

OUR CHANGING PLANET

The Fiscal Year 2003 U.S. Global Change Research Program
and Climate Change Research Initiative



A Report by the
Climate Change Science Program and
the Subcommittee on Global Change Research

A Supplement to the President's Fiscal Year 2003 Budget

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OUR CHANGING PLANET



THE FISCAL YEAR 2003

U.S. GLOBAL CHANGE RESEARCH PROGRAM
AND CLIMATE CHANGE RESEARCH INITIATIVE

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November 2002

Members of Congress:

We are pleased to transmit to you a copy of *Our Changing Planet: The FY 2003 U.S. Global Change Research Program and Climate Change Research Initiative*. The report describes the activities and plans of the U.S. Global Change Research Program (USGCRP), which was established in 1989 and authorized by Congress in the Global Change Research Act of 1990. This year, the report also describes the start-up activities for the U.S. Climate Change Research Initiative (CCRI), established by President George W. Bush to accelerate research on climate change. The CCRI supplements the ongoing USGCRP work by providing focus and targeting resources to areas where significant 2 to 5 year improvements in decision-relevant information are possible. The CCRI is an important part of the Administration's broader approach to climate change that seeks to achieve both environmental protection and a healthy economy, based on the best possible information for action.

This year's *Our Changing Planet* also describes the new science and technology management arrangements announced by the President in February 2002 to ensure that resources invested are used effectively. The new science structure includes the interagency Climate Change Science Program (CCSP), which oversees the entire range of research sponsored by both USGCRP and CCRI. The CCSP is focused on three broad tiers of activities: (1) *scientific inquiry*, which has been a core activity of the USGCRP over the years, (2) *observations and monitoring systems*, which have always been part of the program but need increased integration, and (3) development of *decision support resources*, including detailed analyses of potential environmental, economic and energy system outcomes. The new structure also includes the Climate Change Technology Program (CCTP) that is responsible for accelerating climate change-related technology research and development.

The CCSP and CCTP report through the Interagency Working Group on Climate Change Science and Technology (IWGCCST) to the cabinet-level Committee on Climate Change Science and Technology Integration (CCCSTI). The chairmanship of these coordinating bodies rotates annually between the Departments of Commerce and Energy, with the Director of the Office of Science and Technology Policy serving as the Executive Director of the CCCSTI. The National Science and Technology Council and its subsidiary bodies, the Committee on Environment and Natural Resources and the Subcommittee on Global Change Research, continue to coordinate climate and global change research.

The United States' global change and climate change research programs must consistently meet the highest standards of credibility, transparency, and responsiveness to the scientific community, all interested constituencies, and our international partners. To assure credibility, scientific inquiries must be policy-neutral. The program described in this report meets these standards and will support informed public debate and decision making on climate change and other global environmental issues.

We thank the other participating agencies and departments of the CCSP and CCTP for their close cooperation and support, and look forward to working with Congress in the continued development of these important programs and initiatives.



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Introduction

The U.S. Global Change Research Program (USGCRP) supports research on the interactions of natural and human-induced changes in the global environment and their implications for society. The USGCRP began as a presidential initiative in 1989 and was codified by Congress in the Global Change Research Act of 1990 (P.L. 101-606), which mandates development of a coordinated interagency research program. Participants in the USGCRP include the Departments of Agriculture, Commerce (National Oceanic and Atmospheric Administration), Defense, Energy, Health and Human Services, Interior (U.S. Geological Survey), State, and Transportation; the U.S. Environmental Protection Agency; the National Aeronautics and Space Administration; the National Science Foundation; and the Smithsonian Institution. The Office of Science and Technology Policy, the Office of Management and Budget, and the Council on Environmental Quality provide oversight on behalf of the Executive Office of the President.

Since its inception, USGCRP-supported research and observational activities, in collaboration with several other national and international science programs, have documented and characterized important aspects of the sources, abundances, and lifetimes of greenhouse gases; mounted extensive space-based systems for global monitoring of climate and ecosystem parameters; begun to address the complex issues of various aerosol species that may significantly influence climate parameters; advanced understanding of the global water and carbon cycles; and taken major strides in computer modeling of the global climate.

In February 2002, President Bush announced a new management structure to integrate and provide direction to the USGCRP and the Climate Change Research Initiative (CCRI), which had been announced in June 2001. The CCRI focuses primarily on areas of significant remaining uncertainty and on enhancing the global climate observation system to reduce those uncertainties. The CCRI also develops decision-support products for policymaking and resource management. This structure is depicted in Figure 1.1 (see page 10). The Climate Change Science Program (CCSP) will provide direct oversight and ensure that the USGCRP and CCRI coordinate their activities and accelerate progress on substantial uncertainties regarding the Earth's climate system. For example, various global climate models project significantly different increases in the global average surface temperature: from approximately 1°C during the 21st century to more than 4°C during the same period. Reducing the scientific uncertainty in global climate models, and improving confidence in their ability to project future climate change could, in the long run, make a major contribution to determining optimal strategies for addressing the human-induced aspect of global climate change; help resolve key questions about the relative importance of greenhouse gases, carbon-based aerosols, and sulfate-based aerosols on long-term climate parameters; and provide information on the potential impacts of climate change on ecosystems.

The USGCRP and CCRI are being managed in a coordinated way; under the direction of the CCSP, they are currently completing a joint strategic plan. The introduction to this edition of *Our Changing Planet* describes the nature of the scientific challenges confronting the integrated USGCRP and CCRI and summarizes changes in program organization that will help create an integrated research program. One section of the report describes the CCRI plans for FY2003, focusing on those activities included in the President's FY2003 budget request. Other sections of the report focusing on each of the main research elements of the USGCRP present highlights of recent research and of FY 2003 program plans. An additional section describes international research collaborations. Appendix A describes the roles of participating Federal departments and agencies, including budget and program information.

OVERVIEW OF U.S. RESEARCH ON CLIMATE AND GLOBAL CHANGE

CLIMATE CHANGE: A CAPSTONE ISSUE

The Earth's environment is in a state of continuous change. The climate system, for example, is highly variable, with conditions changing significantly over the span of seasons, from year to year, and over longer timescales. Fluctuations in the amount of energy emitted by the Sun, slight deviations in the Earth's orbit, volcanic injections of gases and particles into the atmosphere, and natural variations in ocean temperatures and currents, all cause variability and changes in climate conditions.

Many scientific observations indicate that the Earth may be undergoing a period of relatively rapid change on timescales of decades to centuries, when compared to historical rates of change on similar timescales. Much scientific evidence indicates that these changes are likely the result of a complex interplay of several natural and human-related forces.

Although humans are relative newcomers in the vast scale of the Earth's geological history, we have become agents of environmental change, at least on timescales of decades to centuries. Atmospheric emissions of greenhouse gases and pollutants, and extensive changes in the land surface, have potential consequences for global and regional climate, weather, and air quality, the Earth's protective shield of stratospheric ozone, the distribution and abundance of many plant and animal species, and the health of ecosystems and their ability to provide life-supporting goods and services. The complexity of the Earth system and the interconnections among its components make it a complex scientific challenge to document change, diagnose its causes, and develop useful projections of how natural variability and human actions may affect the



global environment in the future. Because of these complexities and the potentially profound consequences of climate change and variability, climate has become a capstone scientific and societal issue for this generation and the next, and perhaps even beyond.

The challenge for the USGCRP is to provide the best possible scientific basis for documenting, understanding, and projecting changes in the Earth's life-support systems, and the role for CCRI is to reduce the significant remaining uncertainties associated with human-induced climate change and facilitate full use of scientific information in policy and decisionmaking on possible response strategies for adaptation and mitigation.

FROM "DISCOVERY" TO "COMPARATIVE ANALYSIS"

Because of the scientific accomplishments of USGCRP and other research programs during the last decade, a period that could be termed a productive "period of discovery and characterization," the CCRI, in coordination with the USGCRP, will move into a new "period of comparative analysis of response strategies." In this new phase of the climate science programs, information that allows comparisons of the potential consequences of different responses to global changes, including climate change, will be developed. However, even as some programs move to develop focused, comparative studies, the USGCRP will need to continue to actively support fundamental, discovery-driven research that tests basic assumptions and substantially increases the understanding of cause-effect relationships, and that contributes to reducing key scientific uncertainties.



Future plans for the combined USGCRP and CCRI will focus on three broad tiers of activities: (1) scientific inquiry, which has been the core activity over the years, with several key issues continuing to await resolution; (2) observations and monitoring systems; and (3) development of decision-support resources, potentially including analyses of projected environmental, economic, and energy system outcomes of various proposed scenarios. The CCRI will supplement the ongoing USGCRP by focusing elements of each of these three tiers, where significant 2-to-5 year improvements in decision-relevant information is possible. Pursuing the third tier in a meaningful way will require significant, sustained progress under the first and second tiers.

Scientific inquiry

Over the past decade, the United States has supported long-term studies, research into basic environmental processes, the development of models, and cooperative international field campaigns and assessments. With these resources, the agencies participating

Overview of U.S. Research

in the USGCRP have assembled a comprehensive and interdisciplinary collaboration that has facilitated scientific discovery. The program has sponsored research that has revealed and addressed many of the complex interactions and consequences of climate and other environmental systems. Scientists have started to assemble information on the complex relationships between natural variability and human activities that could contribute to change. U.S. researchers are pursuing fundamental insights about how the climate and Earth system function, insights that are incorporated into advanced models throughout the world. Among the returns from our Nation's investment are the following:

In and over the oceans, USGCRP missions and programs have:

- Developed observing systems and models that enabled the successful prediction of the onset of the 1997-1998 El Niño event and the subsequent La Niña, and that identified several other large-scale patterns of natural climate variability (e.g., the Pacific Decadal Oscillation).
- Reduced the uncertainty in estimates of rainfall over the tropics by one half, thereby helping to improve short-term weather prediction and management of fresh water globally.
- Measured winds at the ocean surface to improve short-term weather prediction and global tracking of major hurricanes and tropical storms.
- Produced ocean color maps that document the daily uptake of carbon by ocean biomass, thereby helping to improve estimates of the amount of carbon dioxide removed from the atmosphere.

In the atmosphere, USGCRP programs have:

- Continued measurements of concentrations of both ozone and ozone-depleting substances and led international assessments of the estimated recovery time of the Antarctic ozone hole.
- Provided quantitative estimates of how much changes in atmospheric concentrations of carbon dioxide, methane, nitrous oxide, and other greenhouse gases are altering the Earth's natural greenhouse effect, and have demonstrated the significant impact of anthropogenically-derived aerosols on the radiative budget of the Earth-atmosphere system.
- Yielded new insights into interactions of how changes in aerosol concentrations can affect cloud processes, supporting continuing improvements in the climate models.

On and over the land surface, USGCRP-supported researchers have:

- Produced the first ever satellite-derived assessments of global forest cover, documenting large-scale changes in land cover and land use that are important to carbon storage, climate change, biodiversity, regional water resources, food supply, and human health.

- Conducted field experiments to help understand the role of vegetation on Earth in removing carbon dioxide from the atmosphere and in regulating the hydrological cycle.
- Studied the interactions of increased CO₂ concentrations with other environmental processes such as nitrogen deposition.

In investigations of the Earth's long-term climate history, USGCRP-supported researchers have:

- Contributed to significant progress in reconstructing the history of the Earth's climate using surrogate (or proxy) records derived from ice cores, tree rings, pollen, coastal coral samples, and ocean and lake sediment analysis, among other paleoclimatic data.

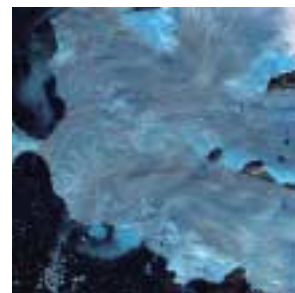
This information is vital to accurately placing 20th and 21st century climate in historical context, evaluating the significance of future changes in climate, and analyzing uncertainties in projections of climate change in order to focus future research.

Over the ice caps, USGCRP-supported researchers have:

- Determined the thinning and thickening rates for the Greenland ice sheet.
- Provided the first detailed radar mosaic of Antarctica (in conjunction with the Canadian Space Agency and RADARSAT International).
- Provided daily observations of the polar regions from space.

All of this information will be crucial to reducing uncertainties regarding the ice-albedo feedback and the future rate and magnitude of changes to these important systems.

As the USGCRP and CCRI look to the future, improving projections of climate variability and change and reducing other significant global change uncertainties will require significant advances in knowledge of the physical, biological, and chemical processes that influence the Earth system. A number of key uncertainties will need to be resolved. In a report commissioned by the Bush Administration, *Climate Change Science: An Analysis of Some Key Questions*, the National Research Council (NRC, 2001) reviewed and evaluated the comprehensive climate change assessment produced by the Intergovernmental Panel on Climate Change (IPCC, 2001) and made a number of recommendations about research needs. At the most fundamental level, the NRC report indicated the need to better understand the causes of warming. The report stated, "The changes observed over the last several decades are likely mostly due to human activities, but we cannot rule out that some significant part of these changes are also a reflection of natural variability."



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The NRC report identified the highest priority areas where additional research is needed to advance understanding of climate change:

Making progress in reducing the large uncertainties in projections of future climate will require addressing a number of fundamental scientific questions relating to the buildup of greenhouse gases in the atmosphere and the behavior of the climate system. Issues that need to be addressed include (a) the future usage of fossil fuels, (b) the future emissions of methane, (c) the fraction of the future fossil-fuel carbon that will remain in the atmosphere and provide radiative forcing versus exchange with the oceans or net exchange with the land biosphere, (d) the feedbacks in the climate system that determine both the magnitude of the change and the rate of energy uptake by the oceans, which together determine the magnitude and time history of the temperature increases for a given radiative forcing, (e) details of the regional and local climate change consequent to an overall level of global climate change, (f) the nature and causes of the natural variability of climate and its interactions with forced changes, and (g) the direct and indirect effects of the changing distributions of aerosols. Maintaining a vigorous, ongoing program of basic research, funded and managed independently of the climate assessment activity, will be crucial for narrowing these uncertainties.

In addition, the research enterprise dealing with environmental change and the interactions of human society with the environment must be enhanced. This includes support of (a) interdisciplinary research that couples physical, chemical, biological, and human systems, (b) an improved capability of integrating scientific knowledge, including its uncertainty, into effective decision support systems, and (c) an ability to conduct research at the regional or sectoral level that promotes analysis of the response of human and natural systems to multiple stresses.

An effective strategy for advancing the goal of understanding climate change also will require (1) a global observing system in support of long-term climate monitoring and prediction; (2) concentration on large-scale modeling through increased, dedicated supercomputing and human resources, and (3) efforts to ensure that climate research is supported and managed to ensure innovation, effectiveness, and efficiency.

The USGCRP and CCRI will focus resources on resolving these and additional uncertainties that need to be addressed to improve understanding of the causes and trajectory of global environmental change.

Observations and Monitoring Systems

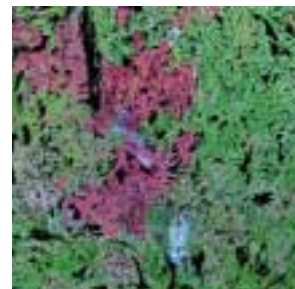
Observations and monitoring systems have been major elements of the USGCRP-sponsored scientific studies throughout the past thirteen years. Because additional space-based and in situ data are needed to significantly improve scientific analyses and

computer models, and because stable, long-term measurement records are essential to interpret Earth system variability and trend data, there is a critical need for a well-designed, comprehensive climate and ecosystem monitoring system. A comprehensive monitoring system necessarily will be global in scope, and the United States should continue to make leadership contributions to the global system design and implementation. The United States is already contributing to the development and operation of several global observing systems, including support for a wide array of NASA and NOAA satellites, the Argo floats being deployed in the world's oceans, the Global Climate Observing System (GCOS) sponsored by the World Meteorological Organization, and the Global Ocean Observing System (GOOS) sponsored by the Intergovernmental Oceanographic Commission. In the past, resources required to operate these operational observing systems, as well as the operational data management and distribution systems, have not been a part of the USGCRP. The new integrated climate program organization is expected to include these programs and to consider the necessary improvements. Within the next few years data from these systems will provide substantially improved information for calibrating global atmospheric and oceanic circulation models and for understanding the mechanisms that contribute to climate and ecosystem variability.

The USGCRP and CCRI will place major emphasis on requirements-driven specification of comprehensive observing systems that incorporate the following attributes:

- Generation of “climate quality” data, with stable measurement methods, consistent exposures, good intercomparison between data sets, and back- and forward-standardization of long-term data records.
- Development of new observing capabilities to illuminate Earth system processes and increase spatial, temporal, or spectral resolution where needed to reduce key uncertainties in climate change and address emerging Earth science questions.
- Provisions for high-quality data assimilation methods, combined with efficient archiving and retrieval methods, to facilitate research, analysis, and forecasting applications.
- Creative capture of the relevant information from the myriad of special research projects conducted throughout the world during recent decades, to optimize the information available for scientific analysis and improve computer model evaluations of global change and climate change.
- Special emphasis on the complex observations and monitoring systems needed to analyze terrestrial and aquatic ecosystem variability.

Space Based Data



In Situ Data



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Decision-Support Resources

A final priority for the USGCRP and CCRI will be the development of comparative information to assist national policymakers, resource managers and other decision-makers, and the general public in further developing strategies for responding to climate change while maintaining sound economic and energy security conditions in the United States and throughout the world. Significant progress in developing and applying science-based decision-support resources is a key goal of the CCRI. Objectives include improving our capacity to use climate and other models to evaluate the potential implications of different strategies and technologies (including those identified by the National Climate Change Technology Initiative), and accelerating the transition of scientific knowledge to applications in resource management, disaster preparedness, planning, and assessment. Data from observations and monitoring programs will be carefully harnessed and applied to take advantage of information on current conditions and recent trends. In some applications, this current information will be coupled with emerging skills to project climate on seasonal timescales. An even more challenging goal is extending applications to take advantage of decadal and longer-term projections of climate as these improve. These efforts will develop pilot activities that demonstrate both the strengths and limitations of current knowledge. They will include careful descriptions of scientific uncertainties that are meaningful to those using the information.

PRODUCTS AND PROCESSES TO MAINTAIN SCIENTIFIC CREDIBILITY

The USGCRP and CCRI will consistently meet the highest standards of credibility, transparency, and responsiveness – to the scientific community, to all interested constituencies, and to our international partners. To ensure credibility, scientific activities of the program will be policy-neutral. In keeping with this policy-neutral approach, products of the program's scientific inquiries will include:

- Scientific descriptions of current climate and ecosystems status, with particular emphasis on the factors that can impact (positively or negatively) current conditions.
- Prioritization of the importance of the various factors that can change current climate and ecosystems conditions.
- Trend information (based on careful evaluation of measurement records, supplemented by reference to scientific and computer model analysis) that helps identify significant patterns of variability, and that suggests the high-priority concerns regarding future changes in climate and ecosystems conditions.

- Descriptions of cause-effect relationships between key climate and ecosystem parameters. These descriptions should typically include both one-by-one cause-effect descriptions relative to individual key factors, and descriptions involving the combined influence of several key factors acting jointly.
- Comparisons between a selection of suggested scenarios that will facilitate our search for the most effective and efficient approaches to adapt to and mitigate the effects of both natural climate variability and potential human-induced climate change.
- Careful statements of the scientific uncertainties relative to each of the matters described above. Note that careful analysis and description of uncertainty will be included as a part of scientific descriptions.

To maintain scientific credibility in the conduct of the USGCRP and CCRI, the following near-term steps are being taken:

- An integrated USGCRP/CCRI strategic plan is under preparation and will be released for open review. The plan will describe major research questions, products, and research needs.
- A workshop will be held in December 2002 to provide an opportunity for a comprehensive review of the updated plans for the USGCRP and CCRI.
- Ongoing reviews of the USGCRP/CCRI will be sought from the National Academy of Sciences/National Research Council. Specifically, the Academy will be asked to review both the process and the substance of the updated program plan (including the public workshop).
- Individual agencies will facilitate review of their research strategies and plans by their respective Federal Advisory Committee Act (FACA) advisory committees to ensure quality, relevance, and timeliness for both the interagency program goals and agency-specific mission goals.
- The director, agency representatives, and staff of the CCSP are regularly involved in ongoing discussions with a wide array of members of the national and international scientific community. The program encourages comments and critiques from all sources in the spirit of promoting open debate, including from interested stakeholders. The program is strictly neutral in these communications.
- The CCSP will provide all plans and reports to interested members of Congress and their staff. Program representatives are available to meet with members and staff upon request.

Finally, an important ongoing objective of the USGCRP/CCRI will be to promote the dissemination and use of global change research and information in a fair and equitable fashion, both nationally and internationally. Open access to the information produced by the program is another way in which the program can promote open debate

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that supports societal decisionmaking. Products from the program inform a variety of decision processes, ranging from El Niño/Southern Oscillation forecast products used in regional and national planning in agriculture and resource management, to research results on climate change that are incorporated in assessments, such as those of the Intergovernmental Panel on Climate Change, which provides scientific underpinning for international negotiations. Information is disseminated on the Internet via the USGCRP and Climate Change Science Program Web sites (www.usgcrp.gov and www.climatechange.gov), the Global Change Data and Information System (globalchange.gov), and the Global Change Research and Information Office (www.gcric.org).

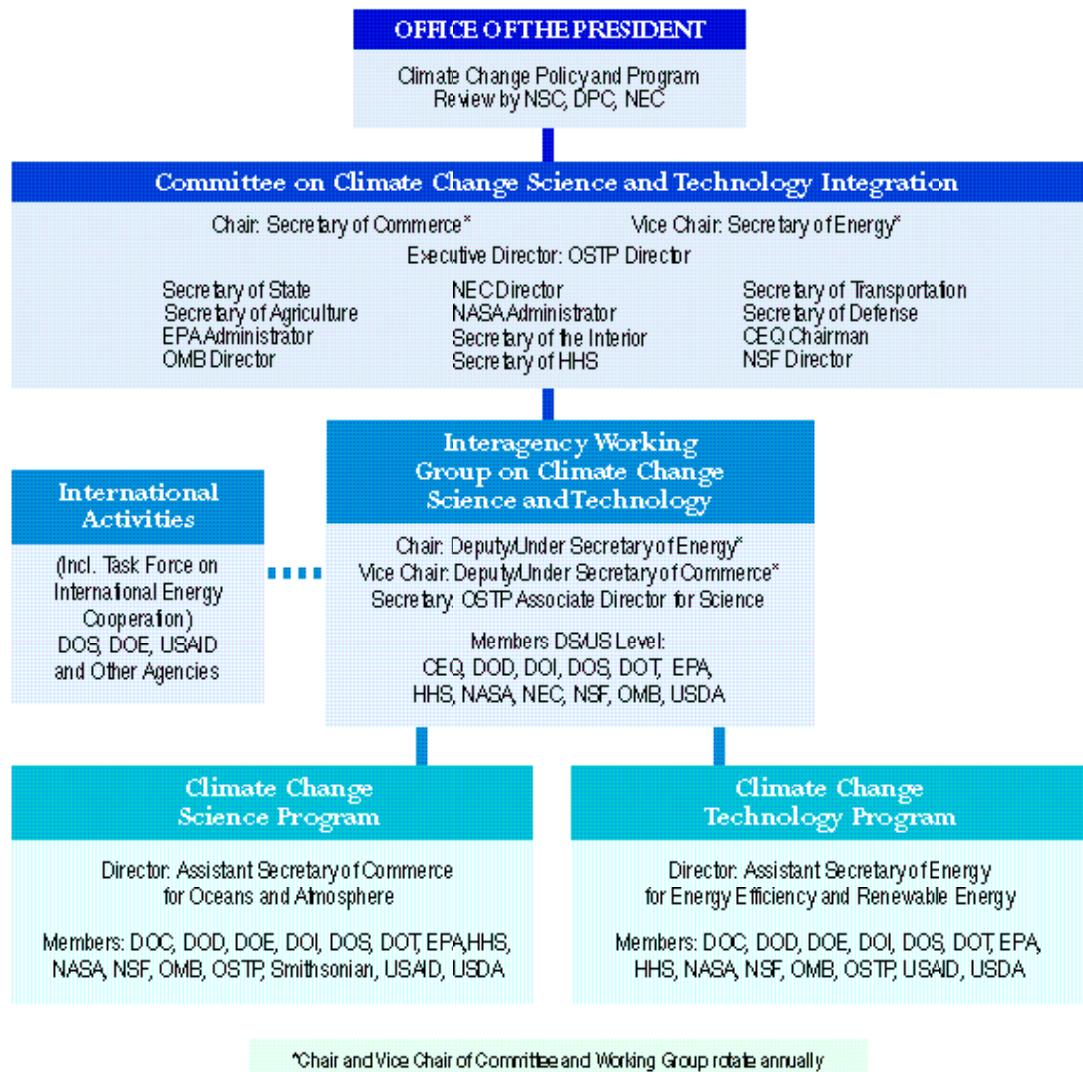


Figure 1.1

November 2002

NEW MANAGEMENT APPROACH

Improving accountability and the flow of scientific information to policymakers

To improve the research support for decisionmaking and to increase accountability, a new management structure for the research program was recently developed. The President announced this change on February 14, 2002, when he established a new high-level structure for coordinating Federal climate change science and technology development (Figure 1.1).

At the highest level, the new structure includes the Executive Office of the President, with program review by a combined National Security Council (NSC), Domestic Policy Council (DPC), and National Economic Council (NEC) panel. The Chair of this panel is the National Security Advisor or other Presidential Appointee. The Chair reports to the President and is responsible for program review.

The Committee on Climate Change Science and Technology Integration was developed to oversee the Federal climate change science and technology programs. The Committee consists of the Secretaries of Commerce, Energy, State, Agriculture, the Interior, Health and Human Services, Defense, and Transportation; the Environmental Protection Agency (EPA) and National Aeronautics and Space Administration (NASA) Administrators; the Office of Management and Budget (OMB), National Science Foundation (NSF), and National Economic Council (NEC) Directors; and the Chair of the Council on Environmental Quality (CEQ). The current Chair of the Committee is the Secretary of Commerce, and the current Vice Chair is the Secretary of Energy. The Chair and Vice Chair positions will rotate annually between the Secretaries of Commerce and Energy. The Executive Director of the Committee is the Director of the Office of Science and Technology Policy (OSTP). The Committee Chair reports directly to the National Security Advisor or other Presidential Appointee. The Committee, in coordination with OMB, provides recommendations concerning climate science and technology to the President, and if needed, recommend the movement of funding and programs across agency boundaries. The Committee Chair is responsible for the final review of recommendations. The Committee will decide on its decisionmaking process and the disposition of recommendations to the Committee by the supporting working group.

The Interagency Working Group on Climate Change Science and Technology reports to the Committee. It is Chaired by the Deputy or Under Secretary of Energy and Vice Chaired by the Deputy or Under Secretary of



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Commerce. The Chair and Vice Chair will rotate annually between the Department of Energy (DOE) and the Department of Commerce (DOC). The Working Group consists of the Deputy/Under Secretaries (or the counterparts of these positions in non-cabinet agencies and offices) of the Departments of State (DOS), Transportation (DOT), Interior (DOI), Agriculture (USDA), Health and Human Services (HHS), and Defense (DOD), EPA, CEQ, NEC, OMB, NASA, and NSF. The Secretary of the Working Group is the OSTP Associate Director for Science. The Working Group will review all programs that contribute to climate change science and technology and will make recommendations to the Committee about funding and program allocations, in order to implement a climate change science and technology program that will contribute to the enhanced understanding needed to better support policy development.

The Climate Change Science Program (CCSP) reports to the Interagency Working Group on Climate Change Science and Technology. It has joint membership with the Subcommittee on Global Change Research (SGCR), the interagency body that coordinates the USGCRP, including representatives from all agencies that have mission and/or funding in climate science research. The CCSP is responsible for defining integrated program goals and priorities and for reviewing all programs that contribute to climate change science (not solely the current research programs in the USGCRP). The CCSP Director reports to the Chair of the Interagency Working Group. Participating agencies are responsible for ensuring their plans and programs implement the goals, priorities, and plans defined by the CCSP in the course of fulfilling their respective agency missions. For this reason, participating agencies' personnel play an active role in the formulation of CCSP strategy.

The Climate Change Technology Program (CCTP) provides for the coordination and development, across all Federal research and development (R&D) agencies, of a comprehensive, multi-year, integrated climate change technology R&D program for the United States. An interagency working group carries out much of the technical coordination. The CCTP Office provides technical and staff support, and performs certain integrative, analytical, modeling, communication, and administrative functions. The Director reports to the Interagency Working Group on Climate Change Science and Technology. Participating agencies are responsible for ensuring their plans and programs implement the goals, priorities, and plans defined by the CCTP in the course of fulfilling their respective agency missions. For this reason, participating agencies' personnel play an active role in the formulation of CCTP strategy.

Improving the productivity of basic research and developing applications

The USGCRP has coordinated research on complex global change issues for more than a decade. While agency expertise and approaches used in the past have helped provide a good foundation for the future, new mechanisms for closer coordination and integration within the USGCRP's distributed, multi-agency structure are needed.

These include:

- New mechanisms for enhancing involvement of the external research community in planning and oversight.
- Enhanced coordination through interagency working groups responsible for preparation of detailed implementation plans that identify how the contributions of the agencies, including capabilities essential to USGCRP/CCRI goals but not normally listed in agency contributions, will be brought together to meet research needs and produce deliverables.
- A new capability to identify and carry out integrative research and activities through a funding mechanism under the direction of the interagency committee responsible for the program.

