurements as well as Lidar Measurements in the Coupling, Energetics and Dynamics of Atmospheric Regions Data Base.

## USDA

- Alabama Cotton Data 1987-1988
- California Cotton Data 1984-1989
- Louisiana Yield Only Cotton Data 1987-1989
- Mississippi Cotton Data 1987-1989
- New Mexico Regional Variety Trials, Cotton Data, 1988-1990
- Tennessee Cotton Data 1989
- Texas Cotton Data 1987-1994
- Chesapeake Bay Pesticide Database
- An extensive series of genome databases, including those for forest trees, grains, cotton, rice, legumes, soybeans, and fungal pathogens.

# APPENDIX E

## Figure Captions

**Figure 1.** La Niña experimental climate forecast: Global temperature forecast for January-March 1999

The International Research Institute for Climate Prediction (IRI) is a new institute sponsored by the USGCRP to focus on seasonal to interannual climate forecasting. In October, 1998, its Experimental Forecast Division issued this Climate Outlook for January-March 1999. The evolution of cooler than average conditions in the eastern and central equatorial Pacific Ocean (La Niña) and the persistence of warmer than average conditions in the western equatorial Pacific were particularly influential factors in this forecast. The sea-surface temperatures of the central and western tropical Indian Ocean were cooling from record high temperatures when this forecast was made, and this trend was expected to continue. It was assumed that the northern and tropical Atlantic Ocean would remain warmer than normal, and that sea-surface temperatures in the South Atlantic would increase during the forecast period.

This Outlook covers January-March 1999. The global map of temperature shows probabilities for expecting that the seasonal temperatures will fall into the warmest third of past years, the middle third of past years, or the coldest third of past years. A qualitative outlook of climatology ("C") indicates that there is no basis for favoring any particular category. Boundaries between sub-regions should be considered as transition zones, and their location considered to be only qualitatively correct.

The procedures, models, and data used to derive this Climate Outlook may be somewhat different from those used by the national meteorological services in North America. Thus, this product may differ from the official forecasts that are issued. The current status of seasonal-to-interannual climate forecasting allows prediction of spatial and temporal averages, and does not fully account for all factors that influence regional and national climate variability; local variations should be expected.

Source: International Research Institute for Climate Prediction (IRI). The figure (and updated forecasts) may be accessed at the IRI web site at http://iri.ucsd.edu/forecast/net_asmt/.

**Figure 2.** Changes in potential distribution of Douglas Fir in western North America under $2xCO_2$ conditions

The U.S. Geological Survey and academic collaborators are modeling the potential effects of future climate change on plant distributions in North America. Studies of the modern relations between climatic parameters and the range boundaries of important trees and shrubs provide the basis for estimating the extents of future changes in the geographic distributions of plant species under potential future climates. The example shown here illustrates the modern distribution of Douglas-fir (Pseudotsuga menziesii) in dark green in

the left panel. Light green in the right panel represents areas where this tree lives under the present climate and where it could continue to grow under an atmospheric carbon dioxide concentration of twice the pre-industrial level (a simulated "$2xCO_2$" climate); red indicates areas where it lives today but would not survive under the simulated $2xCO_2$ climate; and blue represents areas where the species cannot survive today but could potentially live under the simulated $2xCO_2$ climate.

Source: Thompson, R.S., Hostetler, S.W., Bartlein, P.J., and Anderson, K.H., 1998: A Strategy for Assessing Potential Future Changes in Climate, Hydrology, and Vegetation in the Western United States. U.S. Geological Survey Circular 1153. The figure may be accessed on the USGS web site at http://geochange.er.usgs.gov/. This source provides a more complete description of the study.