The USGCRP will identify priorities among the implementation plans and year-to-year activities to provide a framework for agency and interagency planning. The program will also ensure periodic program reviews and evaluations involving both the USGCRP agencies and external partners, including the scientific research community and other users of global change information. Individual agencies will enable external review of their research strategies and plans (e.g., by the NRC and FACA advisory committees) to ensure quality, relevance, and timeliness for both the USGCRP/CCRI and their respective agencies' goals.



CLIMATE CHANGE RESEARCH INITIATIVE FOR FISCAL YEAR 2003

On June 11, 2001, the President announced that his administration would “establish the U.S. Climate Change Research Initiative to study areas of uncertainty [about global climate change science] and identify priority areas where investments can make a difference.” The Secretary of Commerce, working with other agencies, was directed to “set priorities for additional investments in climate change research, review such investments, and to improve coordination amongst Federal agencies.” The Climate Change Research Initiative (CCRI) represents a focusing of resources and attention on those elements of the USGCRP that can best support improved public debate and decisionmaking in the near term. In particular, a goal of the CCRI is to improve the integration of scientific knowledge, including measures of uncertainty, into effective decision-support systems. The CCRI will adopt performance metrics and deliverable products useful to policymakers in a short time frame (2-5 years). To meet this goal, the CCRI aims to: (i) reduce the most important uncertainties in climate science and advance climate modeling capabilities; (ii) enhance observation and monitoring systems to support scientific and trend analyses; and (iii) improve decision-support resources.

Specific CCRI plans and budget requests for FY 2003 are:

- 1. Develop more reliable representations of the global and regional climatic forcing resulting from atmospheric aerosols (\$4 million).** Aerosols and tropospheric ozone play unique, but poorly quantified, roles in the atmospheric radiation budget. FY 2003 CCRI investments (NOAA: \$2M, NASA: \$1M, and NSF: \$1M) will be used to begin implementation of plans developed by the interagency National Aerosol-Climate Interactions Program to define and evaluate the role of aerosols that absorb solar radiation such as black carbon and mineral dust. Proposed activities are field campaigns (including aircraft fly-overs), in situ monitoring stations, and improved modeling and satellite data algorithm development.
- 2. Inventory carbon and model sources and sinks (\$15 million).** Research objectives for carbon cycle science include modeling, inventory, observations, process research, and assessment, integrated according to topic areas that represent some of the field's greatest areas of uncertainty. FY 2003 CCRI funds (NSF: \$9M, NOAA: \$2M, DOE: \$3M, and USDA: \$1M) will be targeted for the Integrated North American Carbon Program (NACP), a priority of the U.S. Carbon Cycle Science Plan. This program will have an intensive focus on North American land and adjacent ocean basin carbon sources and sinks to improve monitoring techniques, reconcile approaches for quantifying carbon storage, and elucidate key controlling processes and



land management practices regulating carbon fluxes between the atmosphere and the land and ocean. The NACP calls for expansion of the AmeriFlux sites, the development of automated carbon dioxide and methane sensors, improvements in ground-based measurements and inventories of forest and agricultural lands, and empirical and process modeling.

3. Climate Modeling Center (\$5 million). The continued development and refinement of computational models that can simulate the past and potential future conditions of the Earth system is crucial for developing capabilities to provide more accurate projections of future global change. In FY 2003, NOAA will establish a Climate Modeling Center within the Geophysical Fluid Dynamics Laboratory (GFDL) at Princeton, New Jersey, which will focus on model product generation for research, assessment, and policy applications as its principal activity. GFDL has played a central role in climate research, pioneering much of the work in climate change, stratospheric chemistry modeling, seasonal weather forecasting, ocean modeling and data assimilation, and hurricane modeling. This core research capability will be enhanced to enable product generation and policy-related research by providing routine and on-demand model products for assessment and policy decision support.

4. Tools for Risk Management under Uncertainty (\$6 million). It is uncertain how potential climate change could affect natural resources and the economy at local and regional geographic scales. Given these uncertainties, it is necessary to develop tools and approaches to manage risks associated with climate change at the regional level. This FY 2003 component of CCRI will direct additional resources to the NOAA Regional Integrated Science and Assessment (RISA) program (\$1M) and NSF-supported research on decision and risk management (\$5M). This innovative interagency approach links RISA's place-based research and applications activities with NSF's more methodological research in how to manage risks associated with climate change under uncertainty.

5. Atmospheric Observations (\$4 million). These FY 2003 CCRI funds will be used by NOAA to work with other developed countries to reestablish the benchmark upper-air network, emphasizing data-sparse areas, and place new Global Atmosphere Watch stations in priority sites to measure pollutant emissions, aerosols, and ozone, in specific regions.

6. Ocean Observations (\$4 million). In FY 2003, NOAA will use these CCRI funds to work toward the establishment of an ocean observing system that can accurately document climate-scale changes in ocean heat content, carbon uptake, and sea-



Overview of U.S. Research

level changes. The requirements for ocean observations for climate have been well documented, the relevant technology is available, and the international community is mobilized through the Global Climate Observing System (GCOS) and the Global Ocean Observing System (GOOS) to implement key elements of the system.

7. Satellite Observations (\$2 million). In FY 2003, NASA will begin a significant long-term effort working with NOAA and the National Polar-orbiting Operational Environmental Satellite System (NPOESS) Integrated Program Office (IPO) toward the development of high-fidelity climate data records from satellite observing systems. Initial efforts will target calibration and validation of instruments planned for the NPOESS Preparatory Project (NPP) satellite and the transition to NPOESS capabilities.



NATIONAL CLIMATE CHANGE TECHNOLOGY INITIATIVE

On June 11, 2001, in conjunction with his establishment of the CCRI, President Bush noted that the United States is a world leader in technology and innovation and that new and advanced technologies offer great promise to address concerns about climate change. Accordingly, he established a technology complement to the CCRI, called the National Climate Change Technology Initiative (NCCTI). The aim of NCCTI is to strengthen Federal leadership of climate change-related technology R&D by improving coordination of R&D investments across Federal agencies and by focusing the Federal R&D portfolio on the President's climate change goals, near- and long-term.

NCCTI builds on an extensive base of ongoing activities in Federal R&D in climate change-related technologies, as documented in the recent *Report to Congress on Climate Change Expenditures* by the Office of Management and Budget. In FY 2002, for example, the *Report* notes that the Department of Energy (DOE) spent \$1.574 billion on climate change-related science, research, and development, excluding what it spent on the U.S. Global Change Research Program. According to the *Report*, this figure may be broken down as follows: (a) energy supply R&D, \$393 million; (b) energy conservation R&D, \$640 million; (c) CO₂ sequestration R&D, \$32 million; (d) science, \$35 million; (e) clean coal and natural gas R&D, \$442 million; and (f) nuclear energy R&D, \$32 million. In addition to DOE, other agencies also spent funds on climate change technology R&D. For example, in FY 2002 the Environmental Protection Agency spent \$115 million, and the Department of the Treasury spent \$38 million in support of the Global Environment Facility. Not included in these totals are other research expenditures at the Department of Agriculture, including forest and rangeland research; agricultural research in soils and other terrestrial sequestration systems; and research on means to improve the management of emissions of greenhouse gas emissions, such as methane, from livestock operations.

The main thrust of the NCCTI is to examine, from the perspective of both near- and long-term climate change goals, the current Federal portfolio of R&D and strengthen its coordination and focus on achieving these goals. The President said on June 11, 2001: "We're creating the National Climate Change Technology Initiative to strengthen research at universities and national labs, to enhance partnerships in applied research, to develop improved technology for measuring and monitoring gross and net greenhouse gas emissions, and to fund demonstration projects for cutting-edge technologies, such as bioreactors and fuel cells."



Overview of U.S. Research



Since the potential impacts of technology on a global scale are relatively long-term, the NCCTI is guided over the long-term by the climate change goals of the United Nations Framework Convention on Climate Change of 1992, ratified by the United States and more than 170 other countries. The UNFCCC calls for the “... stabilization of greenhouse gas concentrations in Earth’s atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.” In order to achieve this long-term goal, net emissions of greenhouse gases on a global scale must ultimately approach levels that are lower than they are today and, in the cases of the most important gases, significantly so.

CURRENT ACTIVITIES

Current activities of the NCCTI include a comprehensive and continuing review of all climate change technology-related research and development programs, with an eye toward improving the integration of supporting basic research activities. The NCCTI interagency working group is developing criteria to identify high-priority programs that may have the largest potential impact in the long term for reducing, avoiding, or sequestering greenhouse gas emissions. NCCTI also includes a proposal to fund a unique competitive solicitation program, in which technology research ideas will be funded on the basis of their potential to reduce, avoid, or sequester greenhouse gas emissions. NCCTI also focuses on measurement systems – such as the development of greenhouse gas sensors, measurement instruments and platforms, monitoring systems, databases, and inference methods – needed to meet basic information, data, and measurement needs of the climate change scientific and technical community.

MANAGEMENT OF NCCTI

NCCTI is guided by the review and coordination processes of the interagency Climate Change Technology Program (CCTP). Federal agencies with relevant R&D programs participating in the CCTP include: the Departments of Agriculture, Commerce, Defense, Energy, Health and Human Services, Interior, and Transportation, as well as other agencies, as appropriate, including the Environmental Protection Agency, National Aeronautics and Space Administration, and the National Science Foundation.

Table 1
U.S. GLOBAL CHANGE RESEARCH PROGRAM
FY 2001 – FY 2003 BUDGET BY AGENCY

(Discretionary budget authority in \$millions)			
Agency	FY 2001	FY 2002	FY 2003 Request
Scientific Research			
Department of Agriculture	51	56	66
Department of Commerce/National Oceanic and Atmospheric Administration (DOC/NOAA)	85	101	100
Department of Energy (DOE)	116	120	126
Department of Health and Human Services/ National Institutes of Health (HHS/NIH)	54	60	68
Department of the Interior/ U.S. Geological Survey (DOI/USGS)	27	28	28
Environmental Protection Agency (EPA)	23	21	22
National Aeronautics and Space Administration (NASA)	257	243	245
National Science Foundation (NSF)	181	188	188
Smithsonian Institution (SI)	7	7	7
Scientific Research Subtotal	801	824	850
NASA Space-Based Observations and Data Systems	919	847	864
U.S. Global Change Research Program Total	1,720	1,671	1,714

Notes:

The USGCRP budget numbers in this table and in the other budget tables throughout this report do not include the FY 2003 budget request for the Climate Change Research Initiative.

Because DOD research activities are conducted for defense-related missions, they are not included in this USGCRP budget crosscut. Related DOD research does contribute to USGCRP goals, however.

Operational space-based, surface, and in situ observing systems and programs are not included in the USGCRP budget crosscut, but contribute to achieving USGCRP goals.

Overview of U.S Research

Table 2
U.S. GLOBAL CHANGE RESEARCH PROGRAM
FY 2001 – FY 2003 BUDGET BY RESEARCH ELEMENT

(Discretionary budget authority in \$millions)

Research Element	Scientific Research		Space-Based Observations		Total	
	FY 2002	FY 2003	FY 2002	FY 2003	FY 2002	FY 2003
	Est.	Req.	Est.	Req.	Est.	Req.
Atmospheric Composition	107	111	191	164	299	275
Climate Variability and Change	305	304	212	198	517	502
Global Carbon Cycle	103	106	115	146	218	252
Global Water Cycle	75	73	236	238	311	311
Ecosystems	118	119	93	91	211	210
Land Use/Land Cover Change	--	13	--	27	--	40
Human Contributions and Responses	112	121	--	--	112	121
TOTAL	824	850	847	864	1,671	1,714

Notes:

USGCRP budget total and Scientific Research totals also include DOE funding for Small Business Innovative Research and Technology Transfer Research (SBIR/STTR) – FY 2002, \$3.1M; FY 2003, \$3.3M (not included as part of budgets for Research Elements)

Scientific Research budget includes activities funded as part of NOAA “Climate Observations and Services” – FY 2002, \$27.6M, FY 2003, \$27.6M

Human Contributions and Responses total includes EPA funding for Regional Research and Interactions, which provides support to all the Research Elements – FY 2002, \$14M; FY 2003, \$15M

Terrestrial and Marine Ecosystems total includes USDA funding for the UV-B Monitoring Network – FY 2002, \$5M; FY 2003, \$9M

Because DOD research activities are conducted for defense-related missions, they are not included in this USGCRP budget crosscut. Related DOD research does contribute to USGCRP goals, however.

Operational space-based, surface, and in situ observing systems and programs are not included in the USGCRP budget crosscut, but contribute to achieving USGCRP goals.

Amounts are rounded to the nearest \$million.

RESEARCH PROGRAM: NEAR-TERM PLANS

The USGCRP is organized in a set of linked research program elements, which together support scientific research across a wide range of interconnected issues of climate and global change. Each of these research elements focuses on topics crucial to documenting and monitoring change, improving projections of change, or developing useful products to support decisionmaking. They all pertain to major components of the Earth's environmental systems, which are undergoing changes caused by a variety of natural and human-induced causes. Changes in one component affect the other components, such that it is not possible to understand the future trajectory of one component, such as climate, without understanding important characteristics of the others.

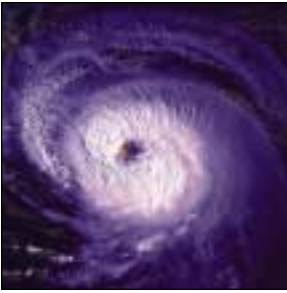
For example, changes in land cover and land use affect many other aspects of the global environment and are a principal driver of change. In the area of atmospheric composition, the concentration of greenhouse gases in the atmosphere is significantly affected by land use and management decisions. Characteristics of land cover (e.g., roughness, albedo) affect local and regional climate. The water cycle depends heavily on vegetation and surface characteristics, which in turn are strongly influenced by land cover and land-use practices. The distribution of nutrients among different reservoirs is strongly affected by land use—for example, the carbon cycle is affected by vegetation and soil recovery from recent history of land use and cover. Finally, ecological resources and the viability of ecosystems in the context of climate variability and change depend, among other things, on the degree to which landscapes are fragmented. Projections of this characteristic depend, in turn, on forecasts of land use/land cover driven by human institutions, population size and distribution, economic development, and other characteristics.

The research program elements include:

Atmospheric Composition — USGCRP-supported research focuses on how the composition of the global atmosphere is altered by human activities and natural phenomena, and how such changes in atmospheric composition influence climate, ozone, ultraviolet radiation, pollutant exposure, ecosystems, and human health. Research addresses: processes affecting the recovery of the stratospheric ozone layer; the properties and distribution of greenhouse gases and aerosols; long-range transport of pollutants and implications for air quality; and integrated assessments of the effects of these changes. Atmospheric composition issues involving interactions with climate variability and change —such as interactions between the climate system and the stratospheric ozone layer, or the effects of global climate change on regional air quality — are of particular interest at present.



Research Program: Near-Term Plans



Climate Variability and Change — USGCRP-supported research on climate variability and change is being focused on how climate elements that are particularly important to human and natural systems — especially temperature, precipitation, clouds, winds, and storminess — are affected by changes in the Earth system that result from natural processes as well as from human activities. Activities in the program are specifically oriented toward: predictions of seasonal to decadal climate variations (for example, the El Niño/Southern Oscillation); improved detection, attribution, and projections of longer-term changes in climate; the potential for changes in extreme events at regional to local scales; the possibility of abrupt climate change; and ways to improve the communication of this information to inform national dialogue and support public and private sector decisionmaking.



Global Carbon Cycle — USGCRP-supported research on the global carbon cycle focuses on: (1) identifying the size and variability of the dynamic reservoirs and fluxes of carbon within the Earth system and how carbon cycling might change and be changed in the future; and (2) providing the scientific underpinning for evaluating options being considered by society to manage carbon sources and sinks to achieve an appropriate balance of risk, costs, and benefits. Specific programs and projects focus on: North American and ocean carbon sources and sinks; the impact of land-use change and resource management practices on carbon sources and sinks; projecting future atmospheric carbon dioxide and methane concentrations and changes in land-based and marine carbon sinks; and the global distribution of carbon sources and sinks and how they are changing.



Global Water Cycle — USGCRP-supported research on the global water cycle focuses on: (1) the effects of large-scale changes in land use and climate on the capacity of societies to provide adequate supplies of clean water; and (2) how natural processes and human activities influence the distribution and quality of water within the Earth system and to what extent the resultant changes are predictable. Specific areas include: identifying trends in the intensity of the water cycle and determining the causes of these changes (including feedback effects of clouds on the global water and energy budgets as well as the global climate system); predicting precipitation and evaporation on timescales of months to years and longer; and modeling physical/biological processes and human use of water, to facilitate efficient water resources management.

Ecosystems — USGCRP-supported research on ecosystems focuses on: (1) how natural and human-induced changes in the environment interact to affect the structure, functioning, and services of ecosystems at a range of spatial and temporal scales, including those ecosystem processes that in turn influence regional and global environmental changes; and (2) what options society has to ensure that desirable ecosystem goods and services will be sustained, or enhanced, in the context of projected regional and global environmental changes. Among the specific focus areas are: the structure and functioning of ecosystems, including cycling of nutrients, and how these nutrients interact with the carbon cycle; and key processes that link ecosystems with climate.



Land Use/Land Cover Change — USGCRP-supported research on changes in land use and land cover focuses on: (1) the processes that determine the temporal and spatial distribution of land cover and land use change at local, regional, and global scales, and how land use and land cover can be projected over timescales of 10-50 years; and (2) how the dynamics of land use, land management, and land-cover change will affect global environmental changes and regional-scale environmental and socio-economic conditions, including economic welfare and human health, and how global environmental changes will affect land use and land cover. Research will identify and quantify the human drivers of land-use/land-cover change; improve monitoring, measuring, and mapping of land use and land cover and the management of data systems; and develop projections of land-cover and land-use change under various scenarios of climate, demographic, economic, and technological trends.



Human Contributions and Responses — USGCRP-supported research on human contributions and responses to global change is relevant to each of the other research program elements. The current focus of this research is on improving understanding of the potential effects of global change on human health; human forcing of the climate system, of land use, and other global environmental change; science-based regional and sectoral assessments that accurately reflect the limits of current understanding; decision support under conditions of complexity and uncertainty; and integrated assessment methods.



The following sections of the report provide an overview of each research program element, with highlights of recent research, highlights of FY 2003 program plans, and tables showing the FY 2003 budget request.



1 | Atmospheric Composition

The USGCRP budget includes \$275 million in FY 2003 for ongoing activities in support of research and observations on the composition and chemistry of the atmosphere. Atmospheric composition and chemistry is integrally related to climate variability and change, the global water cycle, the global carbon cycle, and other components of global environmental change. The contribution to the USGCRP by these atmospheric studies includes many aspects of atmospheric chemistry and the radiation that is affected by it.

USGCRP-supported research on atmospheric composition focuses on major Earth system interactions, including:

- How changes in atmospheric composition alter and respond to the energy balance of the climate system.
- The interactions between the climate system and the ozone layer.
- The effects of regional pollution on the global atmosphere.
- The effects of global climate and chemical change on regional air quality.

Research also focuses on Earth system linkages with human systems, including:

- How the composition of the global atmosphere, as it relates to climate, ozone, ultraviolet radiation, and pollutant exposure, is altered by human activities and natural phenomena; and
- How changes in composition influence human well-being and ecosystem sustainability.

The atmosphere plays several key roles within the Earth system. It transports both energy and atmospheric constituents over many time and space scales. There is a continual interplay between the composition, the chemistry taking place, and radiation within the atmospheric environment. Many greenhouse gases that are being added to the atmosphere, such as the chlorofluorocarbons and carbon dioxide, have long residence times there. This underscores the need to be able to project the likely effects of such climate forcing agents.

The potential role of atmospheric aerosols, also referred to as particulate matter (PM), in air quality and climate forcing is significant. There is much we do not yet

know about natural and human-induced aerosols, both with regard to their particle properties, their distributions in space and time, and their impacts upon the climate system. Both the magnitude and even the sign of their net climate forcing remain uncertain. The National Aerosol Climate Interaction Program (NACIP), which is being developed out of planning efforts at a recently held workshop, has concluded that the aerosol-climate problem must be attacked from an observationally-constrained basis, and has identified five key aerosol phenomena that require special measurement focus in order to significantly reduce the uncertainty in aerosol climate forcing: (1) the strength of aerosol emissions from fossil fuel combustion and biomass burning; (2) the global distribution of black carbon and organic aerosols; (3) the alteration of cloud properties and cloud albedo; (4) the reduction in precipitation efficiency; and (5) the increase in atmospheric solar heating, the reduction in solar radiation at the surface, and the impact on surface evaporation.

The processes leading to stratospheric ozone decreases within the past two decades are now reasonably well-understood. Recovery of the ozone layer is expected to occur

SPRING DUST STORM SMOTHERS BEIJING

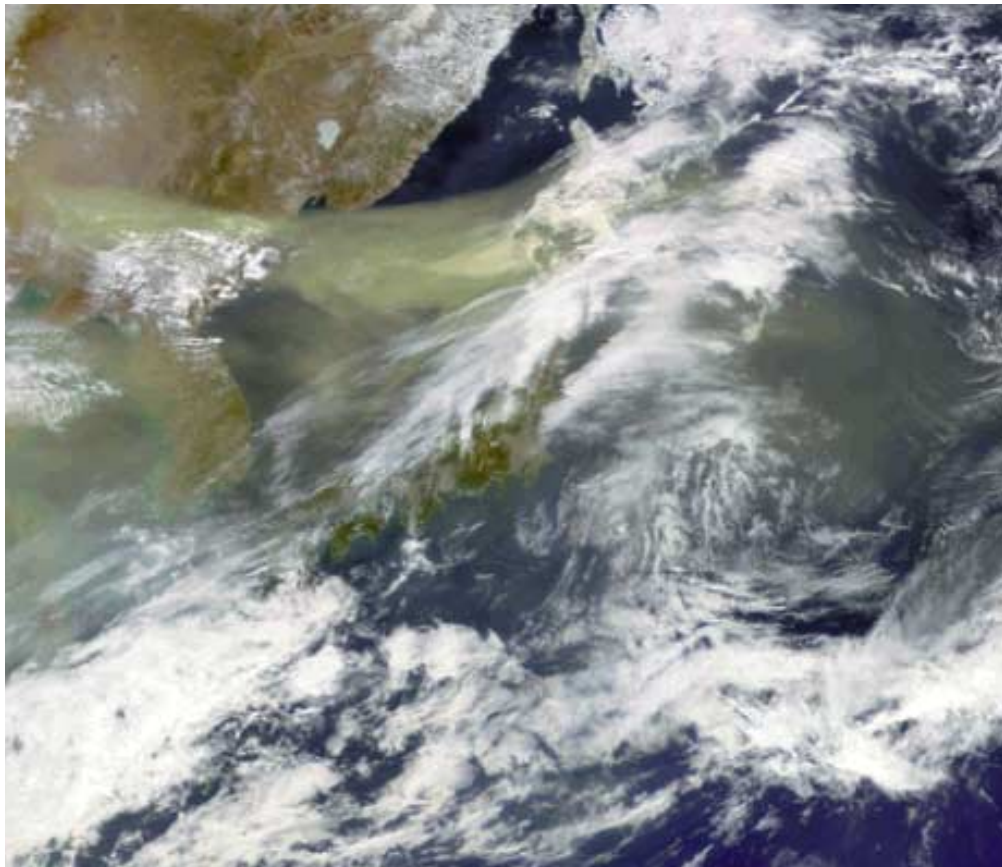


Figure 2.1

In March 2002, a few days earlier than usual, a large, dense plume of dust blew southward and eastward from the desert plains of Mongolia—powerfully affecting air quality for the residents of Beijing and surrounding areas. Citizens of northeastern China call this annual event the “shachenbao,” or “dust cloud tempest.” The massive dust storm (brownish pixels) can easily be distinguished from clouds (bright white pixels) as it blows across northern Japan and eastward toward the open Pacific Ocean.

Credit: NASA Goddard Space Flight Center, SeaWiFS Project; and ORBIMAGE

For additional information see Appendix B.



Research Program: Near-Term Plans

by about the mid-21st century as the chlorine loading of the stratosphere slowly decreases, as a result of the concerted international control effort under the Montreal Protocol. However, as more is learned about the connection between climate change and ozone depletion, there is increasing recognition that rising concentrations of greenhouse gases, which trap heat near the Earth's surface and contribute to a cooling of the stratosphere, are likely to affect the recovery of the ozone layer. In addition, the increase in stratospheric water vapor is playing a role both in cooling the lower stratosphere and in depleting ozone through chemical interactions, thereby contributing to climate processes. Both of these are examples of the complex, interconnected global change issues that can be addressed by future research and observations.

Key research challenges in atmospheric composition include evaluating and projecting the "rehabilitation" of the stratospheric ozone layer; developing a more credible representation of the global distributions and chemical/radiative properties of atmospheric aerosols; quantifying the atmospheric budgets of a growing suite of chemically active greenhouse gases and their effects on the Earth's energy balance; characterizing the effects of global-scale changes in atmospheric composition on air quality; determining the atmospheric inputs to ecosystems on global-to-regional scales; and establishing a "scientifically integrated" assessment process that comprehensively addresses multiple atmospheric issues.

Table 3
**ATMOSPHERIC COMPOSITION
FY 2003 BUDGET BY AGENCY**

(Discretionary budget authority in \$millions)	
Scientific Research	
NASA	54
USDA	19
NSF	17
DOE	13
NOAA	9
SI	<1
Scientific Research Subtotal	111
NASA Space-Based Observations	164
Atmospheric Composition Total	275

(*Amounts are rounded to the nearest \$million)

HIGHLIGHTS OF RECENT RESEARCH

Aerosol Characterization of Asian Dust Storms and Pollution Plumes:

Reducing uncertainty about the role of atmospheric aerosol particles in the Earth's climate system is one of the highest priorities for research in the atmospheric composition area. The Aerosol Characterization Experiment-Asia (ACE-Asia) is making substantial progress toward its goal of characterizing the aerosol particles leaving Asia and moving out over the the North Pacific Ocean, and evaluating their impact on the Earth's radiative budget. Several large dust storms, as well as pollution plumes and regional dust layers, were studied during an intensive field campaign in spring 2001, sponsored primarily by NSF, DOD, and NOAA, with significant assistance from NASA. Significant aggregation of soot and/or sulfate with mineral dust is common when dust from the Chinese interior mixes with pollution plumes from major industrial cities. This aggregation alters the optical properties, and hence the climatic impact, of these aerosols. Some notable differences between Asian and North American aerosols have been identified. The extensive suite of surface-based, airborne, and space-based observations from ACE-Asia is improving the accuracy of modeling the distributions and radiative impacts of Asian aerosols. Further, the Intercontinental Transport and Chemical Transformation (ITCT) study in the eastern Pacific has directly observed the types and abundances of gases and aerosols that can make their way across the Pacific, as well as how well current models can simulate such processes. This program, planned and being implemented by NOAA, NSF, and NASA, is also providing insight into the degree that trans-Pacific transport and transformation could influence the air quality of the western United States.

Effects of Sulfate Aerosols on Cloud Properties: Atmospheric scientists from two USGCRP agencies have analyzed satellite observations of cloud reflectivity in the context of modeled sulfate aerosols to examine the effects of aerosols on cloud properties. It has been recognized for some time that the addition of microscopic aerosol particles from industrial sources leads to increased numbers of cloud drops. This phenomenon is expected to result in increased scattering of sunlight by these altered clouds, thereby exerting a cooling influence on the Earth (though quite likely not as large as the warming influence of the greenhouse gases). Satellite measurements in combination with chemical transport modeling have now observed this effect and have begun to demonstrate and quantify this relationship on scales of days and thousands of kilometers.

Antarctic Ozone Hole: Satellite observations indicate that the Antarctic ozone thinning in the 2001 Austral (Southern Hemisphere) spring began earlier than usual



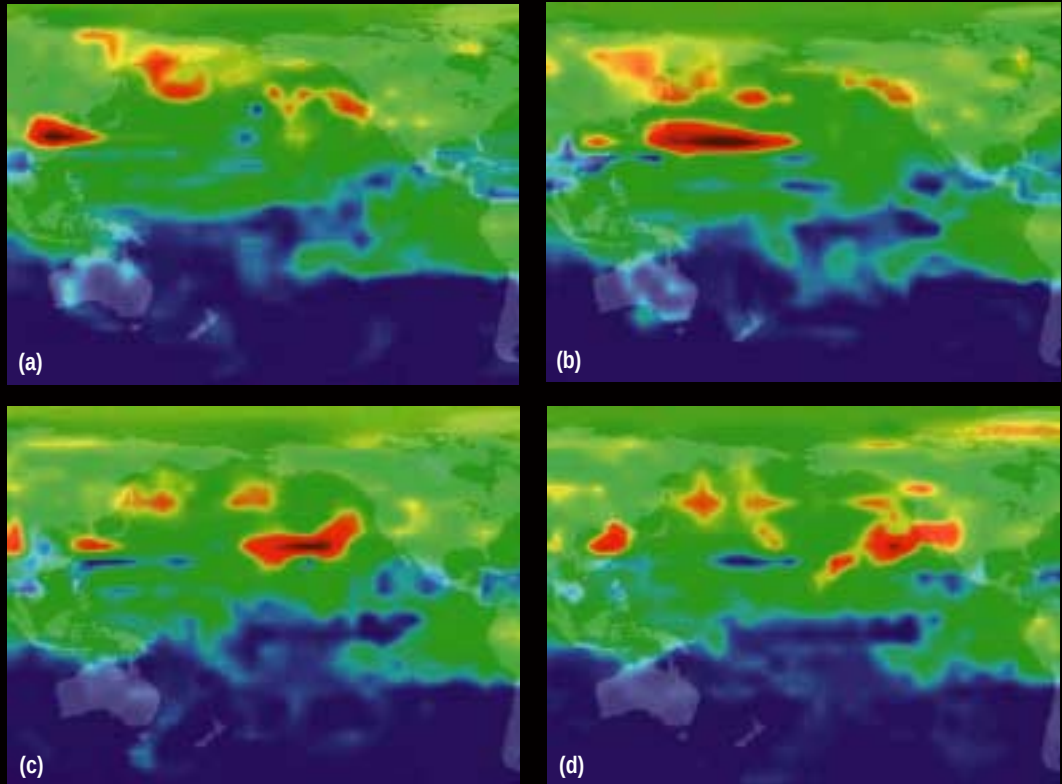
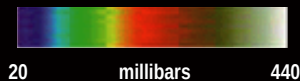
Research Program: Near-Term Plans

AIR POLLUTION PLUME FROM SOUTHEAST ASIA MOVING OVER THE PACIFIC OCEAN AND REACHING NORTH AMERICA (MARCH 2000)

Figure 2.2
Concentrations of carbon monoxide at 15,000 feet: (a) March 10, 2000; (b) March 12, 2000; (c) March 13, 2000; (d) March 15, 2000. Measurements were taken by the Measurements of Pollution in the Troposphere (MOPITT) instrument, onboard the Terra satellite.