**Figure 3.** Continental Scale Impact of Mexican Forest Fires: Long-range transport of smoke and dust from Mexican forest fires to the central and northeastern United States and Canada

Earth Probe satellite observations by the Total Ozone Mapping Spectrometer (TOMS) instrument have demonstrated that large forest fires in Mexico during 1998 produced plumes that were transported not only across the central part of the United States, but that the plumes actually reached the northeastern part of the U.S. (e.g., the Ohio Valley and Appalachian regions) and even penetrated well into Canada (e.g., the Hudson Bay region). The impact of these plumes, which typically exist several km off the ground, on local conditions is a subject of investigation. Potential impacts to be studied include effects on photolysis rates of chemically active species near the surface, changes in the partitioning of trace chemical species through chemical reactions that might occur on the surfaces of the particles, effects on local heating rates that could affect local meteorology, and possible contributions to the burden of particulate matter in a given area. Satellite observations of aerosol particle distributions over land have only recently become possible through the use of data from TOMS; other space-based systems for measuring aerosols produce data only over water-covered regions.

Source: NASA Goddard Space Flight Center

**Figure 4.** Notable past droughts in the United States reconstructed from tree rings

Severe droughts and wet periods in the United States can have enormous social and economic consequences. While much research has been done to improve understanding of the causes of these unusual climatic events in the 20th century, less research has been done on characterizing their long-term variability and patterns of occurrence over the U.S. In order to better estimate this variability and place some notable 20th century dry and wet years in an improved historical perspective, a network of long, climatically sensitive tree-ring chronologies has been examined to reconstruct past drought and wetness over the continental U.S. since 1700. This has been done at 154 grid point locations, which provides considerable spatial detail. The measure of drought used for these reconstructions is the Palmer Drought Severity Index (PDSI), a widely used measure of relative drought and wetness. Moderate-to-extreme droughts fall in the -2 to -6 PDSI range. Equivalent wet periods fall in +2 to +6 PDSI range. Presented here are some examples of

notable past dry and wet years over the United States as reconstructed by tree rings. The figure shows the PDSI maps for eight drought years since 1700. In terms of both severity and areal extent, the 1934 Dust Bowl drought year, which plunged almost 80% of the United States into some level of moisture deficit, stands out clearly as the worst drought to hit the United States in the past ~300 years. If the range of future drought variability over the U.S. remains as it has since 1700, then another "Dust Bowl" event in the near term is unlikely. However, the other less severe and less pervasive droughts are still quite remarkable and would have a severe impact on the U.S. were they to occur today. Note that each drought has a distinct spatial pattern, although there is a tendency for serious droughts to occur in the Great Plains. All of this spatial variability obviously complicates making accurate regional forecasts of drought.

Source: Edward Cook, Lamont-Doherty Earth Observatory, Columbia University. Maps were downloaded from the National Geophysical Data Center, World Data Center-A for Paleoclimatology North American Drought web site (www.ngdc.noaa.gov/paleo/drought.html), where they are available to the public.

Figure 5. Land-cover change in the Tensas River basin

EPA has completed an ecological assessment in the Tensas River Basin, Louisiana, in partnership with the Louisiana Department of Environmental Quality and other stakeholder groups. By examining landscape ecology and water quality issues, this assessment provides an evaluation of the impact of current land-use practices. Because many riparian vegetation areas throughout the United States are being restored, the GIS and landscape methods developed here can be used to help make better decisions on the restoration sites, thereby enhancing environmental quality at lowest cost.

The Tensas River Basin, one of 2,099 individual watersheds located across the United States, encompasses approximately 930,000 acres of Mississippi River alluvial flood plain in Northeast Louisiana. The freshwater marshes, stream bank areas, and bottomland swamps of the Tensas River Basin have been under strong development pressures. Large portions of forest near streams and in backwater swamp areas have been converted to agriculture.