Credit: NASA Goddard Space Flight Center, Scientific Visualization Studio

For additional information see Appendix B.



and did not break up until the first two weeks of December. This depletion of stratospheric ozone produced an extremely large and persistent ozone hole covering almost 10 million square miles (25 million km²) for 20 days. The ozone level fell to 99 Dobson units on September 26, 2001, comparable to the extremely low values observed during the 1990s.

Arctic Ozone Depletion and Polar Stratospheric Clouds: In one of the Arctic stratosphere's coldest winters on record, scientists measured depletion of the ozone layer as great as 60 percent during February and March 2000. The findings may be an indication that future cold winters in the Arctic could prolong the depletion of ozone by industrial chlorine compounds, despite the fact that the amount of chlorine in the atmosphere is now decreasing in response to international agreements. In addition, an unusual class of large Polar Stratospheric Cloud particles was observed for the first time. The newly discovered class of particles has given scientists a better understanding of the processes that "set the stage" for chlorine-caused ozone depletion in

the Arctic stratosphere, and will enable scientists to make better predictions of ozone loss in the Northern Hemisphere in the future. These observations resulted from the SAGE III Ozone Loss and Validation Experiment (SOLVE), conducted from November 1999 to March 2000, using a suite of space-based, ground-based, balloon and air-borne observations. Scientists from NASA, NOAA, other agencies, and academia collaborated in the experiment, which produced a rich data set that scientists are mining to enhance understanding of complex issues associated with chemical reactions occurring on cloud and aerosol particles that play a significant role in high-latitude ozone depletion.

Midlatitude Ozone Layer Change: Trends of stratospheric water vapor over the past half-century were newly characterized in an international study, with the results showing that increases in water vapor have likely made significant contributions to the decline in midlatitude ozone observed over the past 20 years. The increases in water vapor have also played a substantial role in stratospheric cooling. Other analyses have shown that the North Atlantic Oscillation influences ozone changes observed in mid-latitudes. The research shows that a combination of long-term dynamical changes and chemical processes will provide a better understanding of the observed ozone behavior and hence a better predictive capability for future changes in the ozone layer. A better understanding of such processes will help identify and evaluate the beginning of the recovery of the ozone layer that is expected over coming decades, as the abundance of ozone-depleting chemicals continues its decline as a result of the implementation of international agreements.

Exposure of Plants to Elevated Ultraviolet Radiation: Using newly developed ground-based radiometers that measure ultraviolet radiation (UV) at the biologically sensitive wavelength of 300 nm at 31 sites across the United States, the USDA UVB Monitoring and Research Program (UVMRP) has measured threefold differences in noontime UV irradiances over two successive days under clear skies. Transport of low-ozone equatorial air to midlatitudes, as monitored by the Total Ozone Mapping Spectrometer (TOMS) remote-sensing instrument, is responsible for these episodes of sudden high levels of UV. The USDA Agricultural Research Service, in cooperation with UVMRP, the NOAA UV Index Forecast, and the NASA TOMS group, will study the effects of large UV exposure events on plants in their early stages of growth that have not yet developed UV screening material.

Transcontinental Air Pollution Transport: Theoretical models have indicated for a long time that intercontinental transport of pollution is a persistent feature of the atmosphere. Assimilation of data from the Measurements of Pollution in the Troposphere (MOPITT) instrument, onboard the Earth Observing System Terra



Research Program: Near-Term Plans

satellite, into the models is now leading to characterization of this effect. MOPITT is now producing global maps of carbon monoxide (CO), an important tropospheric pollutant. Experimental assimilation and inverse modeling of MOPITT CO data in chemical transport models are providing new insights about global transport of CO and the variability and strengths of its surface sources.



Forest Fires and Carbon Monoxide Abundances in North America: Studies and analyses using airborne instruments have shown that emissions of carbon monoxide from large forest fires can influence the air quality in regions far from the areas burned. For example, the 1995 fires in northwestern Canada were found to be the origin of the previously unexplained episodes of high levels of carbon monoxide measured in the southeastern United States. CO is a local and regional pollutant whose sources were commonly thought to be limited to the surrounding region. Yet the fires in Canada were responsible for more than one-third of total carbon monoxide in the United States for the entire year. These findings have significance for understanding the global CO budget, and indicate that fires are an example of the coupling of local and global phenomena.

Methane Trends and Anomalies: Methane is an important greenhouse gas, as well as playing a role in atmospheric chemistry and contributing to the increase in stratospheric water vapor. Global measurements of the atmospheric concentration of methane have shown that there has been a slowdown in its rate of growth over the last two decades, but USGCRP-supported observations recently indicated that there was a 5 percent increase in growth rate in 1998, compared to the preceding three years of the monitoring record. Global process-based models of methane sources suggest that emission anomalies occur as a result of varying conditions in both the northern wetlands and southern tropical wetlands. Such “event-structure” in decadal trends provides the opportunity for characterization of underlying emission mechanisms, such as correlations between surface temperature and biogenic emissions.

HIGHLIGHTS OF FY 2003 PLANS

The USGCRP will continue to gather and analyze information through measurement, modeling, and assessment studies to enhance understanding of atmospheric composition and of the processes affecting atmospheric and tropospheric chemistry. Key research plans for FY 2003 include:

National Aerosol-Climate Interactions Program: Begin implementation of the National Aerosol-Climate Interactions Program (NACIP), an interagency program

sponsored by NOAA, NSF, NASA, and DOE. Atmospheric aerosols play a significant role in modifying the amounts of solar radiation absorbed at the surface and in the atmosphere. Changes in the distribution of absorbed solar radiation can influence climatic change, which can, in turn, affect the atmospheric concentrations of aerosols, especially on regional scales. Some collaborative interagency activities are already planned or underway. Analysis of measurements made during the ACE-Asia field program will address the question of how aerosol outflow from Asia affects the surface climate of the western Pacific Ocean. This parallels recent findings from the INDOEX field program that documented the effects of aerosols from India on the surface energy budget of the Indian Ocean, which, in turn, can affect the strength of monsoons. The CRYSTAL-FACE field program in southern Florida is expected to reveal the radiative effects on the surface climate of aerosols and ice crystals occurring in cirrus clouds. A major research program investigating aerosol radiative properties and their influence on the local radiation balance of the atmosphere and underlying surface is planned for the Atmospheric Radiation Measurement Southern Great Plains field site in spring 2003.

Global Aerosol Measurements: Provide in FY 2003 the first comprehensive multi-instrument/multi-angle integrated global data set for study of sources, sinks, and distribution of tropospheric aerosols over land, based on data from the TOMS, MODIS, and Multi-angle Imaging Spectroradiometer (MISR) instruments. Continue the analysis of global measurements of the radiative properties of clouds and aerosol particles being made by the MISR and Clouds and the Earth's Radiant Energy System (CERES) instruments on the Terra and Aqua spacecraft. These remote-sensing measurements are expected to lead to enhanced understanding and reduce uncertainty about the role of aerosols in climate change.

Tropospheric Aerosols and Climate: In FY 2003, for the first time, include parameterization of tropospheric aerosol chemistry in a coupled aerosol-chemistry-climate general circulation model. With this model, using projected changes in anthropogenic aerosol emissions, carry out simulations of changes in atmospheric composition over the 21st century. These studies can be helpful in diagnosing the climatic consequences of these emissions and the associated feedbacks on atmospheric composition, and in evaluating models against satellite retrievals vetted and supplemented by *in situ* field measurements.

Effects of Regional Pollution on the Global Atmosphere: Archive and analyze data from the Transport of Chemical Evolution over the Pacific (TRACE-P) airborne mission and associated data sets to characterize the atmospheric plume from East Asia and to assess its contribution to regional and global atmospheric chemical



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composition. Analyze measurements and chemical transport model results from the 2002 Intercontinental Transport and Chemical Transformation (ITCT) study to address the question of current skill in predicting the characteristics of trans-Pacific pollution that reaches the western United States.

Changes in Stratospheric Ozone: Provide continuity of calibrated data sets for determining long-term trends in the total column and profile abundances of stratospheric ozone with sufficient precision to enable assessment of expected ozone recovery as the abundance of ozone-destroying chemicals decreases. Characterize the inter-annual variability and possible long-term evolution of stratospheric aerosol characteristics and profile abundances to assist in the interpretation of observed ozone changes and chemistry-climate interactions. This will require a combination of consistently processed data records from ground-based, airborne, balloon-borne, and space-based measurements. In FY 2003, the SAGE III Ozone Loss and Validation Experiment (SOLVE-2) campaign will provide the data needed to validate the recently launched SAGE III instrument, which provides profile stratospheric ozone and aerosol abundance observations. Further, the Montreal Protocol Scientific Assessment Panel, to which NOAA, NASA, and their international partners contribute, will provide to governments a status of the scientific understanding of the ozone layer. This every-four-year updating is the scientific information that the world governments use as input to their decisions regarding ozone-depleting substances.

Connection Between Greenhouse Gases and Ozone Depletion: Assess the possible impact of the increased abundances of greenhouse gases on the future evolution of Northern Hemisphere high-latitude ozone concentration using data from the SAGE Ozone Loss and Validation Experiment (SOLVE). Document the respective variability of temperatures, ozone concentrations, and water vapor in and above the tropopause level and assess the interconnectedness of these changes through retrospective modeling and data analysis. This research will enhance understanding of how stratospheric trace constituents respond to climate change.

Atmospheric Fate of Industrial Chemicals: Analyze the measured trends in atmospheric trace gas concentrations and compare with those estimated from industrial production and emission data. The analyses will be used to assess the completeness of understanding of the atmospheric persistence and degradation of industrial chemicals, as well as to examine the effectiveness of current regulatory agreements and international reporting on the production and emissions of regulated chemicals. Conduct laboratory studies designed to assess the atmospheric fate of new industrial chemicals by characterizing the key photochemical processes responsible for their atmospheric breakdown.

Carbon Monoxide, Methane, and Water Vapor Measurements: Use data assimilation techniques to combine carbon monoxide and methane measurements from the MOPITT instrument with chemical transport models of the atmosphere to help characterize interannual differences in global emissions. Reduce the uncertainty in the retrievals of upper troposphere/lower stratosphere water vapor (from microwave soundings) by 10-30 percent through improved laboratory spectroscopic measurements of the water vapor continuum. This research will enhance understanding of trends in atmospheric constituents that play an important role in global climate.





2 | Climate Variability and Change

The USGCRP budget includes \$502 million in FY 2003 for research and observations that will lead, ultimately, to the demonstration of practical capabilities for predicting climate variations and projecting with greater confidence human-induced change on timescales of seasons to multidecadal and longer. The research program will also establish the requisite underpinnings of the physical climate system required to identify and reduce uncertainties in the functioning of critical processes and mechanisms that govern the climate system.

The essential scientific questions about global climate system behavior range across a wide range of timescales, from months, seasons, and years to decades, centuries, and millennia. The climate that we experience reflects the influence of various forcings, both natural and resulting from human activities, as well as the couplings between the climate system's various elements – the ocean, atmosphere, cryosphere, and the land surface. Improving the ability to understand and develop models that can accurately simulate the behavior of this complex system requires a research program with considerable breadth and scope. The set of activities must embrace discovery and exploration of relevant historical data and proxies; ensure the development of models that include and faithfully represent critical climate-relevant processes; and potentially provide more useful information and guidance to decisionmakers about likely future climatic conditions. In addition, the program must help to build a comprehensive observing system and analysis effort aimed at monitoring, detecting, and associating climate changes with their causes while also providing critical data needed to facilitate predictive modeling.

Research on climate variability and change is being focused on climate elements that are particularly important to human and natural systems – especially temperature, precipitation, clouds, winds, and storminess. These and other factors are likely to be affected by changes in the Earth system that result from natural events, such as volcanic eruptions and El Niño, as well as by human activities. Changes in climate variability, especially in conjunction with the development of social and ecological systems, are likely to be of greatest significance because such changes could affect vital life-sustaining services that humans draw from the environment. Particularly

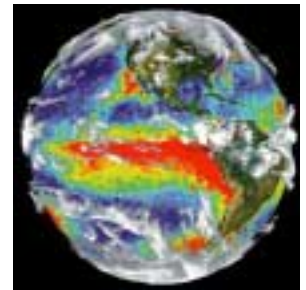
challenging will be determining how best to provide context for communicating this information to support public and private sector decisions in a manner that will improve risk management, reduce vulnerability, seize opportunities, and enhance resilience.

Since 1990, USGCRP-supported research has played a leading role in major scientific advances that have provided valuable insights and information for the public and decisionmakers. Prediction of at least some aspects of coming El Niño events and related regional anomalies has been demonstrated and proven useful to both economic and community leaders. While the accuracy of predictive capabilities still needs substantial improvement, linkages between past ocean temperature anomalies and outbreaks of harmful human diseases have suggested that accurate forecasts of the expected conditions could potentially have considerable value if coupled to actions to adapt and prepare for the anomaly.

Several important patterns of climate variability, including the North Atlantic Oscillation (NAO) and the Pacific Decadal Oscillation (PDO), have been identified and new explanations of their role are evolving. However, we do not yet know to what extent these varying patterns can be predicted and used to improve forecasts of likely variations in the year-to-year and season-to-season climate. In addition, increasing attention is being devoted to estimating the relative likelihood of an abrupt change in climate. There is strong evidence from paleoclimatic records that such changes have occurred in the past. This has given rise to more focused research into likely causes of abrupt or sudden events, especially the role of important processes such as the ocean thermohaline circulation.

Useful climate simulations are possible only if coupled atmosphere-ocean climate models respond realistically to many types of factors, both natural and human-induced, that can affect the climate system. In addition to including and accurately representing critical climate processes and mechanisms, model predictions of the monthly to interannual climatic anomalies depend on having an accurate observational depiction of the global system (and its antecedent evolution). Improving accuracy of long-term projections requires similar information, mainly to validate the realism of model simulations. In addition, increasing confidence in the model results necessitates analysis of model simulations in light of past climatic variations and changes, as documented in the historical instrumental and proxy data records.

Progress in model development and improvement has been significantly accelerated through community-wide model development and verification studies. A new and additional approach to model improvement is proposed that will focus on more rapid



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and integrated use and application of specialized observations as a means of reducing uncertainties in how best to simulate particular high-priority climate processes, such as cloud formation and effects.

Key research challenges in the area of climate variability and change include improving projections of climate change; extending and improving predictions of major modes of climate variability; assessing the potential for changes in extreme events at regional to local scales; characterizing the mechanisms and estimating the likelihood of abrupt climate change and its expected global and regional manifestations; and improving the effectiveness of interactions between producers and users of climate information.

The National Research Council (NRC), in its report, *Climate Change Science: An Analysis of Some Key Questions* (June 2001), summarized key issues of scientific understanding and uncertainties about climate change and identified high-priority areas of research for advancing understanding and reducing uncertainties. In particular, the report identified key issues having to do with climate radiative forcings and feedbacks, the global carbon cycle, regional and local climate change, the nature and causes of natural variability and its interactions with forced changes, and the effects of aerosols. The report calls for a well-supported, innovative, and effective climate research effort, including a global observing system to support long-term climate monitoring and prediction; increased, dedicated supercomputing and human resources for state-of-the-art climate modeling; and enhanced research on society-environment interactions, with “an improved capability to integrate scientific knowledge, including its uncertainty, into effective decision support systems.”

HIGHLIGHTS OF RECENT RESEARCH

OBSERVING, MONITORING, AND DOCUMENTING CLIMATE VARIABILITY AND CHANGE

Climatic Conditions over the United States: Twelve initial sites of the U.S. Climate Reference Network (CRN) have been installed. As nationwide deployment is completed, this network of surface-based climate stations will provide long-term, benchmark high-quality reference observations of numerous variables, including temperature and precipitation, from 250 geographic regions.

Subsurface Ocean Observations: In support of the international Argo collaboration to establish an eventual global network of drifting floats equipped with sensors for measuring the salinity and temperature of ocean water, the United States has (as of

THE 1997 TO 1998 EL NIÑO EVENT

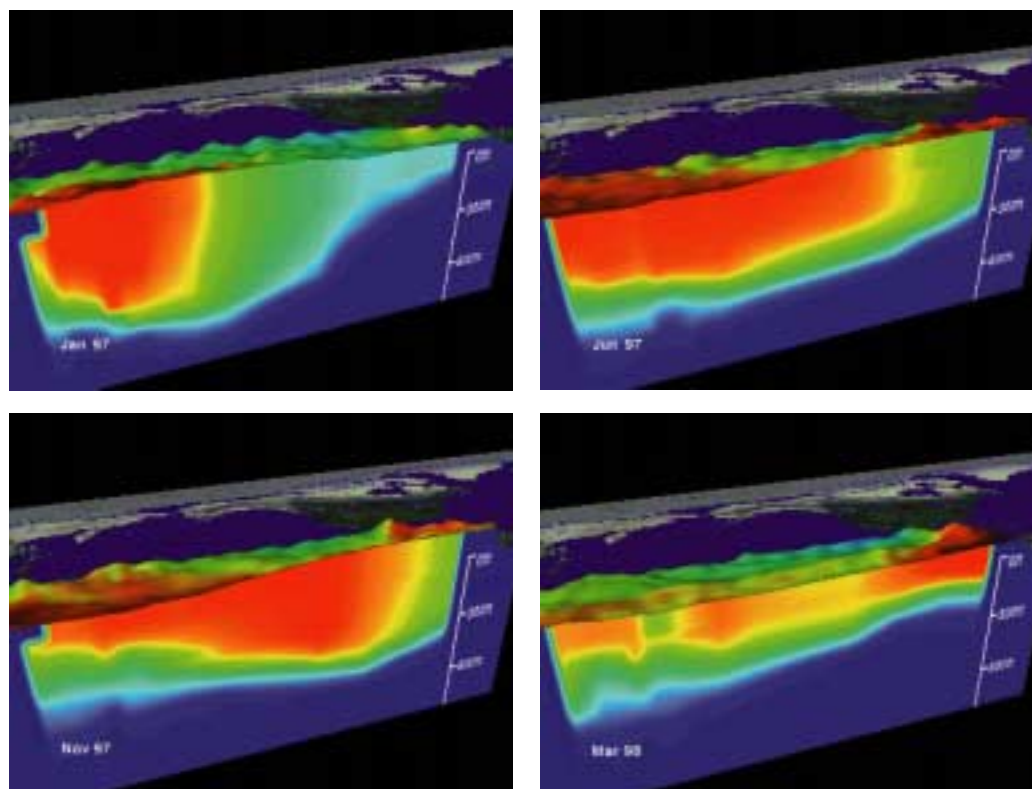


Figure 3.1
1997-98 El Niño event, water temperature and sea-surface topography in the equatorial Pacific Ocean – (a) January 1997; (b) June 1997; (c) November 1997; (d) March 1998

The images show a combined perspective of the El Niño-induced change in sea temperature below the surface as measured by NOAA's Tropical Atmosphere/Ocean (TAO) moorings, the sea-surface topography as viewed from space by the NASA Ocean Topography Experiment (TOPEX) radar altimetry satellite, and sea-surface temperature observed by NOAA's Advanced Very High-Resolution Radiometer (AVHRR) sensor, for the period from January 1997 to March 1998.

Credit: NASA Goddard Space Flight Center, Scientific Visualization Studio; NOAA Pacific Marine Environmental Laboratory

For additional information see Appendix B.

August 2002) contributed 185 of the 535 floats that are now operational. A total of 3,000 floats are planned, with 1,000 to be deployed by the United States.

Sea-Surface Temperature: A new sensor orbiting the Earth aboard the EOS-Terra satellite is now collecting the most detailed measurements ever made of sea-surface temperature and more than 40 other meteorological, biological, and hydrological parameters. Whereas ship measurements are made at only a limited number of points each day, the Moderate-Resolution Imaging Spectroradiometer (MODIS) is making measurements every day all over the globe. Comparison with surface measurements collected from ships and buoys indicates that the MODIS sensor measures sea-surface temperature to within about 0.25°C — better than twice the accuracy of previous satellite observations, thus permitting earlier and more detailed detection of climate signals, for example precursors used in predicting El Niño events. Measurements of ocean temperatures and chlorophyll concentrations are revealing more detail and variability than previously available, while the MODIS chlorophyll fluorescence product adds a whole new dimension to studies of the marine and coastal ecosystems. With this new capability, scientists can observe ocean biology and ocean circulation together

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and obtain unprecedented views of the relationship between the physical and biological state of the ocean.

Monitoring Global Ocean Circulation: The joint U.S./French oceanography satellite, Jason, was launched into orbit in December 2001. Jason joins the TOPEX/Poseidon satellite, expanding the set of observations of the global interactions occurring between the oceans and the atmosphere. Instruments on the satellite are mapping variations in the height of the ocean surface, which provides a means of monitoring the global ocean currents and ocean heat storage. These data are used routinely for initializing ocean circulation models for climate prediction. The decadal trend calculated from ocean height observations can be used to characterize global change in sea level.

Atmospheric Radiation Measurement: Through improvements in measurement techniques and related climate model radiation codes, the Atmospheric Radiation Measurement (ARM) program has improved the agreement between measured and modeled instantaneous clear sky infrared fluxes from 20 Watts/m² to 5 Watts/m². The inclusion of the advanced radiation transfer code into climate models has resulted in extending the forecast period by 7 percent and reducing the computation time required to produce the forecasts.

PREDICTING AND SIMULATING SEASONAL TO INTERANNUAL CLIMATE VARIABILITY

Prediction of El Niño and La Niña Events: Research on understanding the physical mechanisms and predictability of the climate has led to a new hypothesis and demonstration highlighting the role of variability on timescales of less than a season in determining the variations of the El Niño/Southern Oscillation (ENSO). Coupled-model predictions that consider such episodic intra-seasonal variations have demonstrated significant improvements in making 3-6 month predictions of the seasonal variability of ENSO conditions. The results suggest that advancement in coupled model predictions of ENSO may be linked to consideration of intra-seasonal variations.

Skillful Simulation of Climate Fluctuations: Analysis of an ensemble of Atmospheric Model Intercomparison Project (AMIP) simulations was carried out to determine the theoretical limit of predictability of the very disruptive 1988 drought and 1993 floods in the central U.S. The results indicated that model predictions of summertime conditions could become more skillful if antecedent soil moisture anomalies (i.e., extreme dry or wet conditions) that were associated with the strong ENSO event during the previous winter and spring were incorporated into the models.

Consequently, the ability to observe and successfully consider these anomalies in climate models is identified as another area for attention.

Improving Precipitation Forecasts: An improved method for predicting seasonal precipitation was developed. By making maximum use of the sea-surface temperature information gathered from the world oceans, the factors that can contribute to improving predictability were identified. Preliminary tests suggest that overall predictive skill could increase by 10-20 percent, with most of the gain in the spring and summer, a time when predictability is traditionally at its lowest.

El Niño-Induced Disease Outbreak: In a study in Peru, causal links between El Niño and bartonellosis (a deadly tropical disease caused by bites of sand flies) were identified, enabling demonstration of the possibility of predicting disease outbreaks based on predicted and observed changes in sea-surface temperature in the tropical Pacific Ocean. If this linkage is verified, predictions of bartonellosis outbreaks could be developed to enable the public health sector to take preventive measures. Development of health early warning systems may be facilitated through outreach activities and the use of routine forecasts by the International Research Institute for Climate Prediction (IRI).

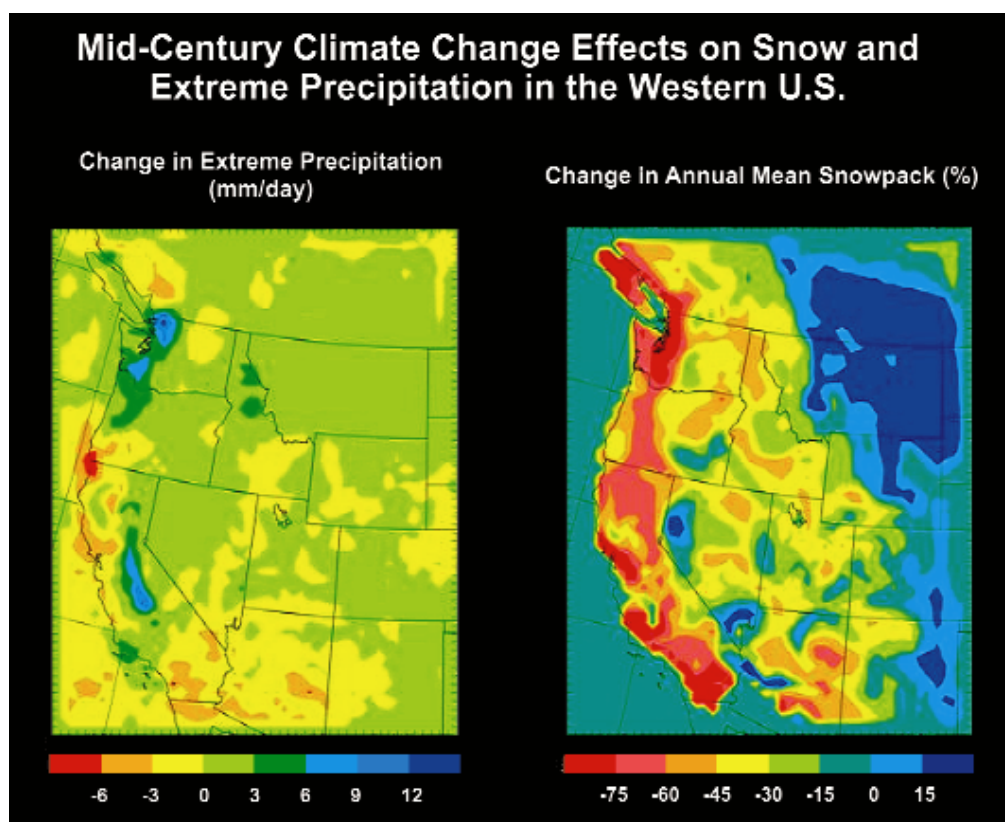


Figure 3.2

Changes in cold season extreme precipitation and mean annual snowpack based on ensemble regional climate simulations of current and mid-21st century climate conditions

This figure shows the difference between three future (2040-2060) regional climate simulations based on the Penn State/National Center for Atmospheric Research (NCAR) Mesoscale Model (MM5) and a control simulation with concentrations of greenhouse gases kept constant at the 1995 level. Results show that, by the mid-21st century, the projected average regional warming of 1-2.5°C would strongly affect snowpack in the western United States. In addition, cold season extreme precipitation is projected to increase along the Cascades and Sierra Nevada ranges. The effects of model biases and uncertainty related to the relationship of projected greenhouse gas concentrations to the projected future climate conditions were not evaluated in this study. Large uncertainties still exist in projecting future climate using climate models, particularly in projecting future precipitation.

Credit: Pacific Northwest National Laboratory.

For additional information see Appendix B.

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UNDERSTANDING AND MODELING CLIMATE PROCESSES AND PROJECTING CLIMATE CHANGE



Model Representation of Weather Systems: Improvements in a very high-resolution general circulation model that assimilates numerous satellite measurements have enabled much more accurate simulation of critical weather systems such as cyclones, fronts, and jet streams. This achievement will enable the model to take full advantage of high-resolution satellite data sets from the fleet of Earth Observing System (EOS) satellites. More accurate, high-resolution observations of surface winds (from the QuikSCAT satellite), and sea-surface temperature and precipitation (from the Tropical Rainfall Measuring Mission [TRMM] satellite) have led to increased lead times in the prediction of Atlantic hurricane intensity, track, and landfall on the southeastern and eastern U.S. coasts.

Projected Changes in Climate Extremes: Simulations with a new hurricane model suggest that tropical cyclone intensities may increase under conditions of warming of tropical sea surface temperatures. The model projects that this warming, representative of the average projected change during the 21st century as a result of human-induced changes in atmospheric composition, results in an increase of approximately 5-10 percent in peak hurricane winds. However, considerable controversy still exists with respect to the correctness of such simulations in light of our inability to assess the veracity of these models due to the lack of consideration of the full complement of climate system changes under a warming scenario and inadequate observational data on hurricanes – areas where continuing research is warranted.