Land cover is the product of past land uses on the backdrop of the biophysical setting. A map of land cover is essentially a picture of the dominant vegetative, water, or urban cover in an area. The images of land cover in the Tensas River Basin for 1972 and 1991 are based primarily on images taken by the Landsat Multispectral Scanner satellite since the early 1970s. The land-cover map was based on the North American Landscape Characterization (NALC) data, a Federal effort to create similar data for the entire country. The resolution of the land-cover data is 60 by 60 meters, so each pixel (picture element) represents an area about the size of a football field. Although individual pixels are far too small to be rendered accurately here, the visual impression of broadscale regional patterns is readily apparent. Forest vegetation shows up on the image as red in color, agriculture shows up as light red, grey, light blue and white and almost always shows a pattern with rows or right angles typical of farm fields. The data in these images were then used to categorize land use. Through these computerized Landscape analyses, the 1972 image was compared to the 1991 image and changes in forest areas and human use areas were determined. As the images show, there was substantial forest loss over that time period,

with forest cover dropping from 34% of the area in 1972 to 22% in 1991. Where forests were removed, agriculture and urban land covers became more dominant. The images also show how the forest, agriculture, and urban land cover vary across the landscape of the Tensas River Basin. Understanding the variation of land cover with respect to landscape features, such as cities, roads, lakes and streams, has formed the foundation for this assessment.

Source: U.S. Environmental Protection Agency

**Figure 6.** Hurricane Bonnie storm cloud

This scientific visualization of Hurricane Bonnie shows a cumulonimbus storm cloud, towering like a skyscraper, 59,000 feet (18 kilometers) into the sky from the eyewall. By comparison, the highest mountain in the world, Mt. Everest, is 29,000 feet (9 kilometers) and the average commercial jet flies at one-half to two-thirds the height of the Bonnie's cloud tops. These images were obtained on Saturday, August 22, 1998, by the world's first spaceborne rain radar aboard the Tropical Rainfall Measuring Mission (TRMM), a joint U.S.-Japanese mission.

Clouds this tall are rarely observed in the core of Atlantic hurricanes. This huge cloud probably happened because at the time the data was collected, Bonnie was moving very slowly. The lack of movement kept funneling warm moist air into the upper atmosphere, thus raising the entire height of the tropopause, which is normally at around 45,000-52,000 feet (14-16 kilometers). The tropopause marks the upper limits of the layer of atmosphere within which the weather occurs. The vast amount of warm, moist air being raised high into the atmosphere, and the subsequent release of latent energy as raindrops form in this tropical airmass, is believed by many scientists to be the precursor of hurricane intensification, which was observed in Bonnie in the 24-to-48 hours after these data were collected.

TRMM has flown over 100 tropical cyclones since its launch in November of 1997. This collection of data enormously enhances our information about cloud structures within tropical storms during their growth and decay phases. The TRMM spacecraft fills an enormous void in the ability to observe world-wide precipitation because so little of the planet is covered by rain gauges or ground-based radars. By studying rainfall regionally and globally, and the difference between ocean and land-based storms, TRMM is providing scientists the most detailed information to date on the processes creating these powerful storms, leading to new insights on how they affect global climate patterns.

Source: NASA Goddard Space Flight Center, via Greg Williams, NASA Earth Science Program. The image may be downloaded from the TRMM web site at http://trmm.gsfc.nasa.gov/archive.html. Text courtesy of NASA Headquarters and Goddard Space Flight Center release, September 1, 1998.

**Figure 7.** Soil organic carbon in the United States

The amount of carbon sequestered as soil organic carbon is an important component of the global carbon budget. Soils can either contribute carbon dioxide to the atmosphere

or remove it, depending on local conditions of moisture, temperature, and land management. The map shows amounts of soil organic carbon, as calculated from the USDA State Soil Geographic data base. The USGS Missisippi Basin Carbon Project is investigating the influence of erosion and sedimentation on the processes that could sequester atmospheric carbon in the soil, or conversely contribute to the release of soil carbon to the atmosphere. Model simulations are being started to show how soil organic carbon can change in response to land management changes over time and space.