Projected Changes in Climate Variations: Analysis of climate model simulations indicates that a progressive warming of the tropical oceans induces major wintertime climate change over the Northern Hemisphere. The model results suggest that the warming of tropical waters, particularly in the western Pacific and Indian Oceans, is leading preferentially to an increase in one sign, or phase, of the North Atlantic Oscillation (NAO), a major pattern of climate variability. The trend toward this single phase of the NAO has resulted in the observed warming over much of the Eurasian continent, causing wetter winters in northern Europe and Scandinavia and drier winters in southern Europe and the Middle East. Research provides evidence that this trend is linked to a concurrent warming trend of the Indian and tropical Pacific Oceans; such oceanic warming is projected in coupled climate models to be a result of anthropogenic forcing. Researchers cannot say with certainty whether this trend toward a single phase of the NAO will continue, or whether it will revert to the opposite phase as part of a low-frequency oscillation.

Table 4
**CLIMATE VARIABILITY AND CHANGE
 FY 2003 BUDGET BY AGENCY**

(Discretionary budget authority in \$millions)

Scientific Research	
NSF	88
DOE	75
NOAA	68
NASA	65
USGS	6
SI	2
Scientific Research Subtotal	304
NASA Space-Based Observations	198
Climate Variability and Change Total	502

(*Amounts are rounded to the nearest \$million)

Indications of Abrupt Climate Change in the Past: Comparisons of sediment-derived records of drift ice in the North Atlantic Ocean with proxies of changes in solar irradiance indicate that changes in solar radiation at certain times over the last 10,000 years may have affected the rate of formation of North Atlantic deep water, and thereby the strength of the Gulf Stream. Past changes of this type have had dramatic effects on the climates of countries bordering the North Atlantic Ocean. Also, results from a highly-idealized model of the tropical ocean-atmosphere system suggest that particular alignments of the Earth's orbital parameters can induce quite rapid (even abrupt) changes in the occurrence of El Niño events, sometimes causing a locking-in of an altered climate pattern for times as long as several centuries. Thus, climate variations on shorter timescales may be inexorably linked to longer-term climate changes.

Improving Key Climatic Features in Models: To remedy systematic shortcomings in model simulations of key climatic features in the eastern Pacific Ocean (specifically the equatorial cold tongue of sea-surface temperatures, the inter-tropical convergence zone, and the extensive stratocumulus cloud decks off the west coast of South America), the Eastern Pacific Investigations of Climate (EPIC-2001) field campaign

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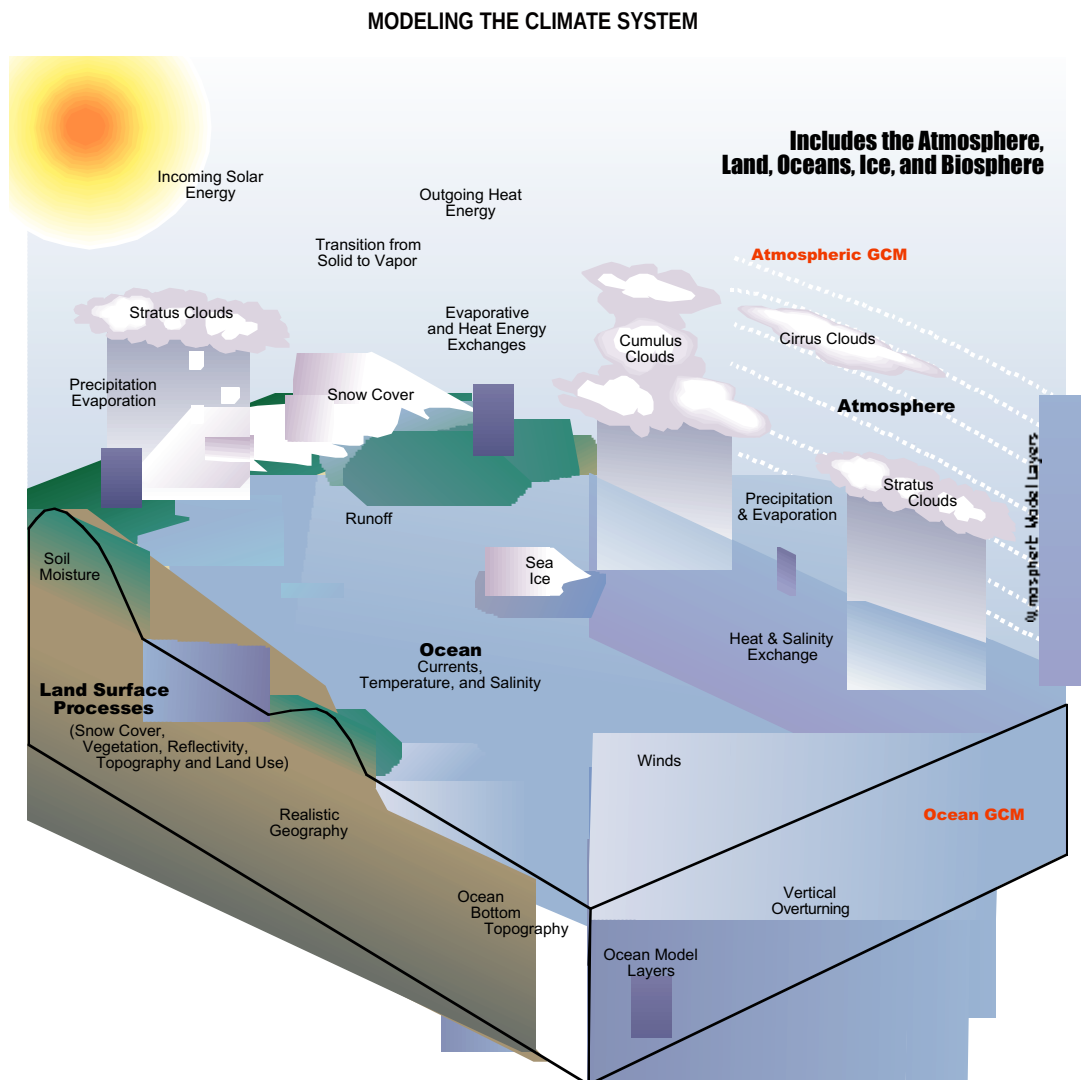
was carried out in the fall of 2001. During the intensive, eight-week observation, measurements of key processes were made from research aircraft, ships, and buoys. The data will be used to improve model representations of relevant processes in ways that are expected to improve the accuracy of predictions of anomalously wet and dry conditions over the Americas, as well as El Niño events.

Global Climate Model Development: A major upgrade of the Community Climate System Model (CCSM) was completed. The upgrade incorporates new state-of-the-art ice, ocean, and land model components, numerous improvements in treatments of important atmospheric phenomena, as well as many algorithmic changes. To date, a 1,000-year simulation with the fully coupled CCSM-2 model has been completed. This simulation demonstrated critical new abilities to represent small-scale land, ocean, sea ice, and river runoff processes. A comprehensive suite of diagnostics describing how the new version addressed key uncertainties is forthcoming.

Figure 3.3
Modeling the climate system

Models are an essential tool for synthesizing observations, theory, and experimental results to investigate how the Earth system works and how it is affected by human activities. Such models can be used in both a retrospective sense, to test the accuracy of modeled changes in Earth system forcing and response by comparing model results with observations of past change, and in a prognostic sense, for calculating the response of the Earth system to projected future forcing. Comprehensive climate models represent the major components of the climate system (atmosphere, oceans, land surface, cryosphere, and biosphere) and the transfer of water, energy, organic chemicals, and mass among them.

For additional information see Appendix B.



HIGHLIGHTS OF FY 2003 PLANS

The USGCRP will continue to enhance observational and modeling capabilities for improved understanding, prediction, and assessment of climate variability and change on all timescales. Key research plans for FY 2003 include:

Climatic Conditions over the United States: Continue deployment of benchmark reference surface observation stations, moving toward full establishment of the 250-site U.S. Climate Reference Network (CRN), which is strategically located for monitoring regional climate trends and changes. Measurements include surface temperature and precipitation, wind speed, solar radiation, and surface ground temperature. Additional sensors, including measurements of atmospheric composition and snow depth, will be incorporated at some sites. CRN data for installed sites will be made available for analysis and incorporation into models, impact assessments, and support for local decisionmakers.

Subsurface Ocean Observations: Procure and deploy 275 floats, in FY 2003 and each subsequent year, toward completion of the U.S. share of the global Argo array. Argo is an international collaboration to establish by 2006 a global network of 3,000 drifting floats equipped with sensors for measuring the salinity and temperature of ocean water. This system will, for the first time, systematically measure the upper-ocean conditions of the global ocean in near real-time. The Argo data will be used operationally and in research programs for initialization of ocean and coupled forecast models, data assimilation, and dynamical model testing. To take full advantage of an even wider set of ocean observations, a consolidated ocean observing system program is being designed that will begin to address the long-term observational needs of the operational forecast centers, international research programs, and the major scientific assessments.

Trends in Extreme Events: Based on an ongoing digitization of older National Weather Service Cooperative Observer Network daily records of several climatic variables, trends in short-duration extreme events since the late 1800s will be calculated during FY 2003. Additionally, using improved observational and model data, changes in the statistics of climate extremes will be documented. A global data set of daily observations of temperature and precipitation is also being assembled separately, as an ongoing activity. In a three-year effort to be completed in FY 2004, a subset of simulations from global climate models will be examined to determine how reliably observed changes in climate extreme indices are being simulated on subcontinental scales.



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Climate Model Development: A new global coupled climate model, the Community Climate System Model (CCSM-2), will be used in simulations of past, present, and future climate. CCSM-2 will include a number of new, carefully tested features that were being implemented in FY 2002 and tested in climate model simulations to be carried out in FY 2003. These new features include:

- Increasing horizontal resolution in the atmosphere from 2.8 degrees (about 300 km) to 1.4 degrees (about 150 km), representing an improvement by a factor of 2. To match this finer level of detail, resolution of oceans and sea ice will be set at approximately 0.7 degrees. This version of CCSM-2, implemented on highly parallel computers, will have a high spatial resolution, placing it among the best fully coupled global climate models currently available worldwide. The improvements in geography and topography available at this higher resolution will allow much more detailed simulation of the regional influences on climate.
- Improved representation of vegetation and how it changes over time, which will enable more realistic representation of the effects of changes in land surface interactions with and feedbacks to the climate system, with more complete representation of the terrestrial carbon cycle.
- An explicit model of the melt ponds that form on sea ice, together with accounting for their effects on surface albedo and ice-albedo feedback.
- Fully interactive representation of natural and human-injected aerosol species, including dust, sea-salt, sulfate, and carbonaceous aerosols.
- Future model refinements: The model computer code is being rewritten in a more scalable manner that will enable full exploitation of multiprocessor capabilities. Data and model processing capabilities at the National Center for Atmospheric Research are being enhanced so that fully coupled ocean-atmosphere experiments with doubled resolution can be initiated by late FY 2003. Work is also continuing on upgrading all CCSM-2 components to improve performance and scaling in anticipation of both the improved calculational speeds and faster communication networks that are becoming available, as well as to ensure that CCSM-2 will be capable of running very efficiently at finer resolutions.

Cloud Modeling: Improve the precision of climate models by delivering a more realistic cloud submodel that reduces the uncertainty in calculations of the atmospheric energy budget by 10 percent.

Simulation of Past Changes in the Climate: Initial diagnostics, including overall model sensitivity, of the new CCSM-2 model will be evaluated. Additionally, ensemble simulations will be started to evaluate climate changes of the past 400 years and the relative contributions from changes and variations in greenhouse-gas concentrations, solar irradiance, volcanic aerosols, and changes in land cover. These simulations will

serve as the definitive community resource for multiple research activities exploring the reasons for the warmth of the 20th century compared to earlier centuries, and to provide a more complete context for analyzing and interpreting projections of climate change resulting from human activities.

Increased Computational Resources in FY 2003: To address the computational shortcomings currently restricting use of climate models and analysis of their results, NSF and DOE will work together to: enable ensemble model runs as a means of quantifying uncertainties in terms of probabilities; increase research community access to high-end computational resources; and develop and employ information technologies that can facilitate quick and efficient access by the community to the large and distributed data sets – of both observations and model simulations – that are needed for producing quantitative information suitable for the study of climate change on regional scales.

Downward-Propagating Effects from the Stratosphere on Climate: Evaluate the importance of downward-propagating effects from the stratosphere to the troposphere on climate using a new generation of the Goddard Institute for Space Studies (GISS) general circulation model, which has increased spatial resolution and improved physics. Analysis using an earlier version of the GISS model has indicated that such effects play an important role in altering tropospheric circulation and regional surface

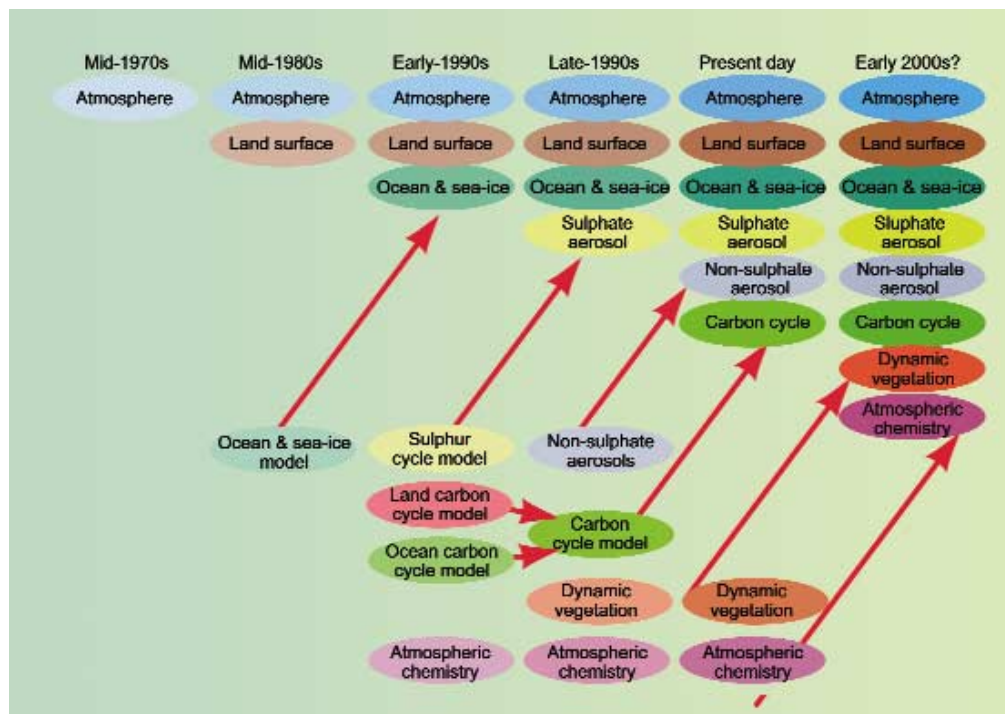


Figure 3.4

The development of climate models: Past, present, and future

The figure illustrates the development of comprehensive climate models over the last 25 years, showing how different components are first developed separately and later coupled together.

Credit: IPCC Working Group I, Third Assessment Report, 2001

For additional information see Appendix B.

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temperatures, primarily through excitation of the Arctic Oscillation — the dominant pattern of natural climate variability in the Northern Hemisphere. The earlier analysis used a coarse-resolution model without a coupled ocean; evaluation with the new model will give a better indication of the robustness of these results.

Experimental Seasonal Forecasts of Seasonal to Interannual Climate

Variations: Upgrade an existing experimental global seasonal forecast system with improvements in the atmospheric and ocean models and the inclusion of surface altimetry (measures of altitude) in the forecast initialization. In preliminary studies, the models produced more realistic mixed layer (ocean surface layer) thickness, showing the potential to improve the model forecasts. The upgrade will be initiated in FY 2003.

Potential for Predicting Large Fluctuations in the Climate: Use improved climate models to evaluate whether multi-year climate anomalies, such as the Dust Bowl of the 1930s, could have been predicted. Developing such a capability could be used to provide warning in the event of a return of such conditions. Preliminary studies have shown some evidence for a link with low-frequency sea-surface temperature variability in the Pacific Ocean. Further investigation of the low-frequency precipitation variations and their linkages to ocean temperature variability will be performed in FY 2003.

Climate Model-Process Teams: Accelerate the rate of improvement of global climate models by working with the scientific community to establish, in FY 2003, pilot-phase Climate Model-Process Teams (CPT) committed to taking greater advantage of research on climatic processes. A coordinated effort by NOAA and NSF will be focused on improvement of the global climate models at the Geophysical Fluid Dynamics Laboratory and the National Center for Atmospheric Research, and perhaps others, in order to quantify and reduce uncertainties in their ability to simulate the most critical climate processes.

Earth System Modeling Framework: Develop an Earth System Modeling Framework (ESMF), a collaborative effort of NASA, NSF, NOAA, DOE and universities. This initiative is in response to the recommendation by the National Research Council to build a common climate modeling infrastructure. Several teams will build a prototype software infrastructure that will make it possible for the nation's most widely used climate and weather models and systems for assimilating the latest observational data to readily operate together. The ESMF is expected to strengthen the national modeling community by substantially reducing the effort researchers must expend on developing software and by significantly enhancing cooperation among

leading Earth scientists. The ESMF will enable full interoperability among atmosphere, land, ocean, and other models to improve the fidelity and predictive capability of the models.

Atmospheric Radiation Measurement: Provide new instrumentation and capabilities for ARM sites to expand measurements of radiative and cloud processes in the Earth's atmosphere, including energy-related aerosols and their radiative properties and to measure the major components of the water cycle. The water cycle measurements are designed to enable scientists to improve the climate model parameterizations of the coupling of radiation, cloud processes, and land surface processes in order to reduce the current uncertainty in predictions of precipitation patterns. The new knowledge gained from the aerosol measurements and water cycle study will be important for improving projections of climate variability and change. Additional staff and equipment will be provided to the ARM Data Archive to quality assure and distribute the data. The investment will increase the number of ARM users from about 680 to 800.

Climatic Benefits of Reducing Black Carbon and Non-CO₂ Greenhouse Gases: Initiate a focused research effort to support evaluation of the potential effectiveness of a climate change mitigation strategy that emphasizes reducing emissions of non-CO₂ greenhouse gases and black carbon during the next 50 years while developing techniques to reduce CO₂ emissions below today's levels. Specific actions, beginning in FY 2003 and extending over the next decade, will include efforts to: reduce uncertainty in sources and character of black carbon emissions through observations and laboratory studies; determine the impact of black carbon emissions within the troposphere on global circulation and cloudiness through model evaluation and in situ and satellite observations; and develop improved aerosol process algorithms within cloud, climate, and radiation models to reduce uncertainty in prediction.





3 | Global Carbon Cycle

The USGCRP budget includes \$252 million in FY 2003 for research and observations related primarily to the Global Carbon Cycle. The USGCRP Global Carbon Cycle program endeavors to identify 1) the size and variability of the dynamic reservoirs and fluxes of carbon within the Earth system and how carbon cycling might change and be changed in the future, and 2) provide the scientific underpinning for evaluating options being considered by society for managing carbon sources and sinks to achieve an appropriate balance of risk, costs, and benefits. This research requires an interdisciplinary approach, bringing together investigators from a multitude of disciplines spanning the atmospheric, oceanic, terrestrial, and human dimensions of the carbon cycle.

We are entering an era in which reducing uncertainties about the carbon cycle will be central to answering questions of future climate change and its consequences for humans. Such questions include: What will be the future atmospheric concentrations of carbon dioxide and methane resulting from environmental changes, human actions, and past and future emissions? To what extent can forest and agriculture management be used to effectively offset emissions of carbon from fossil fuel combustion, regionally, nationally, and globally? How will the natural processes that store carbon in the oceans and on land change in the future? What are the prospects for feedbacks within the climate system, especially those that might prompt large increases in carbon emissions from the land and oceans? Will food security increase or decrease as the composition of the atmosphere continues to change? How do the prospects for carbon storage through increasing the growth of trees and plants compare to and interact with the prospects for storing carbon in the deep oceans and in geological formations?

To answer these and related questions, the USGCRP has initiated an integrated carbon cycle science program, focusing on targeted research areas that are ripe for scientific progress, and that are the most relevant to pressing societal concerns. Key research challenges include quantifying North American carbon sources and sinks and the processes controlling their dynamics; quantifying the oceanic carbon sink and the processes controlling its dynamics; periodically reporting the “state of the global carbon cycle;” evaluating the impact of land-use change and terrestrial and marine resource management practices on carbon sources and sinks; projecting future atmospheric

carbon dioxide (CO₂) and methane (CH₄) concentrations and changes in terrestrial and marine carbon sinks; and providing the scientific underpinning, and evaluations from specific test cases, for enhancing management of carbon in the environment.

In FY 2003, the program has chosen to focus its priority efforts on a targeted, integrated program over North America and the adjacent ocean basins. The North American Carbon Program plans to focus intensively on carbon sources and sinks on the land and in the ocean basins adjacent to North America. Research will be conducted over the next 5-10 years to improve monitoring techniques, reconcile approaches for quantifying carbon storage, and elucidate key controlling processes and land management practices regulating carbon fluxes between the atmosphere and the land and ocean. The North American Carbon Program calls for expansion of the AmeriFlux network, vertical atmospheric profiling over North America, the development of automated carbon dioxide sensors, improvements in ground-based measurements and inventories of forest and agricultural lands, empirical and process modeling, continued remote-sensing observational platforms, and new remote-sensing measurement techniques. It will be implemented in three phases: (1) 2002-2004 – development of new instrumentation and initial modeling capabilities; (2) 2005-2007 – testing and implementing a new observational network and intensive field observations and process studies; (3) beyond 2008 – operational phase, when a legacy of optimized networks and model-data fusion capabilities will provide regular and reliable estimates of net sources and sinks for CO₂, CH₄, and carbon monoxide (CO) for North America and its adjacent ocean basins. Useful data products and assessments of results are planned for as early as 2005 and will continue throughout the study. These results will provide information that could inform future decisions on policies to (1) reduce net emissions of CO₂ and CH₄ and (2) enhance sequestration of carbon through active carbon management.

In addition, research into the ocean carbon sink will continue in FY 2003 with ship-based surveys of carbon and analyses of more comprehensive satellite ocean color data sets. New results will become available on the effects of land use and land management on carbon sources and sinks, on deliberate management practices for carbon sequestration in forest biomass and agricultural lands, and on the effects of large-scale biomass burning and industrial emissions on regional carbon balances.

HIGHLIGHTS OF RECENT RESEARCH

Reconciled North American Carbon Sink Estimates: For the first time, estimates of the carbon sink over North America were reconciled for a given time period (in this case, 1980-1989) using two distinct methods. In the past, atmospheric-based



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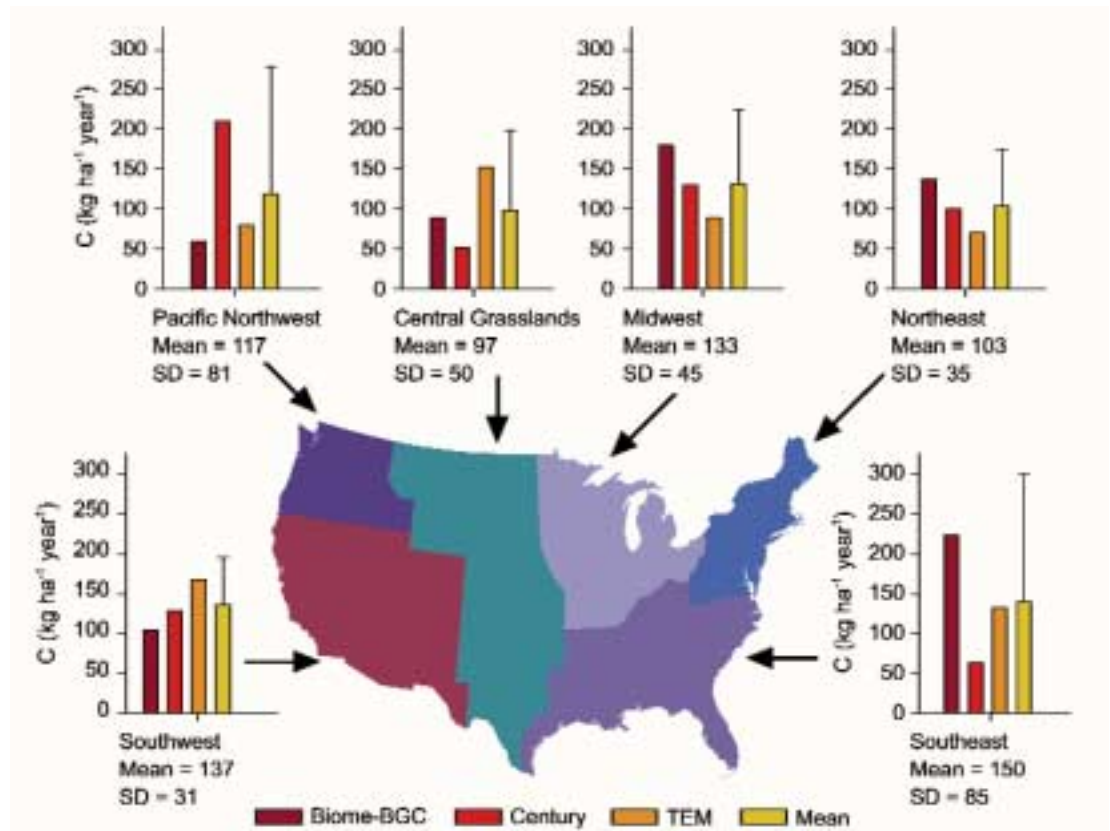
Figure 4.1

Estimates from three biogeochemical models of net carbon storage for different bioclimatic regions of the United States, for the period 1980-1993. The effects of increasing carbon dioxide and changes in climate on net carbon storage in terrestrial ecosystems of the conterminous United States were modeled using new, detailed historical climate information from the NOAA Historical Climate Network database. For the period 1980-1993, results from an ensemble of three models agree within 25 percent, simulating a land carbon sink of 80 million metric tons of carbon per year.

Credit: Schimel, et al., *Science*, March 17, 2000

For additional information see Appendix B.

NORTH AMERICAN TERRESTRIAL CARBON SINK: CONTRIBUTION OF INCREASING CO₂ AND CLIMATE TO CARBON STORAGE BY ECOSYSTEMS IN THE UNITED STATES



methods and land surveying methods did not give statistically similar estimates of the U.S. carbon sink. The methods and data sets used in this recent study pave the way for developing the capability to routinely quantify sources and sinks across North America and understand the underlying mechanisms. Enhancing our ability to estimate the quantity of CO₂ absorbed by North American ecosystems will help hone estimates of atmospheric CO₂ concentrations in future years.

A Large Carbon Sink in Northern Forests: Significant biomass carbon gains in Eurasian and North American temperate forests and losses in some Canadian boreal forests have been revealed from analysis of two decades of AVHRR satellite data in combination with forest inventories. Increases in forest growth have been attributed to fire suppression and forest re-growth in the U.S. and declining harvests in Russia. Decreases in growth in Canada have been attributed to fires and infestations. This research suggests the possibility of surveying forests from space and will help in locating and characterizing the dynamics of terrestrial sinks and their role in sequestering carbon, and the impact of climate change on terrestrial ecosystems. We are now better

able to track changes in global-scale terrestrial productivity, which is important for identifying where the carbon is being stored and where it is likely to continue to be stored.

Agreement of Methodologies for Carbon Uptake Measurement: AmeriFlux research quantified net carbon uptake by a forest ecosystem using two independent measures. Over a 10-year period at the same site at the Harvard Forest, estimates of carbon uptake from both flux tower measurements and intensive forest inventory measurements and biometry were found to be statistically similar. Close agreement of the measures builds confidence in the use of the two different methods for more accurately estimating net ecosystem production and terrestrial carbon sinks.

Insight into Carbon Exchange Using Oxygen Isotope: Researchers have developed a model that simulates the flow of the oxygen-18 isotope in CO₂ and water between plants, soil, and canopy water vapor. The oxygen-18 isotope acts as a tracer that allows scientists to partition the sources of CO₂ and water, thus providing significant insight into the properties governing the carbon exchange between ecosystems and the atmosphere. The model has been incorporated into the NCAR Community Climate System Model (CCSM)—a linked land-surface model. This modification provides a new and powerful tool for providing information on carbon fluxes in the plant and soil components of ecosystems. This research is necessary for understanding and interpreting larger-scale regional and continental fluxes, and for understanding and predicting the behavior of terrestrial carbon sinks.

Identification of Carbon Management Options: At the Forestry and Agriculture Greenhouse Gas Modeling Forum in 2001, two USGCRP agencies convened leading researchers to compare potential greenhouse gas mitigation options in the agriculture and forestry sectors. At this first of what is intended to be a series of annual workshops, attendees compiled and compared North American agriculture and forestry emission-reduction estimates across selected global and national models that link economic and biophysical analyses and identified promising directions for future research to inform decisionmaking about management options.

Synthesis and Collaboration of Carbon Knowledge: The Forest Service led an international, multiagency meeting on carbon dynamics in urban, rangeland, forest, agricultural and wetland ecosystems. The proceedings (published in a special issue of the *Journal of Environmental Pollution*) summarized current understanding of carbon stocks and carbon dynamics in terrestrial systems. The proceedings included numerous papers that emphasized the importance of understanding the roles of disturbances (such as fire), climate, basic ecological processes, and management practices to



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accurately model and project carbon sequestration potential in different regions and ecosystems. This knowledge synthesis documents the “state-of-the-science” to support: (1) increasing carbon sequestration; (2) monitoring and verifying changes in carbon sequestration; and (3) developing accounting rules and guidelines for potential decisionmaking on reporting and trading of future carbon credits.

Estimation of Anthropogenic CO₂ Uptake in Pacific Ocean: The first comprehensive ocean inventories of anthropogenic carbon storage are nearing completion in the Pacific and Atlantic Oceans. Using database methods, the Pacific Ocean was found to carry a burden of anthropogenic carbon that is approximately 45 billion tons greater than in preindustrial times, in agreement with ocean modeling simulations. This represents about 20 percent of the total fossil fuel emissions over the period. A complete synthesis of ocean inventories based upon direct measurements has recently been published. These basin-wide inventories have contributed to our understanding of how much carbon emitted by humans is absorbed by the ocean, as well as how anthropogenic carbon is transported and distributed among the Earth’s major ocean basins.

Air-Sea CO₂ Exchange: The first study of direct air-sea exchange of carbon dioxide in the equatorial Pacific Ocean was completed in 2001. This region is the largest natural oceanic source of carbon dioxide to the atmosphere. The kinetics of gas exchange

Figure 4.2

Carbon dioxide measurements and experiments — (a) AmeriFlux tower; (b) Free Air CO₂ Enrichment (FACE); (c) Elevated CO₂ concentration experiment

Credits: AmeriFlux – Oak Ridge National Laboratory; FACE – Brookhaven National Laboratory; Smithsonian Environmental Research Center

For additional information see Appendix B.



(a) AmeriFlux: The AmeriFlux network, established in 1996, includes more than 40 funded sites operating across North, Central, and South America. AmeriFlux sites constitute an infrastructure for making long-term measurements of CO₂, water, and energy exchanges from a variety of ecosystems.



(b) FACE: FACE facilities can tell us how the structuring and functioning of terrestrial ecosystems will be affected by increasing atmospheric CO₂, including their ability and capacity to take up and sequester CO₂ emitted to the atmosphere from human activities. FACE provides a technology by which the microclimate around growing plants may be modified to simulate climate change conditions.



(c) The Smithsonian Environmental Research Center (SERC) is conducting a series of experiments that expose portions of salt marsh and forest ecosystems to elevated CO₂ concentrations in outdoor chambers.

between the air and sea is currently a major source of uncertainty in quantifying ocean uptake at regional scales. Direct measurements of air-sea CO₂ exchange were accurately obtained using three distinct methodologies. These data will be incorporated into algorithms to improve estimates of ocean uptake of fossil-fuel-derived carbon dioxide.

Interannual and Climate-Driven Variation in Ocean Biomass Observed:

Based on three years of data from the SeaWiFS ocean color satellite instrument, the first continuous global estimates of ocean plant biomass and terrestrial plant photosynthesis that accurately track and characterize seasonal and interannual variability were documented. Strong El Niño/La Niña-related differences were observed, especially in the tropical oceans where significant increases in ocean plant biomass were observed. In addition, the first successful cross-calibration of two ocean-color data sets—from SeaWiFS and Japan’s Ocean Color and Temperature Scanner (OCTS)—was completed, initiating a long-term, highly calibrated ocean color time series for the global ocean. The ability to quantify annual and interannual changes in ocean and land plant productivity will enhance our ability to forecast ecological responses to changes in climate.

HIGHLIGHTS OF FY 2003 PLANS

The USGCRP will continue to focus on understanding and quantifying global carbon sources and sinks, with a particular emphasis on North America and adjacent oceans for the near term, and on filling critical gaps in understanding of the causes of carbon sinks on land as well as processes controlling the uptake and storage of carbon in the oceans. Key research plans for FY 2003 include:

North American Carbon Program: Conduct a range of preparatory activities for the North American Carbon Program (NACP), including detailed implementation planning for observational networks and intensive field campaigns, calls for proposals, establishment of a Science Team, deployment of new observational sites, and development and/or integration of inventory databases and new land-cover data sets. DOE, NOAA, NSF, and USDA have requested funding in FY 2003 as part of the Climate Change Research Initiative to begin implementing parts of the NACP.

Carbon Sequestration Potential in Agriculture: Complete an economic analysis of carbon sequestration potential associated with land-use change and land management activities in the U.S. agriculture sector. Building upon prior biophysical research on technical feasibility, this research on economic feasibility will explore the



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Table 5
**GLOBAL CARBON CYCLE
FY 2003 BUDGET BY AGENCY**

(Discretionary budget authority in \$millions)

Scientific Research	
NASA	40
NSF	24
USDA	15
DOE	14
NOAA	9
USGS	4
SI	<1
Scientific Research Subtotal	106
NASA Space-Based Observations	146
Global Carbon Cycle Total	252

(*Amounts are rounded to the nearest \$million)

economic cost of achieving different levels of net carbon emission reduction in the agriculture sector, and the implications for net emissions, other environmental outcomes, commodity prices and output, and farm income of different levels of financial incentives for sequestration. The research, which will be reported during FY 2003, will provide information to support potential decisionmaking about alternative mitigation strategies.

Forest Carbon Estimates: Initiate development of improved estimates of carbon stored in forest biomass, forest soils, and wood products across the United States. The research, planned to be ongoing, will improve forest carbon measurement and estimation methodology. The results will provide a stronger scientific basis for international and domestic discussions about cost-effective ways to mitigate greenhouse gas emissions through forestry management practices. This work will build on existing expertise in carbon accounting and projection and will utilize U.S. Forest Service Forest Inventory and Analysis (FIA) data.

Carbon Exchange in U.S. Terrestrial Ecosystems: Over the next five years, carbon exchange results from the Ameriflux network of sites will provide more comprehensive estimates of carbon gain or loss by terrestrial ecosystems in the United

States. Additional analyses comparing net ecosystem carbon exchange (based on eddy covariance) with biometric and forest inventory methods will be conducted to identify requirements and protocols needed for accurate and reliable measurement of the terrestrial carbon cycle, and for achieving the goal of quantifying carbon storage in different ecosystems and landscapes. Legacies of prior disturbance and management, especially stand age and composition, will also be evaluated. Data from about five Ameriflux sites and a carbon cycle model analysis of net CO₂ exchange for a given vegetation type or a specified region will be reported in FY 2003.

Measurement of Air-Sea Carbon Fluxes: Instrument additional ships of opportunity with sensors that measure the partial pressure of CO₂ (pCO₂) at the ocean's surface, with the highest priority in undersampled regions in the North Atlantic and North Pacific oceans. The ultimate goal of this effort is to enable quantification of global-scale air-sea fluxes by combining remote-sensing and pCO₂ measurements. To accomplish this goal the variability of mechanisms controlling pCO₂ on short time and space scales must be determined. These data will be important in constraining estimates of the North American carbon budget as part of the developing North American Carbon Program.

Ocean Carbon Inventory: Repeat ocean inventories of carbon measurements, to better understand interannual and decadal variability, which is currently not well-understood. These measurements are part of the global climate observing system. One major goal is to assess changes in decadal inventories of anthropogenic CO₂ in response to increasing atmospheric concentrations of anthropogenic CO₂ as well as climate variability. These constraints will ultimately be used to better predict the behavior of the global oceanic carbon sink in response to further climate perturbations.





4 | Global Water Cycle

The USGCRP budget includes \$311 million in FY 2003 for research and observations related primarily to the Global Water Cycle. The Global Water Cycle program studies the movements and transformations of water, energy, and water-borne materials through the Earth system and their interactions with ecosystems. The movements and transformations of water are important because they appear to control the variability of the Earth's climate and they provide an essential resource for the development of civilization and the Earth's environment. Figure 5.1 schematically illustrates the movements and transformations. This cycling involves water in all three of its phases – solid, liquid, and gaseous – and exchanges large amounts of energy as water moves and undergoes phase changes. Therefore, the water cycle operates necessarily on a broad continuum of time and spatial scales.

Water vapor is a greenhouse gas that maintains temperatures in a range required by life on Earth. Many of the uncertainties in the current projections of the effects of the atmospheric buildup of carbon dioxide are related to the feedbacks between the climate and the water cycle. While warmer temperatures enable the atmosphere to hold more water leading to further warming, the complex interactions among changing cloudiness, precipitation patterns, land cover, and decreasing snow and ice cover have limited the quantitative understanding of the links between water and climate warming.

Water is not evenly distributed over the globe, nor is it always accessible for human use. Society is becoming more vulnerable to variations in the water cycle as a result of expanding populations and increasing water use. The increasing demands for water accompanied by the growing economic losses from droughts and floods place pressure on the science community to develop the knowledge and tools needed to manage our limited water resources more effectively. There are large potential paybacks from increased investments in scientific research to improve the monitoring and prediction of the global water cycle variations and in water management applications.

On a national basis, near-crisis situations have occurred in several dry southwestern river basins, including the Colorado and Rio Grande, where over-allocation has taken place. Recent drought conditions and rapid development in these basins have exposed

the intensity of competition that exists over the available water resources. The development of a capability to predict where water management crises will emerge due to a drought or extended flood conditions is a priority for the Global Water Cycle program. The ability to provide probabilistic forecasts of rainfall and snowfall at various time and space scales is at the center of all potential applications of climate change science and climate information systems. The program has research activities directed at developing experimental predictions that will ultimately benefit society through better protection of human health and assets, and more efficient water system management and infrastructure planning.

Human activity is an integral part of the water cycle. A recent USGCRP-commissioned report, *A Plan for a New Science Initiative on the Global Water Cycle*, issued in 2001, concluded that, among other priorities, there is a pressing need to determine the causes of water cycle variations on both global and regional scales, and to what extent these variations are induced by human activities. In view of this emerging link between water science and water resource issues, the USGCRP global water cycle strategic

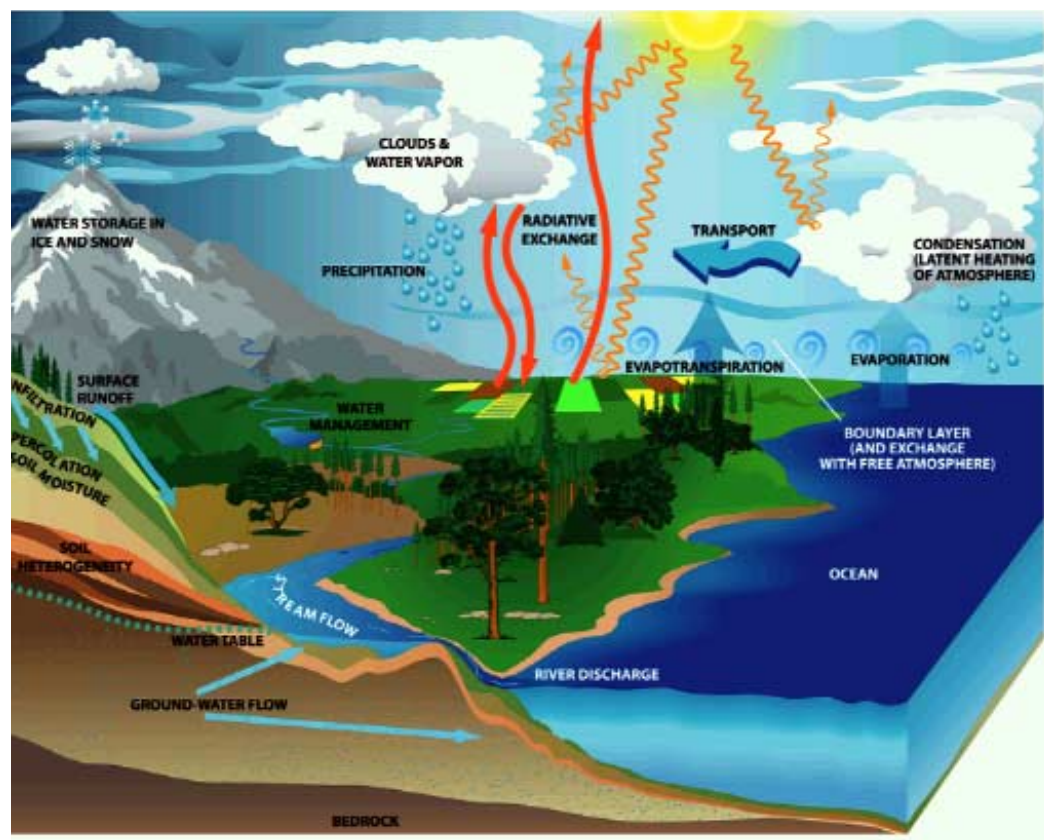


Figure 5.1 Conceptualization of the water cycle

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plan addresses two major questions: (1) What are the effects of large-scale changes in land use and climate on the capacity of societies to provide adequate supplies of clean water, and (2) how do natural processes and human activities influence the distribution and quality of water within the Earth system and to what extent are resultant changes predictable?

Stakeholders are helping to define the Global Water Cycle program at the catchment and larger river basins scales. Users are interested in better forecasts of precipitation, runoff, and soil moisture. Reservoir management decisions require forecast lead times of up to seasons and, in some cases, years. For planning reservoirs, dam recommissioning, and water control infrastructure, and developing new proposals for water law, projections of water variability are required on the decadal to century timescales.

The USGCRP Global Water Cycle program focuses on characterizing, explaining, and predicting variability and long-term changes in the global water cycle and their impacts. To address the issues arising from the intimate role of the water cycle in controlling climate variability on seasonal to multidecadal timescales, the program investigates the pathways of water movement between the biosphere and surface hydrologic systems, the atmosphere, and the oceans, as well as feedback processes between climate, weather, and biogeochemical cycles. Because the biosphere is a substantial regulator of the Earth's carbon cycle, the global water cycle maintains a considerable influence upon the global pathways of carbon. Globally, the cycling of water and its associated energy and nutrient exchanges among the atmosphere, ocean, and land determine the Earth's climate and cause much of climate's natural variability.

A critical contribution of the USGCRP to Federal water activities lies in the benefits that come from drawing together the wide range of programs and expertise from different agencies with the capabilities of the academic community to address these complex issues. The elements of the management structure that the USGCRP has put in place during the past year include: (1) Interagency Global Water Cycle working group, (2) Global Water Cycle scientific steering group, and (3) Global Water Cycle program office. The linkages between the global water cycle, the global carbon cycle, and climate will be explored in the coming year through this strengthened program management structure.

HIGHLIGHTS OF RECENT RESEARCH

Decision-Support Product Testing: Collaborative exercises were developed whereby water managers and water users test experimental products developed by the Water Cycle program in parallel with normal operations to evaluate product utility. In

particular, experimental Land Data Assimilation System (LDAS) products have been developed that will be compared with traditional algorithms used to determine releases from multipurpose reservoirs in the Upper Columbia Basin. Other test sites include the Madison and Jefferson headwaters basins of the Upper Missouri. In addition, a framework for scientist-stakeholder interaction to improve water management was designed for the headwaters of the Red River in southwest Oklahoma in conjunction with the Hydrology for Environment, Life and Policy program.

Precipitation Measurement: Precipitation is the most important variable in developing products for water resource managers on the seasonal and sub-seasonal time scales, yet it is not accurately predicted. Although it is a major component in the climate system, tropical precipitation has not been quantified with a high degree of accuracy. The accurate and detailed three-dimensional observation data provided by the Tropical Rainfall Measuring Mission (TRMM) are improving precipitation predictions and providing information on extreme precipitation events in the remote tropical areas and over the oceans. Combining TRMM data with data from earlier satellites has substantially reduced uncertainty in tropical precipitation estimates from about 50 percent to about 20 percent. In addition, analysis of TRMM observations has shown that dust storms originating in northern Africa, urban air pollution, and biomass burning all result in smaller cloud droplets and change precipitation processes in and near the affected areas.

Water Cycle Observing Systems: Variations in the water cycle lead to variations in the productivity of many sectors including hydropower production, coastal fisheries, agriculture, and forestry, to name just a few. Better monitoring and prediction of water cycle variations will allow for better management of these resources. The recently launched EOS-Aqua satellite carries a suite of observing instruments that enable it to deliver estimates of important water cycle variables, including evaporation from the oceans, water vapor, clouds, precipitation, soil moisture, snow cover, and ice on the land and sea. Aqua also will measure related variables, such as changes in radiant energy, aerosols, vegetation cover on the land, phytoplankton and dissolved organic matter in the oceans, and air, land, and water temperatures. The cloud properties measured by Aqua will complement and enhance those measured by the EOS-Terra satellite, because the afternoon viewing time of Aqua provides more clouds than the morning viewing time of Terra. In addition, Aqua is carrying sophisticated temperature and moisture sounding instruments and a modern microwave imager. A multitude of water cycle and climate studies are expected to utilize data from the Terra and Aqua satellites. Moreover, advances in data processing enable investigators to use data streams from sensors on separate but complementary satellites to separate dynamic processes at various scales. Research that utilized data from space-flight trials over



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Figure 5.2

The “Blue Marble” – Global water and energy cycles
(left) Western Hemisphere; (right) Eastern Hemisphere

The most detailed true-color images of the Earth to date depict the global interactions between the atmosphere, oceans, land surfaces, and snow/ice surfaces, which together comprise the global water and energy cycles of the Earth system.

Credit: NASA Goddard Space Flight Center; USGS

For additional information see Appendix B.

forests, agricultural areas, and grasslands demonstrated the value of remotely sensed measurement of soil moisture. Accurate characterization of soil moisture is critical for modeling hydrologic and atmospheric processes, but until satellite-based instruments were developed, soil moisture data were so sparse soil moisture estimates contributed substantially to output uncertainty. In another study, an algorithm successfully produced measurements of soil moisture on a seasonal timescale from satellite data, and demonstrated the potential of this technology for global mapping of soil moisture.

Earth’s Radiant Energy: Many of the uncertainties in the projections of the warming effects of increasing atmospheric carbon dioxide arise from the inability to adequately represent the cloud and water vapor radiative feedback processes in models. Advances were made in measuring the Earth’s surface energy and describing the interactions of water and energy (heat) in the water cycle. On a global scale, an analysis of satellite data showed that in the tropics, over the period 1985–2000, the thermal radiation emitted by the Earth to space increased, while reflected sunlight decreased. The size of these changes is significant and indicates a decrease in cloud cover accompanying a warming trend in the region. Complementary analyses of upper tropospheric humidity, cloud amount, surface air temperature, and vertical velocity indicate the changes could be associated with an observed long-term (decadal) strengthening of atmospheric circulation in the tropics. Such strengthening leads to more humid, cloudy conditions and more intense convection in certain predictable regions of the tropics and drier (and less cloudy) conditions in other tropical regions and subtropical regions. Improved understanding of this relationship leads to reduced uncertainty in



climate model projections of regional impacts. The recently completed data set of decadal Surface Radiation Budget Climatology was used to identify these patterns in tropical weather systems.

Data Assimilation: The predictions made with many applied models, such as for predicting crop yields, insect populations, health, reservoir management, fire potential and management, all require good input data. Data assimilation is an advanced method for using measurements and models in combination to provide improved input data for these models. Researchers have developed a more effective method of assimilating remotely sensed data to estimate ground heat, sensible heat at the surface, and changes in heat associated with evaporation at regional scales. Progress in data assimilation is needed because the observational networks of the future are very likely to consist primarily of remotely sensed, rather than in situ, data and because current measurements of these variables are either poor or nonexistent. The assimilated data provide a consistent version of observations and model initial conditions in numerical simulations and forecasts. In the Mississippi River Basin, for example, combining high-resolution models and data through data assimilation systems has improved, by as much as 15 percent, the ability to estimate regional water and energy variables. These improvements will enable regional models to do a better job of simulating runoff and streamflow.

Land-Surface Processes: Predictions of water availability for hydropower, reservoir management and flood planning depend on how precipitation is partitioned when it reaches the ground and, for snow, how water moves after the snow melts. Improved

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representations of cold season and land surface processes, such as snow cover and ground frost, produced capabilities for more accurate predictions of regional winter and spring temperatures and the amount and timing of runoff in the Missouri and Mississippi River basins in the winter and spring months. These improvements were incorporated into climate models and operational numerical weather forecast procedures. Regional studies also have demonstrated the effects of Pacific Ocean surface temperatures on the weather that influences snow pack and stream flow in the Pacific Northwest. Modifying models to include these effects is expected to improve water resource predictions. Other integrated studies assessed the effect of different climate histories on ground water levels in the Santa Clara-Calleguas region of southern California.

Water Vapor: Because water vapor is by far the most abundant of the greenhouse gases, accurate water vapor measurements are essential for understanding many atmospheric processes and representing them in climate models. Reliable measurement tools are needed to measure water vapor accurately. Field campaigns at the Atmospheric Radiation Measurement Southern Great Plains field site evaluated the accuracy of water vapor measuring instruments in the upper troposphere, where cold, dry conditions make accurate measurements particularly challenging. They demonstrated the accuracy of three different instruments, which produce measurements that agree within 2 percent, and showed that the other instruments tested will require more work to reach the same level of agreement. Improving the characterization of water vapor flows was identified as essential to improving the predictive capability of water cycle models and their usefulness to water resource management. Studies of variability in the flow of global water vapor revealed a clear pattern in the three-dimensional distribution of water vapor, recurring daily or more often like ocean tides.

Water Quality: Not only does poor water quality limit the water available for use by society, it also affects the productivity of ecosystems. Recent field studies investigated the accumulation of pollutants in ponds and streams, particularly in bed sediments, and subsequent movement of nutrients from land through coastal wetlands. Based on the field results, models are being developed that simulate how aeration, binding, pollution, and storm energy interact in pollution loading to coastal waters. Integrated field and modeling studies in hill-slope environments elucidated flow paths and chemical reactions in the dynamic mixing zones near the soil surface. Water quality in streams and rivers is largely determined by chemical weathering and reactions along runoff flow paths down and through hill slopes and floodplains. Research producing better definition of these pathways and temporary storage locations – their physical, chemical and microbiological characteristics – is building the science needed to predict the impacts of land and its uses and of climate change on water quality and aquatic ecosystems.

HIGHLIGHTS OF FY 2003 PLANS

The USGCRP will continue to improve the capabilities for measuring important aspects of the global water cycle and will conduct a number of important research and analysis projects. Key research plans for FY 2003 include:

General:

Complete and distribute an interagency implementation plan for the USGCRP Global Water Cycle activities that addresses the primary issues in the Water Cycle Science Plan and knits the capabilities, plans, and resources of USGCRP agencies into a coordinated program. The Strategic Implementation Plan will identify high-priority science needed to support improved water management and the reduction of uncertainty in water cycle-climate feedbacks, and will scope initiatives and processes to provide the understanding and products needed for government water cycle priorities.

Specific:

Modeling the Global Water Cycle and its Regional Components Over Land: A scientific strategy with milestones and deliverables will be articulated for water cycle modeling to meet the needs of the user communities for better forecasts. This strategy is designed to lead to an integrated model of the water and energy cycles at global and regional scales that has the capability to predict variations in

Table 6
GLOBAL WATER CYCLE
FY 2003 BUDGET BY AGENCY

(Discretionary budget authority in \$millions*)

Scientific Research	
NASA	49
NSF	13
NOAA	6
USDA	5
Scientific Research Subtotal	73
NASA Space-Based Observations	238
Global Water Cycle Total	311

(*Amounts are rounded to the nearest \$million)



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precipitation and other hydrologic variables, and exploit improved observations of precipitation and soil moisture. The strategy also calls for end-to-end research involving global and regional observations, data assimilation, and analysis to improve understanding of processes, and monitoring of key components of the water and energy cycles. The development and use of models that integrate the disparate range of scales, processes, and interactions involved in the water cycle is important also for quantifying the role of water cycle feedbacks in climate change.

Quantifying and Monitoring Trends in the Global Water Cycle: New data products are planned to fill existing gaps in our ability to quantify and monitor trends in the global water cycle. These include analysis and validation of the first year of data from the EOS-Aqua, GRACE, and ICESat satellites, all launched in FY 2002 or to be launched early in FY 2003.

New sensors on the Aqua satellite (afternoon equator crossing) will provide complementary data when paired with the identical instruments on Terra (morning equator crossing). Outputs from one new sensor will be combined with other existing sensors to provide atmospheric temperature and water vapor profiles, and sea surface temperatures, with unprecedented accuracy. Beginning in 2003-2004, these data will be used to evaluate and improve models that simulate the global atmospheric water cycle, and, as a result, improve predictions of weather and extreme events (e.g., floods), and seasonal-to-interannual water cycle variability (e.g., droughts). For the first time, series of data will be analyzed from the combination of sensors measuring water cycle parameters from the Terra, Aqua, TRMM, and NOAA satellites to provide more accurate measurements of rainfall and other water cycle variables.

Analysis and calibration of the first series of data from the GRACE satellite are designed to provide information on large-scale changes in deep-layer soil water and large land water bodies (reservoirs, lakes, and aquifers) for validating large-scale hydrologic models.

ICESat, which covers the Arctic, the Antarctic, continental high elevations, and the oceans, will monitor changes in ice sheets and glaciers, and sea surface and sea ice topography.

These observations will be critical for determining the consequences of climate change and the rate at which they are occurring.

Reducing Uncertainty in Cloud Feedbacks: Clouds remain one of the largest sources of uncertainty in climate models being used to project climate change scenarios. Realistic representation of small-scale cloud processes in large-scale models is one

of the major challenges in climate modeling. Single-column models are a computationally efficient means of testing the physical integrity of a parameterization as well as assessing the impacts of a range of atmospheric conditions and cloud regimes. This approach makes very effective use of high-density, limited-area observations from intensive field observing programs.

Prediction of Warm Season Rain: Effective water management in the southwestern U.S. depends on knowing the intensity and timing of the summer monsoonal rains. A field program and modeling experiments will be initiated to assess the role of land in monsoonal circulations associated with the Gulf of Mexico and the Gulf of California and its effect on the patterns of warm season precipitation. Better understanding of monsoonal circulations is expected to lead to more timely and accurate predictions of warm season storm activity and precipitation. A related project will demonstrate how climate forecasts can be combined with advanced hydrological models to produce streamflow forecasts useful for practical resource management decisions in the western United States.

Evaluation of Climate Products: Over the next few years, experimental Land Data Assimilation System (LDAS) products will be tested and evaluated in several contexts. For example, one product will be used to assess the value added by research products of the Global Energy and Water Experiment (GEWEX), and forecasts using the Advanced Hydrologic Prediction System, to flood and drought water resource management in the Upper Columbia River Basin. Another project will evaluate LDAS surface energy budget products for improved water demand forecasting in the Yakima irrigated areas, and integrate these demands into river system operational decisions. These tests are designed to yield better estimates of consumptive use of water by crops and by vegetation on river banks, and open water evaporation, for selected reaches of the river. Better estimates will improve water management efficiency, which will save water. The tests also will yield estimates of the economic value of water saved for irrigation, enhanced habitat, increased hydropower generation, improved crop production, and enhanced fisheries. The successful demonstration of the efficacy of these climate products is expected to speed their application by water resource managers.



Figure 5.3
North Carolina coast after Hurricane Floyd

The global water cycle plays a pivotal role in the transport of sediment and nutrients through the Earth system, as exemplified in this Landsat-7 image of the North Carolina coast. The image was taken on September 23, 1999, one week after Hurricane Floyd hit the continent. Along with soil swept away by the flood waters, the estuaries were filled with human and animal waste, fertilizers, and pesticides.

Credit: NASA Goddard Space Flight Center; Water Cycle Study Group

For additional information see Appendix B.



5 | Ecosystems

The USGCRP budget includes \$210 million in FY 2003 for research and observations primarily related to understanding changes in ecosystems. Ecosystems sustain life on Earth by providing a wide variety of goods and services, including food, fiber, shelter, energy, clean water and air, and recycling of elements, as well as providing cultural, spiritual, and recreational benefits to society. Changes in the local environments experienced by ecosystems are leading to changes in the structure and functioning of some ecosystems, affecting in turn the flow of valuable ecosystem goods and services. Observed ecological responses to recent climate change and variability include the shifting of geographic ranges of plant and animal species, lengthening of plant growing seasons, and increased mortality of tropical corals.

Ecosystems are influenced by a variety of factors, both natural and human-induced, including food web interactions, biogeochemical cycles, introduction and spread of exotic species, atmospheric chemistry, climate, extreme weather events, disturbances (e.g., fire, erosion, and sea level change), land use (e.g., forestry, crop, range, and urban uses), land management (e.g., harvest cycles, tillage, and livestock grazing), and water uses (e.g., municipal supplies, agriculture, and fisheries). The USGCRP recognizes the interconnectedness of global changes in atmospheric chemistry, climate change and variability, biogeochemical cycles, ecosystem disturbance, species movements, and land, water, and resource use and management, and coordinates ecosystem research and assessment with research and assessment in these other topic areas.

Ecological effects of environmental changes and variability may be manifested in unexpected ways. Climate warming may enhance the growth of some trees by extending the growing seasons, but pathogens able to better survive winters because of milder conditions might at the same time decrease forest productivity. Subtle changes in the salinity or temperature of ocean currents may alter the ranges and population sizes of fish species, affecting catches for better or worse. Small changes in environmental conditions might alter plant and animal species mixes in ecosystems, resulting in long-term changes in ecosystem functioning.