Source: Courtesy of Norman Bliss, U.S. Geological Survey. Information about the Mississippi Basin Carbon Project may be found on the USGS web site at http://geochange.er.usgs.gov.

**Figure 8.** Ocean circulation profiling floats

The figure shows the trajectories of an array of about 400 Profiling Autonomous Lagrangian Circulation Explorer (PALACE) floats deployed at a depth of 1500 meters in the North Atlantic Ocean between 1996 and 1998. This measurement program has been a major component of the Atlantic Circulation and Climate Experiment (ACCE), which is a component of the World Ocean Circulation Experiment (WOCE). Vertical profiles of temperature and salinity are collected when floats rise to the surface at approximately 10-day intervals. These instruments have been deployed to explore specific scientific questions about the nature of convection in the Labrador Sea and the overturning at high latitudes, the production and circulation of mode water in the subtropics, and the circulation and fluxes of heat and fresh water in the Tropics. In addition, this successful deployment of a large number of PALACE floats has shown for the first time that it is feasible to observe changes in ocean heat and fresh water content in near-real time over an ocean basin. A proposal for a global Array for Real-time Geostrophic Oceanography (ARGO) is a new FY 2000 USGCRP initiative.

Source: Courtesy of Eric Itsweire, National Science Foundation, Division of Ocean Sciences

Figure 9. Ocean circulation: Comparison of modeling and observation

Many elements of a global ocean observing network are either in place now or the technology exists with which to develop and implement them. Progress in ocean modeling and computer architecture has enabled realistic, eddy-resolving models of ocean circulation to be constructed. (By eddy-resolving, we mean able to actually simulate the most natural scale of motions in the oceans, typically tens of kilometers in size.) The figure shows a comparison of an eddy-resolving simulation of Sea Surface Height variance from the Miami Isopycnal Ocean Model (MICOM), compared with sea-level variance from TOPEX altimetric measurements.

Source: Courtesy of Eric Chassignet, University of Miami, Rosenstiel School of Marine and Atmospheric Science, Miami, FL. The figure may be accessed on the web site of the Miami Isopycnic Coordinate Ocean Modeling Group at the University of Miami, at the link titled "Very-high-resolution (1/12 deg.) North Atlantic MPP simulation" (http://panoramix.rsmas.miami.edu/micom/micom_highres.html).