Ensuring the provision of ecosystem goods and services needed and valued by a growing human population requires an improved understanding of the potential impacts of global change and how to reduce the vulnerability, seize opportunities, and enhance resilience of ecosystems to such change. The development of strategies and technologies to reduce ecosystem vulnerability, seize opportunities, and enhance resilience to potentially adverse or positive global change depends on such knowledge. The USGCRP is contributing to these societal goals by pursuing an improved scientific understanding of potential relationships between global change and terrestrial, freshwater, and marine ecosystems, and by developing options for effective responses. The three overarching long-term questions for USGCRP ecosystem research are:

- (1) How do natural and human-induced changes in the environment interact to affect the structure, functioning, and services of ecosystems at a range of spatial and temporal scales, including those functions that can in turn influence regional and global climate?
- (2) How can projections of the state of ecosystems and ecosystem services, which are dependent on explicit scenarios for climate, land use, and economic activity, be measurably improved to begin to provide decision-relevant information?
- (3) What options does society have to ensure that desirable ecosystem goods and services will be sustained or enhanced in the face of potential regional and global environmental changes?

The USGCRP agencies have identified five major goals for ecosystem research in global change over the next 10 years:

- (1) Improve the understanding of the most important linkages among the structure and functioning of ecosystems, biogeochemical cycles, climate, and ecosystem management.
- (2) Determine the effects of global change on ecosystems and ecosystem services.
- (3) Identify options for sustaining and improving ecosystem goods and services valued by societies, given projected global changes.
- (4) Develop improved methods and resources to provide decision-relevant information about climate-ecosystem interactions for a range of spatial and temporal scales.
- (5) Identify the fundamental knowledge gaps, information needs, and uncertainties that are or would be most important to address to provide support for decisionmaking.



HIGHLIGHTS OF RECENT RESEARCH



Longer Growing Season Observed: Data from the AVHRR satellite spanning two decades have confirmed that the growing season in the Northern Hemisphere above 40 degrees north latitude is getting longer, with spring arriving earlier and fall somewhat later. Researchers using ground-based temperature records in tandem with satellite vegetation data found a tight linkage between changes in the growing season length of northern vegetation and year-to-year changes in temperature. The temperature component of this analysis came from the Global Historical Climate Network, which uses data from several thousand meteorological stations around the world. The satellite imagery was used to construct Normalized Difference Vegetation Indices (NDVIs), which serve as surrogates for plant growth. The findings indicated an increase since 1982 in the Eurasian growing season of nearly 18 days, while that in the U.S. increased by 12 days. Further research is needed to document fully the carbon cycle aspects of increased growing season length. However, the findings could potentially indicate enhanced carbon uptake in parts of the Northern Hemisphere.

Extensive Coral Bleaching Documented: Reefs provide protection from erosion to coastlines and sand for beaches as well as harboring a tremendous diversity of animal and plant species. In 1998, extensive worldwide tropical reef coral bleaching was documented. The bleaching was triggered by high water temperatures related to the 1997-98 El Niño event. Coral bleaching occurs when coral colonies expel their symbiotic algae (zooxanthellae) under physiological stress, most commonly associated with high temperature and high input of solar radiation. Corals may recover from short periods of bleaching, but extended periods can be lethal. For example, the 1998 thermal anomaly lasted for about three months in Belize and induced mass mortality of corals throughout an area of 375 km² in the south central lagoon of the Belizean Barrier Reef. Corals on the main outer barrier reef experienced some bleaching but mortality was minor compared to the catastrophic damage in the lagoon. The composition of the corals in extracted cores indicated that the magnitude of mass mortality during 1998 had not occurred in this area for at least 3,000 years. This record is a reason for concern that increased climatic variability and change (manifested most intensely during periods of warm variations) is leading to the degradation of coral reef ecosystems.

New Estimates of Insect Diversity: The largest existing data set of tropical insects collected from identified plant species in the field was developed. The data set includes 75,000 records of 1,100 insect species hosted by 62 plant species. Analysis of the host specificity of these tropical herbivores showed that most leaf-chewing

insects feed on several plant species, contrary to popular conceptions of high host specificity among tropical insects. The observation that these insect species apparently specialize on plant genera, rather than plant species or families, is of practical importance in understanding the impact of selective logging, range changes induced by climatic change, invasive species, and biological control. The observation also reduces estimates of global arthropod (insects and relatives) diversity from 31 million, based on plant species numbers, to 4-6 million arthropod species. This figure for arthropod diversity agrees with estimates based on taxonomic collections, reconciling an order of magnitude discrepancy between extrapolations of global arthropod diversity based on ecological samples of tropical plant communities and those based on sampling of regional faunas.

Model Evaluation and Improvement: A rigorous evaluation of nine terrestrial ecosystem models was completed with the support of DOE, NASA, NSF, and the government of Canada. Models were compared to three years of field data collected on ecosystem water use, net primary production, gross primary production, net ecosystem production, and soil respiration in a boreal spruce forest. In this most extensive comparison of forest ecosystem models with independent field data conducted to date, it was discovered that more complex models tended to provide more accurate predictions of short-term (i.e., daily) water and carbon dioxide exchange rates, but not more accurate monthly and annual predictions. Several model improvements resulted from this work. This type of evaluation is required to understand the extent of remaining uncertainties and limitations of models used to predict the effects of global and regional environmental changes on the structure and functioning of terrestrial ecosystems.

Wetlands Sensitive to Global Change: Results of several research studies have shown that both aquatic and marine wetlands are sensitive to increased sea level, higher frequency of wildfires, increased atmospheric CO₂ concentration, and other factors. For example, a three-year study indicated that marsh burning temporarily increased plant root volume, thus increasing sediment elevation. Additional research evaluating effects of global and regional rates of sea-level rise and subsidence on coastal wetlands showed that some wetlands are able to “keep up” with sea-level rise by accumulating elevation through the production of roots and rhizomes, while other wetlands require inputs of mineral sediments via overland flow of sediment-laden water. In other research, species-specific differences in growth and productivity of coastal marsh plants in response to elevated CO₂ observed in greenhouse experiments indicated potential changes in coastal marsh vegetation dominance in an elevated CO₂ environment.



Research Program: Near-Term Plans

HIGHLIGHTS OF FY 2003 PLANS

The USGCRP will continue to support research to understand ecosystem processes and their relationship to climate, carbon cycling, and resource management; determine the potential responses of ecosystems to climatic and global change; and identify options for reducing vulnerability, seizing opportunities, enhancing resilience, and sustaining ecosystem goods and services. Key research plans for FY 2003 include:

Impacts of Biomass Burning and Industrial Emissions on Ecosystem

Functioning: By the end of FY 2003 assemble and publish the first comprehensive regional analysis of the relationship between emissions of trace gases and aerosols resulting from biomass burning and industrial activities, and the functioning of the ecosystems of southern Africa, using in situ, airborne, and satellite sensors.

Characterize effects on ecosystems due to nutrient losses or deposition and changes in incident solar radiation and regional climate.

Impacts of Precipitation Change on Forest Ecosystems: Complete synthesis of responses of an eastern Tennessee temperate deciduous forest ecosystem to nine years of experimental manipulation of precipitation inputs to the soil. In this

Table 7
ECOSYSTEMS
FY 2003 BUDGET BY AGENCY

(Discretionary budget authority in \$millions*)

Scientific Research	
NSF	30
NASA	29
USDA	26
USGS	15
DOE	14
SI	4
Scientific Research Subtotal	119
NASA Space-Based Observations	91
Ecosystems Total	210

(*Amounts are rounded to the nearest \$million)

synthesis, effects of increases and decreases in precipitation will be evaluated with respect to forest water use, growth and survival of understory vegetation and large overstory trees, forest net primary productivity, nutrient cycling, litter decomposition and soil organic matter turnover, root growth and mortality dynamics, biochemical characteristics of forest trees, and other ecologically important variables. The synthesis is expected to be applicable to a large part of the eastern United States, and may shed light on future options for managing forest resources in the event of an altered precipitation regime. Results of the synthesis will be published as a book, scheduled to be completed by the end of FY 2003. Also during FY 2003, results of the field experiment will be used to test at least 10 ecosystem models on their predictions of forest growth, water use, and carbon balance.

Monitoring Change in Mountain Plant Diversity: Refine methodology and expand its application to establish baseline information and quantify changes in native and non-native plant diversity along elevation gradients in the Colorado Rockies, to assess future responses to climatic change. The technique, involving long-term forest transects, appears to be particularly effective at monitoring the spread of invasive species. Monitoring changes in biodiversity and species composition is needed to better understand how these ecosystems function and to provide information to support the development of management and conservation plans.

Interaction of Ecosystems and Biogeochemical Cycling: Sponsor new research dealing with the interaction between many physical and natural components of ecosystems and biogeochemical cycling. A particular area of interest includes relationships of cycling of carbon to the cycling of other nutrients and elements (e.g., nitrogen, iron) in terrestrial, atmospheric, polar, freshwater, and marine environments, and the feedback relationships between carbon cycling and ecological dynamics, population genetics, ecosystem productivity, and the evolution of species.

Effects of Carbon Dioxide Enrichment on Grassland: Complete a five-year study during FY 2003 of the impacts of enriched atmospheric CO₂ on ecosystem productivity, plant community composition, and trace gas fluxes in a perennial grassland system on the Northern Great Plains. The influence of CO₂ and partial defoliation (simulated grazing) will be quantified. Different perennial grasses have responded differently to the treatments, so data on root growth and soil microbiological characteristics that will be collected in the final phases of the experiment in 2002 are expected to be of particular significance to understanding the overall response of the system. In addition to use in more than two dozen planned publications, the data will support an assessment of increased CO₂ and global change on the world's grasslands, to be completed by the Global Change and Terrestrial Ecosystems (GCTE) project of the



Research Program: Near-Term Plans

International Geosphere-Biosphere Programme within three years. Combined with information obtained in related experiments, range management recommendations will be developed during the next three years to minimize adverse effects of global change on Northern Plains grasslands, and take advantage of possible benefits that may be identified.

Figure 6.1

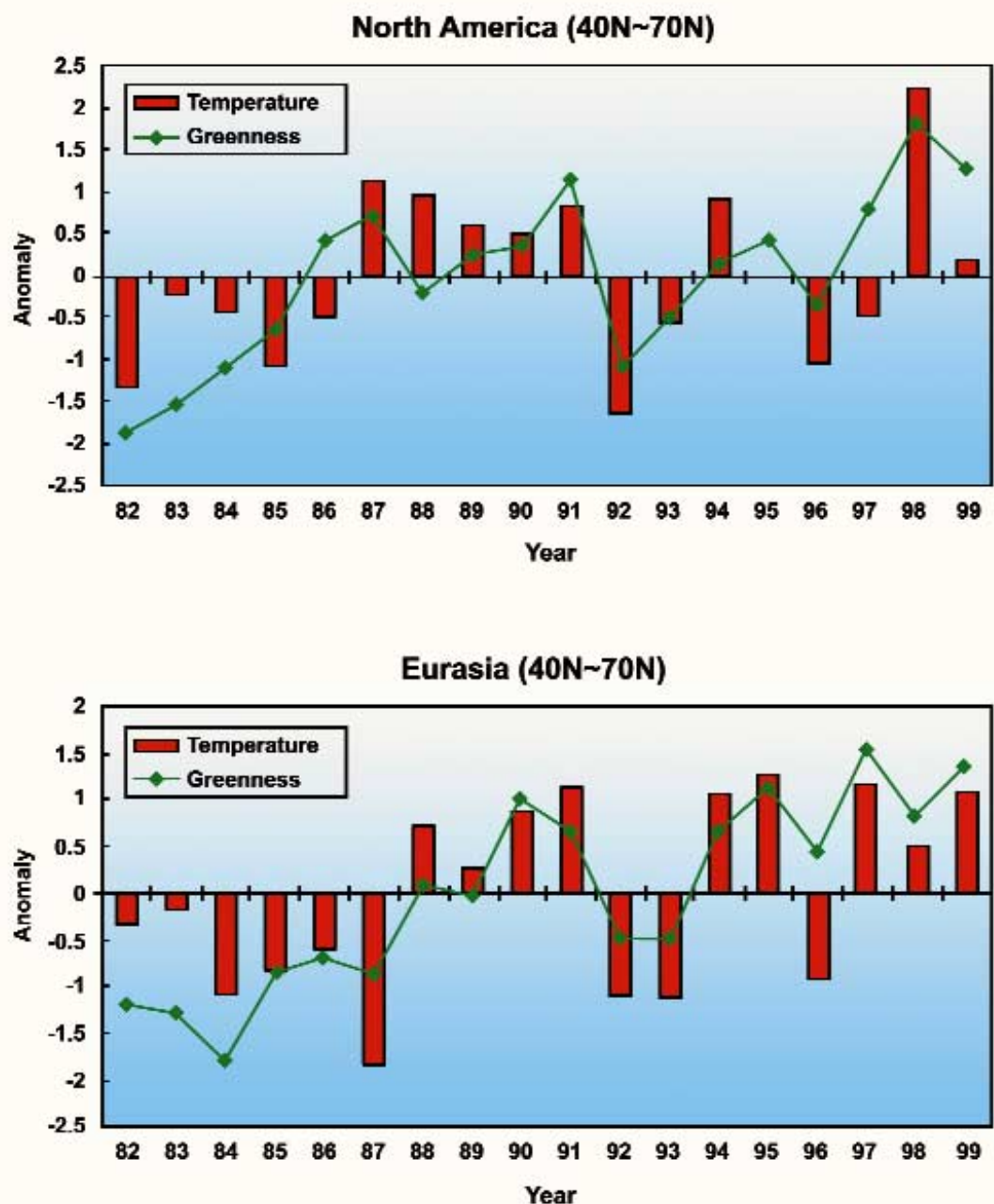
Trends in surface temperature, vegetation greenness, and duration of growing season, North America and Eurasia, 1982-1999

(left) Temperature and greenness; (right) Changes in growing season duration

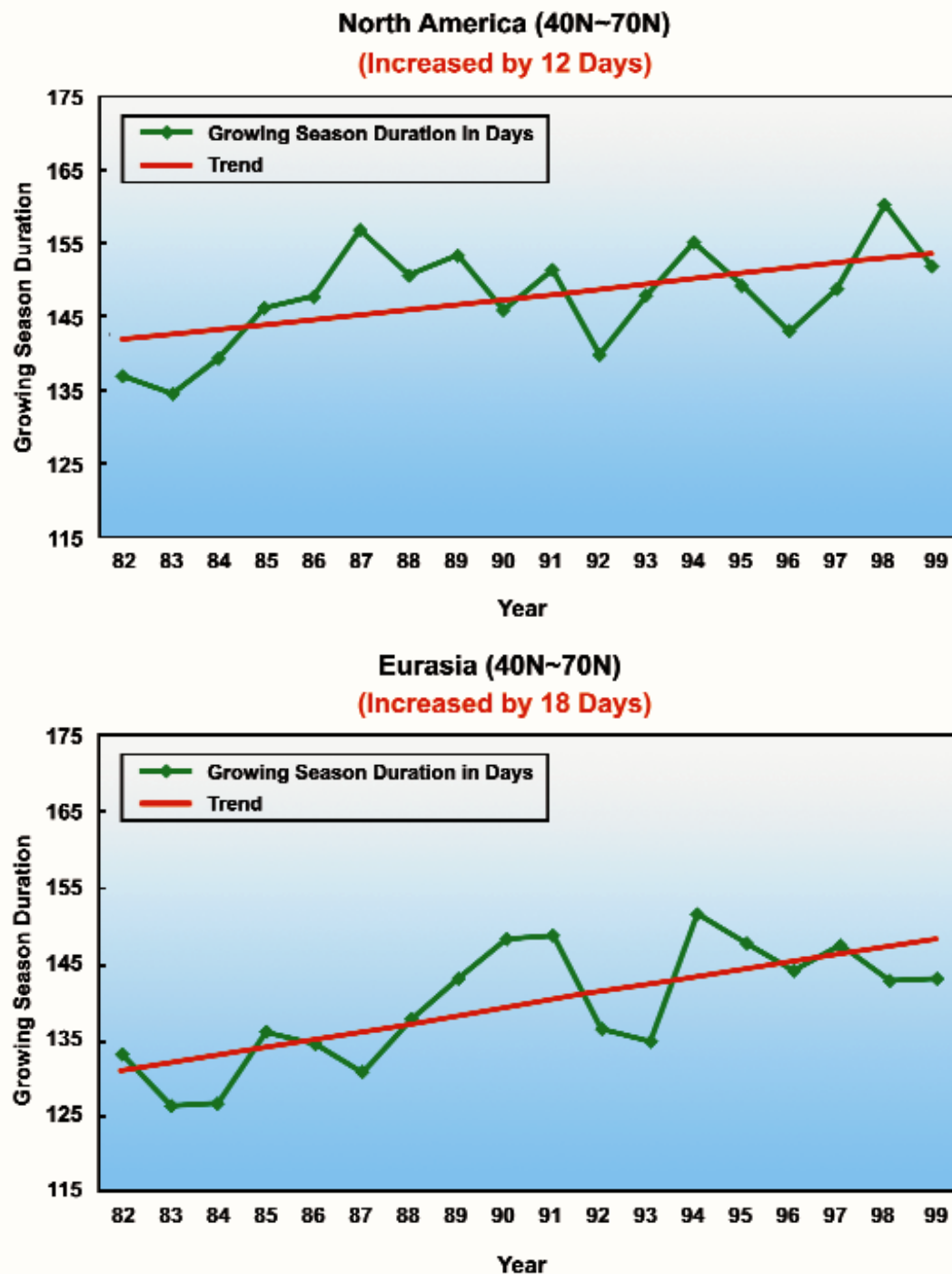
An analysis of two decades of satellite data confirms that the growing season in the Northern Hemisphere is getting longer and that plant life is also becoming more lush. Ground-based temperature data and satellite-based vegetation data indicate that year-to-year changes in growth and duration of the growing season of northern vegetation are tightly linked to year-to-year changes in temperature. The greening trend is more pronounced in Eurasia than in North America, particularly throughout the forests and woodlands in central Europe, Siberia, and the Russian far east.

Credit: Boston University Climate and Vegetation Research Group; NASA Goddard Space Flight Center

For additional information see Appendix B.



Ecosystem Carbon Sequestration Capacity: Initiate studies to determine how much of the “excess” CO₂ assimilated by a salt marsh exposed to twice-ambient levels of CO₂ for 13 years is exported in groundwater to the adjacent estuary. Similar studies in a Florida scrub oak forest will quantify how much excess carbon is sequestered below ground. This research will help to assess the capacity of different ecosystems to store carbon over time and will also provide insight into possible carbon mitigation options.





6 | Land Use/ Land Cover Change

Land-use change is perhaps the most pervasive and obvious form of global environmental change. It is also a form of change that can be managed. The current patterns of land cover around the world reflect past and current land use and management decisions. Changes in land cover and land use have been accelerating, driven by a host of factors including population, technology development, economic growth, and climate. We know that land-use changes interact with natural processes to drive land-cover change, but the fundamental processes that control the type, rate, and spatial characteristics of land-use change are poorly understood. A better understanding of the processes, rates, causes, and consequences of land use change and land management practices is essential for many areas of global change research.

Changes in land cover and land use, as well as the management practices within land uses, affect the concentrations of greenhouse gases in the atmosphere, air and water quality, soil fertility, the capability of terrestrial and aquatic ecosystems to provide goods and services, the productivity of agriculture, the character of the urban landscape, local weather, the occurrence and spread of infectious disease, and other aspects of human health and welfare. The role of climate change on land use and the combined impacts of land-use change and climate change and variability are likely to affect natural resources and ecosystems in complex ways.

Land Use and Land Cover Change (LULCC) is a new research element of the USGCRP. It has direct societal relevance and is truly interdisciplinary, involving the combination of social and physical sciences. In the design phase, key questions were identified for the LULCC element:

- (1) What processes determine the temporal and spatial distribution of land-cover and land-use change at local, regional, and global scales?
- (2) How can land use and land cover be projected over timescales of 10-50 years?
- (3) How will the dynamics of land-use, land-management, and land-cover change affect global environmental changes and regional-scale environmental and socioeconomic conditions, including economic welfare and human health?
- (4) How will global environmental changes affect land use and land cover?

Broad goals were developed for this element, which involve learning from the past, understanding the present, and modeling the future, and a number of research objectives were outlined. Key research challenges include quantifying the human drivers of land-use and land-cover change; improving monitoring, measuring, and mapping of land use and land cover and the management of data systems; and integrating consideration of land-use, land-management, and land-cover change with other global environmental change elements. In the coming year the LULCC element will be working with scientists and stakeholders to refine these goals and develop the LULCC Science and Implementation Plan.

HIGHLIGHTS OF RECENT RESEARCH

National Land Cover Database: A 1992 National Land Cover Database (NLCD) was completed, validated to determine accuracy, and released via a seamless Internet map server. The development of the NLCD was supported by four USGCRP agencies. The NLCD was produced using 1992 Landsat Thematic Mapper satellite data; it included the categorization of 21 general land cover types, spanned the 48 contiguous states, and had 30-meter spatial resolution. The dataset was

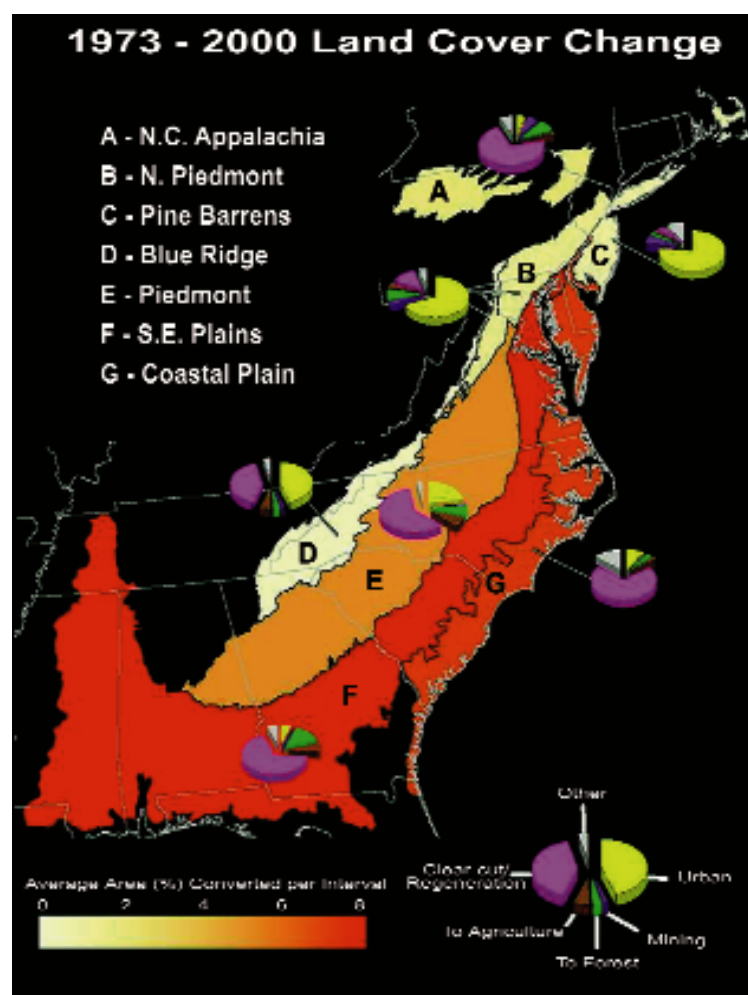
Figure 7.1

Land Cover Change in Eastern U.S. Ecosystems, 1973-2000

An analysis of land use and land cover change in eastern U.S. ecological regions provides evidence of distinctive regional variation in the rates and characteristics of changes. The USGS, in cooperation with EPA and NASA, used Landsat images from five years (1973, 1980, 1986, 1992, and 2000) to map the rates of ecoregion change in each time interval (portrayed in ecoregion color), and the primary land cover transformations (portrayed in the pie charts). Land cover of approximately 20 percent of the land in the Mid-Atlantic Coastal Plain and Southeastern Plain changed during the nearly 30-year period due to the rapid, cyclic harvesting and replanting of forests. The adjacent Piedmont region also showed substantial change in forest cover. Urbanization was the dominant conversion in the Northern Piedmont and Atlantic Coast Pine Barrens. The two Appalachian regions studied (Blue Ridge and North Central Appalachia) had comparatively low overall change, with the primary transformations being urban development and forest conversion, respectively.

Credit: USGS EROS Data Center.

For additional information see Appendix B.



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designed to support a wide range of environmental assessments, including analysis of the rates of land cover change, impacts of land cover change on water quality, and the evaluation of ecosystem form and function. Its national and regional applications include watershed management, environmental inventories, transportation modeling, fire risk assessment, and land management. Access to the data is through the following Web site: <http://landcover.usgs.gov>

Land Use/Land Cover Change in U.S. Ecological Regions: An analysis of land-use and land-cover change in nine eastern U.S. ecological regions has been completed. In the first phase of a study to document land-use and land-cover change for five periods from 1973 to 2000 (1973, 1980, 1986, 1992, and 2000) for 84 U.S. ecological regions, Landsat satellite data were interpreted to determine the contemporary rates of change. During the nearly 30-year period, land use/land cover changed over approximately 20 percent of the area of in the Mid-Atlantic Coastal Plain and Southeastern Plain, due to the rapid, cyclic harvesting and replanting of forests. The adjacent Piedmont region also showed substantial change in forest cover.

Urbanization was the dominant conversion in the northern Piedmont and Atlantic

Coast Pine Barrens. The two Appalachian regions studied (Blue Ridge and North Central Appalachia) experienced comparatively low levels of change, with the primary transformations being urban development and forest conversion, respectively. The early results of this national study provided evidence of the distinctive regional character and variation in the rates and characteristics of land-use and land-cover change.

Land Use/Land Cover Change and Changes in Soil Carbon and Nitrogen: Recent satellite and ground-based studies in the southern United States indicate that woody encroachment into grasslands can significantly

Figure 7.2

Forest cover increase and abandonment of marginal agricultural lands in the Upper Midwest

An increase in forest cover since 1970 has been found in analyses of the U.S. Upper Midwest. This increase results in increased carbon sequestration because forest cover is primarily replacing pastures and croplands.

Credit: School of Natural Resources and Environment, University of Michigan

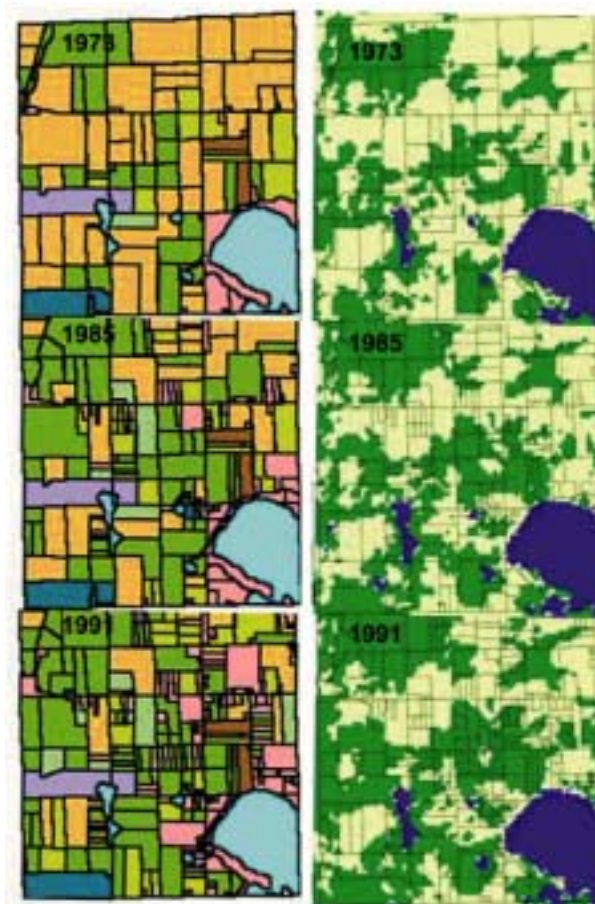
For additional information see Appendix B.

Grand Traverse County, Michigan

The left image illustrates land use change by parcel interpreted from aerial photographs. Green colors are forest, beige/yellow is agriculture and pink color is residential development.

The right image is forest cover from Landsat MSS satellite images. Green is forest and light yellow is not forest.

The images illustrate the forest regrowth that is occurring across the Upper Midwest concurrently with parcel fragmentation, agricultural abandonment, and rural residential development.



alter biogeochemical cycling in arid to semi-arid ecosystems. Specifically, shifts from grasslands to shrublands and forestland in northern Texas have increased substantially during the past 70 years, contributing to increases in plant and soil carbon and nitrogen stocks in the region. These changes have occurred primarily as the result of abandonment of agricultural and pasture lands as well as changing fire and grazing practices. Together, these changes have implications for future land management.

Fire Disturbance and Forest Carbon Storage: Increasing atmospheric CO₂, climatic variation, and fire disturbance all play roles in the historical carbon cycle dynamics of Alaska. Analyses of the distribution of the ages of tree stands in Alaska indicate that fire has likely become less frequent since 1950, compared to the first half of the 20th Century. Quantitative results from application of the Terrestrial Ecosystem Model (TEM) indicate that the key factor responsible for the substantial carbon storage in Alaska during the 1980s was regrowth under a less frequent fire regime. In the context of the overall U.S. carbon budget, the analyses with TEM indicate that Alaska is likely to be an important region of carbon storage. The applications of mechanistic models, such as TEM, represent complementary tools to atmospheric analysis, with the potential to provide information on the quantity of changes in carbon storage at finer spatial scales, and also to provide information on factors responsible for changes in carbon storage. This information may be useful in evaluating policy options related to the U.S. carbon budget.

Table 8
**LAND USE /LAND COVER CHANGE
FY 2003 BUDGET BY AGENCY**

(Discretionary budget authority in \$millions)	
Scientific Research	
NASA	8
USGS	3
USDA	1
SI	1
Scientific Research Subtotal	13
NASA Space-Based Observations	27
Land Use/Land Cover Change Total	40

(*Amounts are rounded to the nearest \$million)



Research Program: Near-Term Plans



Forest Cover Increase and Carbon Sequestration: Forest cover increases averaging 7 percent per decade between about 1970 and 1990 have been found in analyses of the U.S. Upper Midwest. Data from 136 representative study sites were collected using satellite data, aerial photography, and field data, combined with regional Geographic Information System-based models. The results indicate increased carbon sequestration, because forest cover is primarily replacing pastures and croplands. Forest regrowth and planting in the temperate forests of the Northern hemisphere due to land-use change may account for some of the “missing sink” in carbon budgets. The observed increase in the Upper Midwest resulted primarily from the abandonment of marginal agricultural lands as the farm economy in the region has declined. A significant decade-scale lag effect was observed between abandonment and regrowth. A countervailing trend is extensive dispersed rural development in the region, driven by demand for recreation and retirement destinations as well as for seasonal homes. This work highlights, and also raises questions about, the dependence of land-use change and consequent carbon sequestration on agriculture policies, infrastructure investments, and regional and local planning efforts. (See Figure 7.2)

Land Use/Land Cover Change and Native Species Viability: Analyses of Landsat imagery, along with aerial photographs, indicate that conifer forests expanded by more than 7 percent in the Greater Yellowstone Ecosystem during 1975-95. The major land-cover changes were a 347 percent increase in urban area and a 400 percent increase in rural residences. A key finding is that hot spots for native species overlap with intensive land use in the same small portion of the landscape. A critical consequence is that development on private lands threatens the viability of some native species in Yellowstone National Park and other nature reserves. Another key finding is that human population and economic growth are associated with changes in ecosystem attributes; rapid change has important implications for carbon storage and biodiversity. Information from this study can be used to better manage the urban-park interface to ensure conservation of natural resources while encouraging regional economic activity.

HIGHLIGHTS OF FY 2003 PLANS

The USGCRP will support research to identify, quantify, and understand fundamental processes of land-use and land-cover change and their consequences. Key research plans for FY 2003 include:

Assessment of Global Forest Extent: Develop a high-quality database of current global forest extent, mapping forests by country, continent, and biome, through the use of data from EOS MODIS. This database will be an improvement on the previously

produced inventory of forest cover, which used early 1990s data from the NOAA Advanced Very High Resolution Radiometer. The new product will use higher spatial resolution (500-meter) observations, and estimates of forest cover will be generated using an approach independent of the often-conflicting definitions of “forest” — not using a single threshold but using a variety of values applicable to multiple users. The product can be applied to document forest extent and change to estimate carbon and other biogeochemical fluxes to the atmosphere, interactions of the land surface with climate, and forest habitats.

New Enhanced National Land-Cover Database: Assemble a comprehensive global Landsat-7 database of geometrically corrected Enhanced Thematic Mapper scenes from circa 2000. This 30-meter data -set will support the Millennium Ecosystem Assessment initiative in addition to supporting the development of a new National Land-Cover Database (NLCD). The new NLCD, supported by five USGCRP agencies – USGS, USDA, EPA, NOAA, and NASA — and slated for completion in 2005, will complement the recently completed 1992 NLCD, but will be enhanced with expanded geographic coverage (all 50 states) and additional land-cover attributes.

Land Use/Land Cover Change in the Amazon Region: Document areas and rates of all major forms of disturbance in the Amazon region: deforestation, regeneration, forest fragmentation, selective logging, and fire. Satellite imagery from the latest sensor suites on Landsat, Terra, Aqua, and EO-1 will be used to document disturbance patterns and relate them to processes using quantitative estimates of the relationships among, for example, the rate at which logging is converted to deforestation, the rate at which fragments are cleared, the magnitude of logging occurring some distance from edges, or the magnitude of fire associated with logging and edges. These data will be put into multi-agent prognostic models that, in turn, will be used to drive carbon and climate models. The satellite and derived data will be made available to researchers and policymakers through distributed data and information systems and Web-based interactive geographic information systems. The maps at 30-meter resolution will allow direct tracking of land-use change and provide a prototype for a global approach.





7 | Human Contributions and Responses

The USGCRP budget includes \$121 million in FY 2003 primarily for the study of the human contributions and responses to global change. Humans are a part of the Earth system, are drivers of land-cover change, and are significant contributors to the condition of other natural resources. Humans also respond to changes in their environment. Adaptations, when effective, enhance the resilience of both managed and natural systems. Research on human contributions and responses to global change have helped explain how humans drive important interventions in the Earth system, how they are affected by interactions between natural and social processes, and how humans devise mitigation and adaptation strategies in response to environmental change. The USGCRP looks to the study of human contributions and responses to understand the means by which human populations influence the natural world, anticipate the future, handle uncertainty, and prepare for change. Developing a more integrated understanding of the complex interactions of human and Earth-system processes is desirable for identifying vulnerable systems and pursuing opportunities and options to enhance resilience. The study of the human interface with change in the global environment is especially important because of its capacity to inform public policy.

Research on human contributions and responses to global change has been organized around questions first identified by the National Research Council in *Global Environmental Change: Research Pathways for the Next Decade* (1999) and then been more finely honed by the USGCRP agencies. The focus of the USGCRP's human dimensions research is currently on:

- Potential effects of global change on human health.
- Human forcing of the climate system, of land use, and other global environmental change.
- Potential regional and sectoral vulnerability and resilience.
- Decision support under conditions of complexity and uncertainty.
- Integrated assessment methods.

HIGHLIGHTS OF RECENT RESEARCH

Health Effects of Ultraviolet (UV) Radiation: Various research projects currently focus on the effects of UV radiation on human health, including basic molecular studies, chemoprevention and risk control research, examinations of immune system function, epidemiological studies, and the development of preventive products and technologies. Epidemiological studies show a higher prevalence of cataracts in regions of the world that have unusually high UV exposure. In addition, scientists have shown that either single high-dose or multiple low-dose UV exposure can produce cataracts in animals. Researchers are studying UV damage of DNA and the repair mechanisms that exist to control such damage, especially those mechanisms that relate to the development of cancer.

URBAN POPULATION DENSITY OF NORTH AMERICA

**Figure 8.1**

Urban population density of North America

Based upon satellite measurements of city lights, this image is a map of the urban population density of North America. Red, yellow, and green are urban areas, and blue is the urban periphery. The city light data is laid over elevation data (black is sea level, light gray is over 10,000 feet). Most major cities are in level areas along an ocean, bay, large lake, or navigable river.

Credit: NASA Goddard Space Flight Center; Flashback Imaging Corporation, Ontario, Canada

For additional information see Appendix B.



Research Program: Near-Term Plans

Human Dimensions of the Health Effects of UV Radiation: A large-scale analysis designed to (1) describe the changing patterns of melanoma mortality rates among whites by demographic factors and geography, and (2) assess the relationship between the geographic patterns and ultraviolet radiation levels, concluded that melanoma mortality in the United States reflects the complex interplay of ultraviolet (UV) radiation levels in each geographic region, the sun-protection behaviors of each generation of males and females in childhood and adulthood, the geographic mobility of the population, and risk awareness and early detection.

Health Effects of Combined Exposures to Climatic and Environmental Factors: In August 1999, NASA and NIH/National Institute of Environmental Health Sciences initiated a joint research project to assess the health effects of combined exposures to climatic and environmental factors. Preliminary findings on hospital admissions for cardiovascular diseases in the city of Denver indicate that higher temperatures do not appear to be an important factor in increasing the hospital admissions except for congestive heart failure. In contrast, exposures to higher air pollutant concentrations (carbon monoxide, sulfur dioxide, ozone) appear to have an increasing effect on the number of hospital admissions for cardiovascular diseases as a whole.

Consequences of Global Change for Human Health: Ongoing assessments are examining the potential consequences of global change for human health. A

Figure 8.2

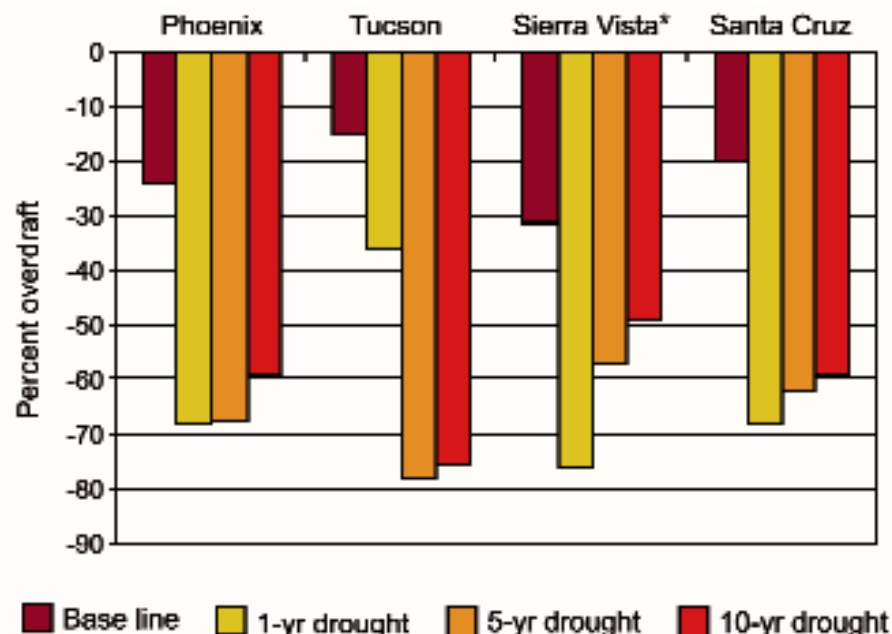
Groundwater overdraft in response to drought in Arizona's urban areas, 2025

A team from the University of Arizona analyzed the water budgets of several Arizona cities to determine how severe the drought impacts would be from the deepest one-year (1900), five-year (1900-1904), and ten-year (1946-1955) droughts on record. The study showed that, even under assumptions of continuing "average" climate conditions, the possibility of achieving "safe yield," (i.e., supply and demand are in balance), remains uncertain.

Credit: University of Arizona project

For additional information see Appendix B.

GROUNDWATER OVERDRAFT IN RESPONSE TO DROUGHT IN ARIZONA'S URBAN AREAS 2025



recently-completed assessment concluded that at present, most of the U.S. population is protected against adverse health outcomes associated with weather and/or climate change, although certain demographic and geographic populations would be at increased risk. The assessment concluded that vigilance in the maintenance and improvement of public health systems, and their responsiveness to changing climate conditions and to identified vulnerable subpopulations, should help to protect the U.S. population from any adverse health outcomes associated with projected climate change. In another project, a team of researchers found strong links between epidemic bartonellosis, a bacterial disease transmitted to humans through a sand fly, and ENSO-related weather patterns in Cuzco and Caraz, Peru. The team will use these findings to develop an epidemiologic and climate risk model to use as a basis for cost-effective disease control programs.

Regional Assessments of Global Change Consequences: Ongoing regional assessments are examining the consequences of and responses to global change in natural and human systems.

Integrated Assessment of Response Strategies: An Integrated Assessment model was developed that, through linked models of urban and global chemistry with

Table 9
HUMAN CONTRIBUTIONS AND RESPONSES
FY 2003 BUDGET BY AGENCY

(Discretionary budget authority in \$millions*)	
Scientific Research	
NIH**	68
EPA***	22
NSF	15
NOAA	8
DOE	8
USDA	<1
Human Dimensions Total	121

* Amounts are rounded to the nearest \$million

** Includes \$67M for Health Effects of UV Radiation

*** Includes \$14M for Regional Research and Interactions, which supports all the other research elements.

Research Program: Near-Term Plans

economic analysis of all relevant emissions, could analyze the relationship between policies to control greenhouse gases and measures directed to the reduction of urban air pollution. Other types of Integrated Assessment models are also under development. Related research is being carried out through international activities focused on the Asian brown cloud phenomenon.

Institutions and Environmental Change: Ongoing fundamental research in social, behavioral, and economic sciences is examining human contributions and responses to global change. For example, researchers are studying deforestation, land-use and land-cover change, and the processes through which forest cover is gained and lost. Analyses of the effect of various kinds of government ownership on forest conditions suggest that no simple association exists between forest conditions and specific types of property-rights regimes. Instead, enforcement explains much of the variance found in forest conditions in areas that vary in property-rights regimes.

HIGHLIGHTS OF FY 2003 PLANS

The USGCRP will continue to support fundamental research and assessments of the effects of human activities on the global environment and the potential societal consequences of global change. Key research plans for FY 2003 include:

Global Change Effects on Human Health:

EPA, NOAA, NSF, and the Electric Power Research Institute plan to award competitive multiyear grants as part of an interagency program on Climate Variability and Health.

Regional Assessment of Vulnerability and Resilience:

NOAA will enhance and refine its decisionmaking-based, regional research in the United States and will expand its cross-regional research efforts to address such issues as transboundary resource management.

Decision Support:

During FY 2003, NSF will continue to support research on environmental decision-making and valuation through its own programs and through a special competition conducted jointly with EPA.

NOAA will continue to support the development of methods for more effective communication, dissemination, and evaluation of information about climate variability and change to support decisionmaking in the public and private sectors.

Integrated Assessment Methodology:

DOE plans to include carbon aerosols in an Integrated Assessment model, including the appropriate specification of emissions, costs of control, and chemical and radiative characteristics of those aerosols. This will allow studies of comprehensive greenhouse-relevant emissions and potential climate change.



INTERNATIONAL RESEARCH COOPERATION

U.S. scientists and research institutions supported by the Climate Change Science Program participating agencies coordinate many of their programs with those of their counterparts in other countries, thus providing essential inputs to the increasingly complex models that enable scientists to improve analysis and prediction of global change. Some highlights of recent, ongoing, and planned global change research and related activities in which CCSP-supported scientists are heavily involved, and for which international cooperation, participation, and support are especially important, include:

Bilateral Cooperation on Climate Change Research and Technology

President Bush has stressed the role of bilateral cooperation in addressing climate change, acknowledging that all countries must actively work together to achieve the long-term goal of stabilizing greenhouse gas concentrations in the atmosphere at a level that will prevent dangerous human interference with the climate system. The United States has moved forward aggressively to build on our already extensive bilateral relationships with key partners in the developed and developing world, including the European Union, Italy, Japan, China, India, and Australia and we intend over the next year to expand bilateral discussions to include a number of additional countries.

The White House announced in July 2001 that the United States and Italy had agreed to cooperate in climate change research and technology within four broad areas: global and regional climate modeling; atmospheric studies related to climate; carbon cycle research; and low carbon technologies. As the first step in developing such cooperation, science program managers from both countries met in Rome in January 2002. The objectives of this initial interaction were to identify, first, specific scientific areas in which joint research is needed; and, second, specific actions to develop such research and a timetable for these actions.

The United States and Japan agreed in February 2002 to cooperate on a broad range of joint climate change science and technology research activities. This consensus was developed at the second meeting of the Climate Change Science and Technology Working Group, which had been established earlier through U.S.-Japan High-Level Consultations. This meeting was conducted under the June 2001 agreement of

President Bush and Prime Minister Koizumi to undertake “high-level U.S.-Japan government-to-government consultations to explore common ground and areas for common action on climate change.” The two sides identified more than 40 joint climate change science and technology research activities for possible implementation.

Multilateral Collaboration in Research

U.S. Government research agencies and CCSP-supported scientists are active participants in a number of important international research programs and assessment activities, including those sponsored by the World Meteorological Organization (WMO), the Intergovernmental Oceanographic Commission of UNESCO (IOC), and the United Nations Environment Programme (UNEP). These include the WMO’s triennial scientific assessments of ozone depletion, the assessments prepared by the Intergovernmental Panel on Climate Change (IPCC), the World Climate Research Programme (WCRP), the International Geosphere/Biosphere Programme (IGBP), and the International Human Dimensions Programme (IHDP).

U.S.-Japan Cooperation in Global Change Research

The USGCRP, through the Working Group on International Research and Cooperation, supports very active collaboration with Japan in global change research. The overall coordinating mechanism for this bilateral effort is the U.S.-Japan Liaison Group on Geosciences and Environment. The Liaison Group meets annually to coordinate and support a wide range of activities, including more than 100 bilateral collaborative arrangements.

In October 2001 the Liaison Group, the USGCRP, and the Japanese Ministry of Education, Culture, Sports, Science and Technology supported the 9th U.S.-Japan Workshop on Global Change Research. The workshop, held in Tokyo, focused on carbon cycle management and terrestrial ecosystems. More than 60 American and Japanese scientists participated. Both the Japanese and U.S. scientists involved in the workshop are looking for ways to advance two key recommendations, one dealing with building model data sets and the second addressing the development of new research tools for measuring plant responses to CO₂ enrichment. This year, the United States will host the 10th workshop, which will focus on global change and the water cycle.

Japan (and also Brazil) cooperated on NASA’s Aqua satellite mission. Aqua, which was launched in May 2002, will obtain a precise set of data on the atmosphere and ocean to understand their role in the Earth’s climate and its variations. Japan supplied the AMSR-E instrument on Aqua. AMSR-E is providing improved rainfall-mapping

International Research Cooperation

capabilities outside the tropics. To validate AMSR-E data, the United States and Japan will jointly carry out several validation activities, including a validation campaign in the Sea of Japan.

Observations in Support of Global Change Research

To expand international cooperation, the President has announced that the United States will invest \$25 million in climate observing systems in developing countries. The primary goal is to promote development and expansion of global observing systems through the Global Climate Observing System (GCOS) and the Argo program for ocean observations, through further multilateral and bilateral cooperative efforts similar to those already initiated.

International Cooperation in Satellite Remote Sensing

NASA leads the United States' cooperation with other countries in a broad range of satellite remote-sensing activities in support of global change research. These programs have strong involvement from Europe, Canada, Japan, and Central America. Two examples of such international cooperation include:

Global Precipitation Measurement (GPM)

To build on the successes of the Tropical Rainfall Measuring Mission (TRMM), the United States and Japan, together with other international partners, are planning a new initiative for the study of atmospheric precipitation on a global basis. The GPM initiative will utilize a constellation of satellites and an advanced data processing system to produce global rainfall distribution maps every three hours. These products may be used, not only in meteorological and climate research, but also in many application areas, such as weather forecasting, water resource management, flood warning, and agriculture management.

Ground-based and Suborbital Measurement

The United States works with many countries in Europe, Asia, Africa, and Central America on ground and suborbital measurements to quantify information and perform satellite validation. Examples of these activities include the Aerosol Robotic Network (Aeronet); the space geodetic network; and SOLVE, an aircraft campaign that assesses ozone changes in the North polar regions.

Climate and Societal Interactions

The Climate and Societal Interactions Program supports Regional Climate Outlook Fora, pilot application projects, workshops, training sessions, capacity building, and technical assistance for better understanding of climate variability and extreme events,

and for prediction and forecasting capability and data management, in Africa, Latin America and the Caribbean, Southeast Asia, and the Pacific. The Radio Internet (RANET) Project will improve access to and operation of information systems for climate and weather in support of the above activities. Currently, RANET has developed over Africa and is expanding to parts of Southeast and South Asia.

The International Research Institute for Climate Prediction (IRI)

A center for climate modeling and applications supported by the United States and Taiwan, the IRI cooperates in climate science and modeling with Japan and Taiwan, and works closely with national labs, applications research programs, and the broader university community to build the capacity and regional networks to help countries cope with and adapt to climate variability. The IRI generates useful knowledge and information related to climate and society. Recent examples include the release of a timely report entitled “The Drought and Humanitarian Crisis in Central and Southwest Asia: A Climate Perspective” (November 2001), and a training effort focused on climatic variability and food security. The training is designed to advance the capacity of developing countries to utilize scientific information to address climate-sensitive dimensions of agricultural production.

A Joint Study With the Peoples Republic of China/Chinese Academy of Sciences-China Meteorological Administration (CMA)

The United States and China continue a collaboration in climate sciences, with a focus on the comparative study of regional climate change in both countries. Key components include preparing climate data for validating and improving global and regional general circulation climate models, and using the improved models to understand and project regional climate changes and the associated impacts resulting from increasing greenhouse gases and aerosols due to anthropogenic activities. Recent major accomplishments in this area include: the development of a 2000-year time series of winter half-year temperature reconstructions (primarily from rainfall data) for the middle and lower reaches of the Yellow and Yangtze Rivers; and measurements (primarily of methane) of emissions from agricultural systems in China and their effects on the carbon cycle. The Science Team for this study plans to meet during the first part of 2003 in China.

The International Group of Funding Agencies for Global Change Research (IGFA)

IGFA facilitates international global change research in the natural, economic, and social sciences by bringing the perspective of national funding agencies to strategic

International Research Cooperation

research planning and implementation. At its October 2001 meeting, IGFA member nations reported generally stable levels of funding for global change research. In Spain, Germany, the U.K., South Africa, and Switzerland, new centers were established to study global change research. The Netherlands, Japan, and Germany are developing new computing facilities, while the U.S. and Taiwan announced new initiatives on satellites/space programs, especially the Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC). An agreement between the U.S. and Taiwan was signed to launch the COSMIC program in 2005.

APPENDIX A

THE USGCRP BUDGET AND PROGRAM BY AGENCY

The budget pages for participating USGCRP agencies that follow include a listing of programs designated for inclusion in the USGCRP budget, as well as a general description of each agency's "Areas of Global Change Research." For each agency, a "FY 2003 Program Highlights" section outlines briefly 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 2002 appropriated funds and the FY 2003 budget request are estimates only, and are subject to adjustments 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 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 activities in the USGCRP budget are funded by six separate Appropriations bills. Thus, the relationship between the USGCRP budget crosscut and the Appropriations process is complex.

Appendix A

DEPARTMENT OF AGRICULTURE

USDA	Program Title	FY 2001	FY 2002	FY 2003 Request
ARS	Agriculture and Rangeland Global Change	12.6	12.4	14.1
ARS	Methyl Bromide Research	16.7	17.9	17.4
CSREES	Global Change Research	2.6	6.9	15.0
CSREES	UV-B Monitoring Network	1.4	1.4	2.5
ERS	Economics of Global Change and Agriculture	0.8	0.4	0.4
FS	Forest Global Change Research	16.9	16.9	16.9
USDA Total		51.0	55.9	
President's Request				66.3

ARS: Agricultural Research Service
 CSREES: Cooperative State Research, Education, and Extension Service
 ERS: Economic Research Service
 FS: Forest Service



Areas of Global Change Research. USDA-sponsored research continues to support long-term studies to improve our understanding of the roles that terrestrial systems play in influencing climate change and the potential 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. USDA's research program is strengthening efforts to determine the significance of terrestrial systems in the global carbon cycle, and to identify agricultural and forestry activities that can contribute to a reduction in greenhouse gas concentrations. USDA's research agencies will support the Department in responding to the President's directive to develop accounting rules and guidelines for carbon sequestration projects. Contributions from the USDA's research program include the development of improved emission and sequestration coefficients, new tools for accurately measuring carbon and other greenhouse gases, and the development of improved methodologies.

FY 2003 Program Highlights. ARS's national program on global change research addresses carbon cycle and carbon storage, trace gas emissions and sinks, impacts of environmental changes on agricultural systems, and feedbacks among agricultural systems, weather systems, and the water cycle. The program proposed for FY 2003 will strengthen our abilities to: predict changes and extremes in the environment that pose risks to agriculture; quantify potential benefits and losses to agriculture posed by assorted environmental changes; identify and manipulate processes that occur in agricultural systems to minimize adverse impacts and take advantage of potential benefits of environmental change; and develop ways in which agriculture can help reduce the rate of net greenhouse gas emissions by the United States. New plans include: creation of AgriFlux, a network of 30 sites measuring the effect of environmental conditions and agricultural management decisions on carbon exchange between the land and the atmosphere; studies to identify crop management practices to optimize crop yield, crop quality, and carbon sequestration at carbon dioxide concentrations and other environmental conditions expected in the 21st century; and research leading to new ways for prediction and early detection of drought in agricultural systems based on weekly and monthly climate forecasts.

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 and assessment of the potential for damage to ecosystems. Global change research in CSREES's National Research Initiative (NRI) Competitive Grants Program and formula-funded programs aims to increase understanding of the possible impacts of global environmental change on the sustainability of agriculture and forestry. Increases in the CSREES National Research Initiative will fund a wide range of research to help agricultural producers that range from very small to very large respond to climate variability, especially drought, and to evaluate opportunities for carbon sequestration. The NRI initiative includes programs for carbon and water cycles, land use and cover change, and managed ecosystem research.

The Economic Research Service will focus efforts on the potential economic implications of climate change on U.S. and global agricultural markets, and will examine options for designing incentive systems to promote carbon sequestration and greenhouse gas emissions reductions in the agricultural sector. ERS will support collaborative applied economics research in cooperation with the Environmental Protection Agency and the government of Canada that will focus on the economic implications of alternative net greenhouse gas emission reduction and carbon sequestration options.

The Forest Service has identified the following key issues for future program emphasis: 1) developing, testing, and evaluating technologies to maintain or increase productivity and carbon storage in forests and wood products; 2) developing management practices that meet society's needs for a variety of forest products under a changing climate; 3) improving the ability of land managers to minimize the impacts of disturbances on forest productivity and sustainability; 4) identifying watersheds that are sensitive to global change, and developing suitable monitoring and management practices; and 5) developing strategies for maintaining species and genetic diversity in the face of global change.

Related Research.

Climate Change Research Initiative: In FY 2003, USDA will invest \$1 million to improve the measurement and accounting systems needed to reduce uncertainty in carbon inventories at the national and project levels. The Forest Service compile estimates of carbon fluxes from forestlands, including trees, understory, forest soils, and wood products. The Natural Resources Conservation Service will develop new measurement technologies, analytical techniques and information management systems to measure the benefits of conservation practices on carbon fluxes and the emissions of greenhouse gases.

Technology Research: In FY 2003 ARS will invest \$4.5 million to strengthen basic climate change technology research and to develop methods for measuring carbon in soils. Within this program, ARS will develop methods to manage crops, soils and grazing systems to achieve the best balance of agricultural productivity, resource conservation, and greenhouse gas emissions reductions and carbon sequestration. ARS will also invest in new methods for rapid and accurate measurement of carbon in soils and greenhouse gases in the atmosphere associated with agricultural systems, and develop methods for managing livestock to minimize emissions of methane. The Forest Service will invest \$1.5 million to support the development of measuring tools and monitoring technologies to improve estimates of carbon fluxes from forested systems.

Mapping of Budget Request to Appropriations Legislation. In the Agriculture, Rural Development, Food and Drug Administration, and Related Agencies Appropriations Bill, USGCRP activities are funded under Title I-Agricultural Programs, within the ARS, CSREES Research and Education Activities, and ERS; and under Title II-Conservation Programs, within the NRCS Conservation Operations account. In the Interior and Related Agencies Appropriations Bill, USDA USGCRP activities are funded in the USDA FS section under Title II-Related Agencies, within the FS Forest Research account.

Appendix A

DEPARTMENT OF COMMERCE / NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

DOC	Program Title	FY 2001 Actual	FY 2002 Estimate	FY 2003 Request
NOAA	Aerosols	1.1	1.1	1.1
NOAA	Applications of Regional Forecasts	3.8	4.6	3.8
NOAA	Atmospheric Chemistry	6.8	6.8	6.8
NOAA	Carbon Cycle Science	4.8	4.9	4.9
NOAA	Climate Change Data and Detection	6.9	6.9	6.9
NOAA	Climate Dynamics and Experimental Prediction	17.9	18.4	18.4
NOAA	Climate Variability and Predictability (CLIVAR)	23.2	23.3	23.1
NOAA	Global Energy and Water Cycle Experiment (GEWEX)	5.8	5.8	5.8
NOAA	Human Dimensions of Global Change Research	1.9	1.9	1.9
NOAA	Climate Observations and Services	13.0	27.2	27.2
DOC/NOAA Total		85.2	100.9	
President's Request				99.9

NOAA

National Oceanic and Atmospheric Administration



Areas of Global Change Research. NOAA's long-term global change efforts are designed to develop a predictive understanding of the variability and change of the global climate system, 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 water 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 problems of social and economic consequences; and archiving, management, and dissemination of data and information useful for global change research.

FY 2003 Program Highlights. NOAA research will continue to advance the understanding of the modes of climate variability and change through whole-system dynamics, the development of predictive modeling capabilities and the application of information generated by this research to decisionmaking processes in climate-sensitive regions and sectors. FY 2003 program highlights in support of the USGCRP research elements include:

Climate Variability and Change:

Increasing understanding of the role in climate variability, predictability and change, of the El Niño-Southern Oscillation (ENSO), the North Atlantic (or Arctic) Oscillation, Tropical Atlantic Variability, the ENSO-like decadal variability in the Pacific, and the Pan-American monsoons.

Continuing the advancement of the sustained global ocean observing system to support Climate Variability and Predictability (CLIVAR) research, operational and experimental climate forecasting, and the major scientific assessments.

Advancing the improvement of climate prediction and project models and climate forecasting systems for seasonal to centennial time scales through pilot climate model-process teams.

Advancing detailed studies of past climate variability on seasonal to centennial timescales using century to millennia-long paleoenvironmental proxy records in order to improve the current understanding of seasonal to decadal variability.

Developing and applying advanced statistical techniques to detect climate change signals and attribute these to specific causes.

Atmospheric Composition:

Characterizing the “ozone-friendliness” of substitutes for ozone-depleting gases, including proposed substitutes that have short atmospheric lifetimes; developing approaches for the detection of the recovery of the ozone layer; and participating in the final review and preparation of the 2002 international assessment of the ozone layer.