# APPENDIX F

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## Abstract

*Our Changing Planet: The FY 2000 Global Change Research Program* is a report to Congress supplementing the President's FY 2000 budget, pursuant to the Global Change Research Act of 1990. The report describes the U.S. Global Change Research Program (USGCRP); outlines a perspective for global change research in the decade ahead and the changing vision for the research agenda; presents an implementation plan for the USGCRP in FY 2000, with a discussion of each of the Program Elements; outlines a FY 2000 initiative in Carbon Cycle Science; summarizes key USGCRP accomplishments in 1998; and provides a detailed view of the FY 2000 USGCRP budget, including FY 2000 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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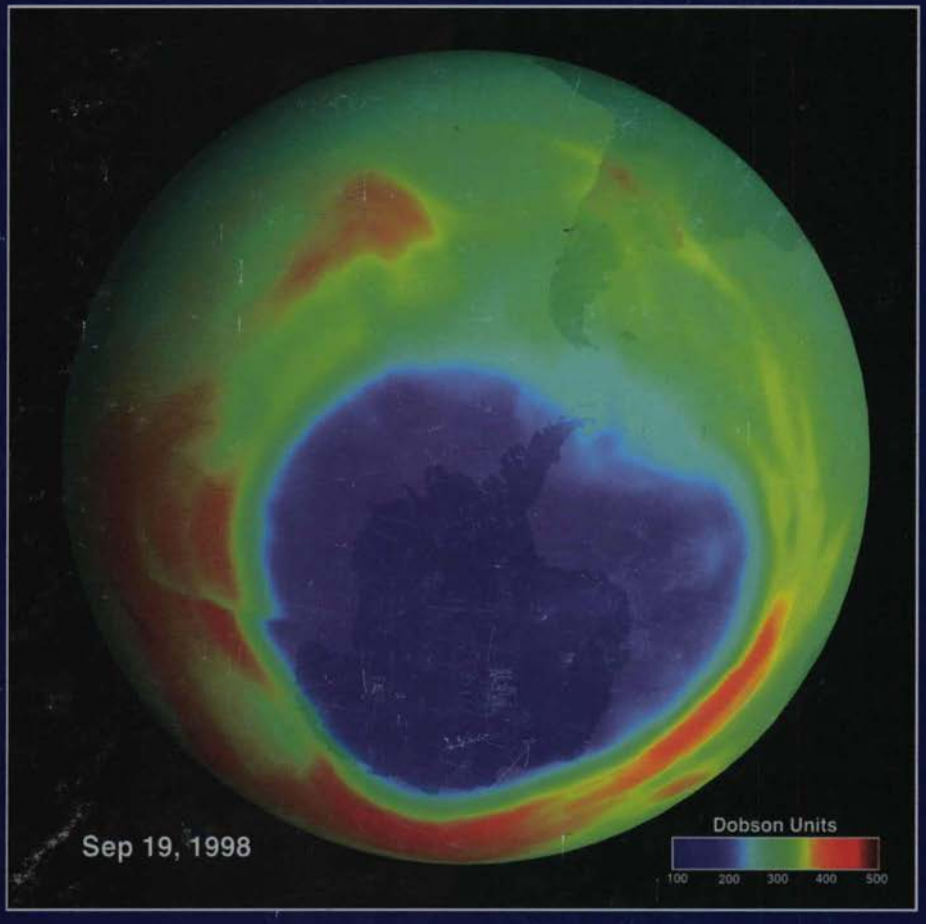
## On the Back Cover

Record large 1998 Antarctic Ozone Hole: The 1998 Antarctic "Ozone Hole" was of record size, with the largest size being in excess of 27 million square km, observed briefly in September. This is some 5% larger than the largest previously observed hole, which was seen in 1996. The large area of ozone depletion was due to a correspondingly large Antarctic polar vortex in 1998. There is sufficient chemically activated chlorine in the polar vortex during this time period that all the air in the lower stratosphere inside the vortex is highly depleted in ozone. The vortex in 1998 also remained large later into the spring than is typically seen, so the region of ozone depletion associated with the polar vortex during the later part of the spring (especially the second half of November) was much larger in 1998 than in recent years. The reasons why the Antarctic polar vortex in 1998 was particularly large and stable are not understood, however, and remain an active area of research in stratospheric meteorology.

Recovery of the ozone layer could be delayed by global warming because accumulation of greenhouse gases in the troposphere is expected to cause a cooling of the stratosphere. Recent model calculations have suggested that such changes in atmospheric temperature distributions and, therefore, wind systems, could result in more stable polar vortices, colder temperatures in the lower stratosphere, and concomitantly increased ozone depletion, especially at high latitudes. It is speculated that increased concentrations of greenhouse gases might, therefore, be at least partly responsible for the very large Arctic ozone losses observed in recent winters (especially 1996-97). Furthermore, this mechanism could result in Arctic ozone losses increasing for a decade after stratospheric chlorine levels peak, with future Arctic ozone losses rivaling those observed at present in the Antarctic. The severity and duration of the Antarctic ozone hole could also increase. These findings suggest the possibility that recovery of the ozone layer (confirmation of which will be complicated by the potential for large interannual variability in stratospheric meteorology) could be significantly delayed, and underscore the need for well-focused observations and further modeling to elucidate this potentially significant coupling of climate change with the state of the ozone layer.

Source: The Total Ozone Mapping Spectrometer Research Group, NASA Goddard Space Flight Center

The U.S. Global Change Research Program

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