Quantifying the trends and sources/sinks of long-lived greenhouse gases; characterizing the variance of tropospheric ozone and its role in the heat budget, including participation in a study of the intercontinental transport of ozone into the eastern Pacific/West Coast U.S. region; and characterizing the fundamental processes that control the shorter-lived radiative species, including a study on the role of tropical cirrus clouds in the vertical atmospheric transport of climate-relevant gases.

Advancing efforts to reduce uncertainties in the understanding of radiative forcing by tropospheric aerosols through an integrated program focused on targeted *in situ* measurements of aerosols integrated with model analyses.

Global Carbon Cycle:

Advancing efforts to produce more accurate projections of future atmospheric CO₂ concentrations by better parameterization of transfers of CO₂ between ocean, atmosphere, and terrestrial biosphere, and development of dynamic, coupled carbon cycle models.

Initiating observations and modeling necessary to quantify the magnitude and variability of the Northern Hemisphere terrestrial sink, with an initial focus on large scale observations over the North American continent and adjacent ocean basins.

Continuing to document the inventory of carbon in the ocean as it accumulates, and characterize how that inventory might be affected by changes in ocean circulation in the future.

Global Water Cycle:

Implementing model and field studies to assess how the role of land in monsoonal processes associated with the Gulf of Mexico and the Gulf of California affect the patterns and prediction of warm season precipitation.

Participating in the first year of the Global Energy and Water Experiment (GEWEX) Coordinated Enhanced Observing Period through the provision of data, data management services, land data assimilation and other regional and global model products.

Appendix A

Finalizing and publishing legacy data sets from GEWEX Continental-Scale International project (GCIP) including a 5-year hourly radar rain data set and water and energy budget fields over the Mississippi River Basin.

Assessing the use of climate forecasts together with advanced hydrologic models to produce useful seasonal streamflow forecasts for practical water resource decisions in the western U.S.

Human Dimensions of Global Change:

Advancing understanding of societal vulnerability, opportunities, and response options related to climate variability on seasonal to decadal timescales (including climate extremes and surprises), and the potential use of climate information for economic, management, and policy planning purposes.

Advancing efforts to foster the application of reliable, scientific forecast information in climate-sensitive regions and sectors such as agriculture, water resources, energy, marketing, human health, and transportation infrastructure.

Related Research. In addition to focused USGCRP research, related activities include short-term weather forecasting and advance warning services; marine ecosystem research; prediction and observation systems in support of weather and seasonal to interannual climate forecasts; and facilitating the dissemination of global change information.

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 itemized in the Climate and Global Change Program and Climate Observations and Services components of the Oceanic and Atmospheric Research budget.

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 unique Defense research and infrastructure associated with the USGCRP is described below. Because these efforts are not part of the OMB Global Change Research Program construct, a budget table is not included. All data and research results are routinely made available to the civil science community. DOD S&T investments are coordinated and reviewed through the Defense Reliance process and published annually in the Defense Science and Technology Strategy, the Basic Research Plan, the Defense Technology Area Research Plan, and the Joint Warfighting Science and Technology Plan.



FY 2003 Program Highlights.

Atmospheric Composition. DOD areas of interest and S&T investment for the Continental boundary layer are — Transport and diffusion, and Clouds and obscurations. For the Marine boundary layer issues are — Maritime and coastal meteorology; major storms, worldwide, with particular emphasis on tropical cyclones, and synoptic to mesoscale prediction. Common interest areas are — coherent structures; subgrid scale parameterization; large eddy simulation; nested models of all scales, surface energy balance; cloud formation and processes; and data assimilation. For example, the Naval Research Laboratory's Special Sensor Ultraviolet Limb Imager, launched in late 2001, provides long term baseline data for investigations of global change in the upper atmosphere. Analysis and prediction of worldwide aerosol concentrations, including desert dust, biomass smoke, marine and anthropogenic aerosols, and a radiative transfer algorithm yielding atmospheric transmission coefficients are generated by the Navy Aerosol Analysis and Prediction System.

Climate Variability and Change. The Defense Modeling and Simulation Office [DMSO] sponsors the Master Environmental Library (MEL). The mission of MEL is to provide direct and timely access to natural environment information, data, and products, wherever they reside. This includes non-geospatial data such as models, algorithms, and documents, as well as basic environmental data. MEL is currently focused on DOD modeling and simulation users, but is accessible to other DOD, Federal, commercial, and academic communities as well. The Master Oceanographic Observation Data Set (MOODS), and the Generalized Digital Environmental Model (GDEM) are public domain data sets and models available through NODC and NAVOCEANO respectively. The recent Ice-Free Arctic Symposium sponsored by the Oceanographer of the Navy looked at observed and forecast Arctic change. Submarine data reveal a 40% decrease in Arctic sea ice volume. Satellite passive microwave data since the 1970s demonstrate a decrease in sea ice extent of 3 percent per decade. Model data suggest that a sea ice thickness decrease of 30 percent and an ice volume decrease between 15 and 40 percent by 2050.

Several DOD funded projects under the aegis of the National Oceanographic Partnership Program [NOPP] contribute directly to USGCRP goals. The Ocean Acoustic Observatory Federation involves government and private research organizations to exploit data from active and retired Navy Sound Surveillance System [SOSUS] stations for ocean acoustic tomography and thermometry measurements in the Eastern Pacific. Another NOPP research effort, Estimating the Circulation and Climate of the Ocean [ECCO] is underway now to describe ocean transport and transport fluctuations of heat, volume, and freshwater and their relationship to air-sea fluxes. The DOD High Performance Computing [HPC] Challenge is sponsoring two relevant projects: a high resolution coupled atmosphere-ocean-ice

Appendix A

model, the Coupled Environmental Model Prediction [CEMP] system, and a 1/32-degree global ocean nowcast/forecast model. The Distributed Ocean Data System [DODS] is another NOPP sponsored effort to facilitate data access by providing a transparent interface to recognize and process data in various formats. The DODS plug-and-play feature simplifies access via the internet. DODS software is free; details are at <http://www.unidata.ucar.edu/packages/dods/>. Data and model output fields are available from the GODAE World Wide Web server at the Fleet Numerical Meteorological and Oceanographic Center — <http://www.usgodae.fnmoc.navy.mil>.

Global Water Cycle. WindSat will be launched in January 2003 on the STP Coriolis Mission to demonstrate multiple Naval remote sensing requirements, including measuring ocean wind speed and direction. WindSat will illustrate the viability of using polarimetry to measure the wind vector from space and provide operationally usable tactical information directly to Navy units and other military and national users. The payload provides risk reduction data and developmental technology that the NPOESS IPO will use in the development of the Conical Microwave Imager Sounder (CMIS).

Terrestrial and Marine Ecosystems. DOD S&T investments include Physical, chemical, biological, optical modeling, and prediction for the marine environment. In addition, several research efforts are coordinated under the NOPP umbrella. For example, the Ocean Biological Information System [OBIS] is a public-private partnership and a new component of the UN Global Biodiversity Information Facility [GBIF]. Navy is directly investing in the development of new, inwater instruments capable of measuring biological and chemical properties of the sea associated with the fine structure of biological and chemical dynamics via the Thin Layers (Critical Scales) Program. The Strategic Environmental Research and Development Program [SERDP] is supporting related research to develop long-lived miniaturized sensors to measure terrestrial and marine ecosystem parameters.

Related Research and Infrastructure. Other DOD-sponsored research and supporting infrastructure, not described above, also contribute to observing, understanding and predicting environmental processes related to global change. Associated research 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 investment in environmental infrastructure, such as the Oceanographic Research Vessel Fleet, the Cold Regions Research and Engineering Laboratory, and the various services' operational oceanographic and meteorological computational centers, will continue to provide data and services useful to the USGCRP.

Mapping of Budget Request to Appropriations Legislation. In the Department of Defense Appropriations Bill, research associated with the USGCRP is funded under Title IV – Research, Development, Test and Evaluation.

DEPARTMENT OF ENERGY

DOE	Program Title	FY 2001	FY 2002	FY2003 Request
BER	Climate and Hydrology	71.2	70.5	74.7
BER	Atmospheric Chemistry & Carbon Cycle	25.2	26.2	26.3
BER	Ecological Processes	11.4	12.4	13.9
BER	Human Interactions	7.9	8.0	8.1
BER	SBIR/STTR	0.0	3.1	3.3
DOE Total		115.7	120.2	
President's Request				126.3

BER Biological and Environmental Research

Areas of Global Change Research. Research supported by DOE's Office of Biological and Environmental Research (BER) is focused on the effects of energy production and use on the global Earth system, primarily through studies of climate response. Research includes climate modeling, atmospheric transport and chemistry, atmospheric properties and processes affecting the Earth's radiation balance, and sources and sinks of energy-related greenhouse gases (primarily CO₂). It also includes research on consequences of climatic and atmospheric changes on ecological systems and resources, and the development of improved methods and models for conducting integrated economic and environmental assessments of climate change and of options for mitigating climate change, and education and training of scientists for climate change research.



FY 2003 Program Highlights. DOE will continue the support of climate change research at its National Laboratories and other public and private research institutions, including universities. In FY 2003, DOE along with the other USGCRP agencies will continue to integrate research on climate processes, climate theory, and computational science to accelerate progress in climate simulation model development, testing, and application. In support of the USGCRP, highlights of the BER climate change program include activities in the following four key areas to provide the data and predictive understanding for developing objective, scientifically rigorous assessments of the potential for, and consequences of, human-induced climate change:

Climate and Hydrology: DOE will continue to develop, improve, evaluate, and apply the best, fully coupled atmosphere-ocean-sea ice-land surface general circulation models (GCMs) that simulate climate variability and climate change over decade to century time scales. Data collection at the Atmospheric Radiation Measurement (ARM) Cloud and Radiation Test Bed sites will be continued to improve understanding of the radiative transfer processes in the atmosphere and to formulate better parameterizations of these processes, especially cloud and aerosol effects, in atmospheric GCMs. DOE will invest additional funds (\$4.1 million in FY 2003) to provide new instrumentation and capabilities for ARM Cloud and Radiation Test Bed sites to expand measurements of radiative and cloud processes, including energy-related aerosols and their radiative properties.

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A multi-institutional research consortium will continue to be supported as a model testbed to further the development, testing, and improvement of comprehensive coupled GCMs for climate prediction that are of higher spatial resolution and contain accurate and verified representation of cloud effects on climate and other important climate processes. Ensembles of coupled model simulations will accurately incorporate the dynamic and thermodynamic feedback processes that influence climate, including clouds, aerosols, and greenhouse gas forcing. Support will continue to acquire the high-end computational resources needed to complete ensembles of climate simulations using present and future models.

BER will also support research to develop and employ information technologies that can quickly and efficiently work with large and distributed data sets of both observations and model predictions to produce quantitative information that may prove suitable for analysis of regional climate changes. Research will also be supported to develop improved algorithms needed to effectively exploit the new massively parallel computing technology. BER will also increase the emphasis on research on data assimilation methods so as to quickly make use of high quality observational data streams provided by the ARM program and other climate data programs, including satellite programs, to evaluate climate model performance.

Atmospheric Chemistry and Carbon Cycle: DOE will continue the support of field, laboratory, and modeling studies to improve our understanding of the atmospheric processes associated with transport, transformation, and dispersion of energy-related emissions and their effects on air quality and climate, including studies of oxidants, aerosols, and the heterogeneous chemistry of these materials. Research will include studies of chemical and physical processes affecting air pollutants such as sulfur and nitrogen oxides, tropospheric ozone, gas-to-particle conversion processes, and the deposition and resuspension of associated aerosols. It will also include studies to improve understanding of the meteorological processes controlling the dispersion of energy-related chemicals and particulates in the atmosphere, including primary and secondary aerosols.

BER research in both terrestrial and marine environments will be continued to improve understanding of the global carbon cycle. As part of the Administration's Climate Change Research Initiative (CCRI), BER will expand support of the network of carbon dioxide flux measurement sites in North America (AmeriFlux) in FY 2003 to test how well point measurements of net CO₂ exchange between the terrestrial biosphere and atmosphere represent larger areas and allow estimates of carbon sources and sinks on a regional basis. This research supports the North American Carbon Cycle Science Plan. DOE will also continue research to refine and test terrestrial carbon cycle models for use in assessing the role of the terrestrial biosphere as a source or sink for atmospheric CO₂ and predicting which ecosystems or ecosystem types are likely sinks or sources of CO₂. DOE will also continue to fund the development and application of new molecular biological probes to understand the linkages between carbon and nitrogen cycles in near shore marine environments and to incorporate this information into ocean carbon cycle models.

Ecological Processes: DOE will continue to support large-scale, long-term experimental field manipulations of environmental factors in important North American terrestrial ecosystems. The goal is to understand, and be able to predict, effects of environmental changes on the structure and functioning of terrestrial ecosystems. The research focuses on physiological and growth responses of plants and microbes, ecosystem nutrient and water cycling, plant community dynamics, plant-microbe interactions, and acclimation and adaptation of plants, microbes, and ecosystems to environmental changes.

Continuing long-term experiments include a field study on effects on forest structure and functioning of (a) chronic changes in precipitation (water supply) on a southeastern deciduous hardwood forest,

and (b) elevated CO₂ and ozone on a constructed deciduous forest in northern Wisconsin. Recently initiated research includes field manipulations of temperature, precipitation, CO₂ concentration, and or/enhanced nitrogen deposition in a boreal forest, arid shrublands, temperate old field grassland undergoing succession, and a temperate deciduous forest. These, and similar experiments, are needed to gain confidence in applying ecological response models (through model testing with experimental results), which form the basis of most assessments of effects of potential ecological responses to environmental changes associated with energy production and use.

Human Dimensions: The DOE human dimensions program will continue its support of fundamental research to develop and improve data, models, and methods for use by others to analyze and assess the economic, social, and environmental implications of climate change and of various potential policy options for mitigating or adapting to climate change. In FY 2003, research will emphasize improving integrated assessment models to include other greenhouse gases, as well as carbon dioxide and carbon sequestration. It will also include research to develop an integrated assessment model that can simulate the effects of climate on crop yields, the amount of crop and pasture land necessary to provide a sufficient diet in developing countries under climate change, and the likely increase in dietary requirements as developing countries become richer.

DOE will also continue support of its Global Change Education program, including support of undergraduate and graduate students through the DOE Summer Undergraduate Research Experience (SURE), the DOE Graduate Research Environmental Fellowships (GREF), and collaboration with NSF with the NSF Significant Opportunities in Atmospheric Research and Science (SOARS) program. Support will also be continued for the Carbon Dioxide Information and Analysis Center (CDIAC) to enable it to respond to data and information requests from users from all over the world who are concerned with the greenhouse effect and global climate change.

Related Research. DOE plays a major role in carbon sequestration research to reduce atmospheric concentrations of energy-related greenhouse gases, especially carbon dioxide, and their emissions to the atmosphere. The research builds on but is not part of the USGCRP. It focuses on both developing the scientific information needed to enhance the natural sequestration of excess CO₂ in terrestrial and ocean systems and assess the potential environmental consequences and ancillary benefits. It also includes research to develop biotechnological approaches for sequestering carbon either before or after it is emitted to the atmosphere. Research on carbon sequestration is also supported by DOE's Office of Fossil Energy. This research includes R&D on direct CO₂ capture and storage in geologic formations, sequestration of carbon in minerals, and technologies for monitoring and verification of carbon sequestration in terrestrial systems.

Mapping of Budget Request to Appropriations Legislation. In the Energy and Water Development Appropriations Bill, DOE's 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 activities is included as part of the appropriation for Biological and Environmental Research.

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DEPARTMENT OF HEALTH AND HUMAN SERVICES

HHS	Program Title	FY 2001 Actual	FY 2002 Estimate	FY 2003 Request
NIEHS	Human Health Effects of Exposure to UV Radiation and CFC Replacement Chemicals	8.7	9.7	10.6
NEI	Health Effects of UV Radiation	14.5	16.5	17.6
NCI	Health Effects of UV Radiation	30.8	34.0	39.1
NIAMS	Health Effects of UV Radiation	0.3	0.3	0.3
HHS Total		54.3	60.5	
President's Request				67.6

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



Areas of Global Change Research. Four National Institutes of Health institutes support research on the health effects of UV and near-UV radiation. 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 2003 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 the 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, and the variety of ways these organisms repair damage to DNA resulting from UV exposure.

The NEI supports studies on the impacts of UV radiation on the eye (retinal damage as well as corneal capacity). A major 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. This project is investigating the role of UVB radiation, which has been implicated as a specific risk factor in cataract development. Another important area of research is the understanding of certain 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.

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 (morphological effects that might precede skin cancer),

including photoaging, non-melanoma skin cancers, and melanoma caused by exposure to UV radiation. 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.

The NIAMS supports basic and clinical research on the effect of UVA and UVB radiation on skin.

Related Research. In addition to research areas designated as part of the USGCRP budget, HHS agencies conduct other research relevant to the overall USGCRP program. For example, NIH/NIEHS supports 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 include those that contribute to the greatly increased incidence of childhood asthma and that disrupt the normal functioning of the endocrine system. NIH initiated a program in 1995 to assess the impact of population change on the physical environment and to account for feedback from the physical environment on parameters of population change. Projects funded by the NIH National Institute of Child Health and Human Development (NICHD) and NIEHS have examined how population pressure impinges on the environment in the Florida Everglades, the U.S. Great Plains region, the rainforests of Brazil, a rural province of Nepal, the forests of India, and an agricultural area in Thailand. A new inter-disciplinary research program from NIH's Fogarty International Center, entitled Health, Environment and Economic Development, is designed to examine impacts on health of economically-driven environmental change, such as the human health effects of changes in agricultural land use, crop production, and water and land uses for productive purposes expected to derive from climate change in developing countries. The research may also address changes in vector ranges, include evaluations of different mitigation strategies to respond to climate change in developing countries, or explore sustainable livelihood strategies available to developing country populations in order to prevent outbreaks of disease conditions brought on by climate change.

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. One area of research, conducted both by NIH and the Centers for Disease Control and Prevention (CDC), is the use of remote sensing to study ecologic systems relevant to transmission of specific infectious diseases, especially vector-borne diseases. For example, in cooperation with NASA, NIH National Institute of Allergy and Infectious Diseases (NIAID) grantees have used remote sensing and geographic information system (RS/GIS) technologies to correlate specific ecologic conditions with outbreaks of infectious diseases. With remote sensing (RS), they have collected geographic and meteorologic data via satellite or aerial photography. These data are cross-referenced with ground-based observations using geographic information systems (GIS), complex computer programs that combine mapping and database functions. Scientists are using RS/GIS to try to predict future disease outbreaks and identify areas where disease prevention programs should be targeted. Examples of research by CDC using remote sensing and other geographic/spatial technologies include studies of hantavirus, plague, and Chagas disease. Sin Nombre virus, carried by the deer mouse, causes hantavirus pulmonary syndrome (HPS) in the Americas. Since 1994, CDC has collaborated with local academic institutions to study the effect of climatic variation, such as that associated with El Niño/Southern Oscillation, on changes in population densities of deer mice. The goal of the U.S.-based studies is to develop a model using satellite imagery to predict increases in risk of HPS at specific locations across the western United States. These studies have already helped CDC predict and post warnings of increased disease risk in the southwestern United States in 1998 and 1999. A CDC-sponsored study of plague in the four corners area of the U.S.

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Southwest also employs remote sensing technology to develop a predictive model for increased plague transmission in the area. Finally, CDC is applying GIS and ecological niche analysis using GARP (Genetic Algorithm for Rule Set Prediction), a form of spatial/temporal analysis, to study the eco-epidemiology of Chagas disease in Guatemala, Mexico, Brazil, and Argentina, and to improve collaborative efforts aimed at disease surveillance and control in these regions.

Both CDC and NIH sponsor broader research related to climate change and infectious diseases. CDC's Division of Vector-Borne Infectious Diseases is currently collaborating on studies to outline adaptation measures for vector-borne infectious diseases that may be affected by climate change. Its Guatemala field station is studying the impact that adverse climatological events, such as El Niño and Hurricane Gilbert, have had on the transmission dynamics of malaria and other diseases. These catastrophic events create tremendous changes that can simultaneously create new vector habit, reduce the levels of sanitation, and overwhelm the ability of the public health system to respond. Other CDC units are collaborating on studies of the effects of climate change on dengue on the US-Mexico Border. In 2003, CDC will co-sponsor an International Meeting on Climate Change and Infectious Diseases to be held in Rio de Janeiro, Brazil. Multiple NIH components support the "Ecology of Infectious Diseases" program, designed to assess the impact of anthropogenic environmental changes on the transmission of infectious agents. For example, the NIAID awards under this program address malaria vectors in Belize, enzootic arbovirus transmission in Peru, and encephalitis transmission vectors in the southeastern United States. Also, NIAID's long-running International Collaborations in Infectious Diseases Research Program (ICIDR) launched an Opportunity Pool in the fall of 1999 to support emerging research opportunities due to unexpected disease outbreaks or scientific advances. Relevant research through this program includes investigation of the hantavirus outbreak in Panama and an investigation into the dengue outbreak in Bangladesh. In FY 2002, NIAID funded a research initiative entitled "U.S.-Based Collaboration in Emerging Viral Disease Research," which will establish multi-disciplinary research units to develop and evaluate the scientific information and tools needed to control emerging viral diseases. These research units will analyze new, environmentally sound vector-control tools and strategies needed to intervene in the emergence and spread of arthropod-borne infectious diseases.

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 / U.S. GEOLOGICAL SURVEY

DOI	Program Title	FY 2001	FY 2002	FY 2003 Request
USGS	Global Change Research	26.7	28.0	28.0
DOI/USGS Total		26.7	28.0	
President's Request				28.0

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. Studies seek to understand the character of past and present environments and the geological, biological, hydrological, and geochemical processes involved in environmental change.



The USGS supports a broad area of global change research, with a focus 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 the response of biogeographic regions and features, particularly montane, coastal, and inland wetland ecosystems.

FY 2003 Program Highlights.

Climate Variability and Change. USGS 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. Emphasis is on the Holocene (last 10,000 years). Historical perspectives of past changes in landscapes and ecosystems and their relation to human activities are developed. Reconstruction of land-use histories, records of fire frequency, changing climate, and shifts in plant communities give a unique perspective on current environmental trends and help to distinguish the human imprint on ecosystems and landscapes. Research in hydroclimatology monitors trends in the accumulation and dissipation of snow and ice stored in selected U.S. benchmark glaciers; investigates the relations between climatic conditions and regional hydrologic variability, including long-term patterns and trends in hydrologic extremes; and develops improved procedures for simulating hydrologic processes and conditions in global climate models.

The Global Carbon Cycle. USGS conducts a broad range of carbon cycle research focused on North America, principally in four topical areas: biogeochemical cycling in lakes, streams and wetlands; carbon cycling and sequestration in soils and sediments; land cover trends; and climate-vegetation change history and modeling, all with a focus on public lands managed by DOI. Biogeochemical cycling research is developing an understanding of the interactive influence of climate and ecosystems on car-

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bon cycling by understanding 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 carbon fluxes.

Understanding of the role of land-use change and associated erosion and sedimentation processes on carbon storage in soil and sediments is key to determining human influences on carbon cycling.

Research in Alaska is developing an understanding of boreal soil carbon dynamics and the historic and modern interactions among climate, surface temperature and moisture, fire, and carbon sequestration. Land cover trends research is developing an understanding of rates, patterns, and impacts of landscape changes in North America and their consequences for carbon stocks. Vegetation change research is developing a detailed history of vegetation change and models of possible future changes in North America to better understand future carbon stocks.

Changes in Ecosystems. USGS ecosystems research focuses on impacts on terrestrial and coastal ecosystems and fish and wildlife by determining the exposure, sensitivity, and adaptive capacity of natural systems and ecological processes to multiple environmental factors, including climate and other natural and anthropogenic influences at the local, landscape, regional, and continental scale. Research provides the scientific knowledge and technologies for conservation, rehabilitation, and management of ecosystems needed by public land management agencies. Land surface characterization includes research and development of techniques to monitor, analyze, describe, and predict land use, land cover, and other surface characteristics data. These data sets are used to characterize and map the Earth's surface, model land surface processes, detect changes over time, project the response of the land surface to changes in climate and other environmental influences, and investigate the impact of land-cover changes on the environment. Research to understand the causes and consequences of land-cover change is also conducted, in part, to improve model development and application.

Satellite Data Management and Dissemination. The USGS also operates and continually enhances the capabilities of the EROS Data Center to serve as the National Satellite Land Remote Sensing Data Archive, by maintaining existing datasets, adding new ones, and converting older data sets from deteriorating media to modern, stable media. This archive supports all research components that investigate the land surface and the ecosystems it supports.

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	FY 2001	FY 2002	FY 2003 Request
ORD	Assessment of Consequences of Climate Variability and Change	20.0	20.0	20.0
ORD	Changes in Ecosystems	3.0	2.0	2.0
EPA Total		23.0	22.0	
President's Request				22.0

ORD Office of Research and Development

Areas of Global Change Research. EPA's Global Change Research Program is an 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. This entails: (1) improving the scientific basis for evaluating effects of global change in the context of other stressors and human dimensions (as humans are catalysts of and respond to global change); (2) conducting assessments of the risks and opportunities presented by global change; and (3) assessing adaptation options to increase resiliency to change and improve society's ability to effectively respond to the risks and opportunities presented by global change.



EPA's program emphasizes the integration of the concepts, methods, and results of the physical, biological, and social sciences into decision support frameworks. Consistent with the Administration's objectives, assessments are conducted that provide useful and credible scientific information to decisionmakers in a timely manner. This includes the development of decision-support resources (e.g., interactive, web-based tools) for resource managers and decision makers. Also, as called for by the National Research Council (2001), EPA supports and fosters assessment processes that link knowledge producers and users in a dialogue that builds a mutual understanding of what is needed, what can credibly be said, and how it can be said in a way that maintains both scientific credibility and political legitimacy.

The EPA program contributes to several USGCRP research elements, including the Global Water Cycle, Land Use and Land Cover Change, and Ecosystems elements. The EPA program also supports research on USGCRP enabling and integrating activities, including the Human Contributions and Responses to Global Environmental Change and Regional Research and Interactions.

FY 2003 Program Highlights. EPA will continue to make significant contributions to the ongoing assessment activities of the USGCRP. The EPA-sponsored assessments will continue to be conducted through public-private partnerships that actively engage researchers from the academic community, decisionmakers, resource managers, and other affected stakeholders in the assessment process.

EPA's intramural assessment program has four areas of emphasis: (1) human health; (2) air quality; (3) water quality; and (4) ecosystem health. These four focus areas are consistent with EPA's mission and the strengths of EPA's research program.

The first of the four focus areas is Human Health. Because health is affected by a variety of social, economic, political, environmental, and technological factors, assessing the health impacts of global change

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is a complex challenge. As a result, health assessments in EPA's Global Program go beyond basic epidemiological research to develop integrated health assessment frameworks that consider the effects of multiple stresses, their interactions, and human adaptive responses. There are research and assessment activities focused on the consequences of global change on weather-related morbidity and vector- and water-borne diseases. In addition, the results from the Global Program's air quality assessments will be used to evaluate health consequences. In FY 2003, EPA will continue to develop and apply methods for evaluating the effects of climate change and climate variability on weather-related morbidity. In FY 2003, EPA will produce two assessments. The first will examine the effects of heat and cold morbidity in vulnerable populations (*e.g.*, children, elderly). The second will examine the effects of extreme heat on emergency department and hospital admissions.

The second focus area is Ecosystems. EPA's mission is not only to protect human health but also to safeguard the natural environment. EPA has pledged to provide environmental protection that "contributes to making communities and ecosystems diverse, sustainable, and economically productive." Consistent with this goal, EPA's Global Program has planned three research and assessment activities that evaluate the effects of global change on 1) aquatic ecosystems (which includes watersheds and coastal ecosystems); 2) invasive non-indigenous species; and 3) ecosystem services. In FY 2003, EPA will produce a report summarizing the problem formulation phase of an assessment of the consequences of global change on watersheds and coastal aquatic ecosystems at the regional level.

EPA's assessments of the effects of global change on aquatic ecosystems will use as input the research being done by other USGCRP agencies on marine and terrestrial ecosystems. Therefore, EPA's ability to successfully complete its assessments depends crucially upon the ability of other USGCRP agencies to complete their related research and assessment activities.

The third focus area is Air Quality. Few studies have investigated the effect of global change on air quality. Given EPA's legal mandates with respect to air pollution, substantial capability and expertise in modeling air quality, and evaluating integrated response actions, examining the effects of global change on air quality is a logical focus of the Global Program. Assessments are planned that will examine the potential consequences of global change on tropospheric ozone and particulate matter. Each of these assessments is paired with a related Human Health assessment. In FY 2003, EPA will produce a report summarizing the results of an effort to downscale meteorological data to regional scales for use in the EPA air quality assessments. Also, EPA will investigate and report on alternative fuels and vehicle technology scenarios to determine their influences on emission rates, including the time profile for the market penetration of these technologies.

The fourth focus area is Water Quality. Water quality is affected by changes in runoff following changes in precipitation and evapotranspiration and/or changes in land use. The program plans assessments of the possible impacts of global change (climate and land use change) on water quality. The water quality assessments will either contribute to or benefit from Human Health and Ecosystems assessments. In FY 2003, EPA will produce two assessments of the effects of global change on water quality. The first will examine the impacts on pollutants and pathogens in surface waters. The second will examine the impacts on wastewater treatment.

Intramural and extramural research contribute to all of EPA's assessments. In an attempt to capitalize on expertise in the academic community, a significant portion of the program's resources are dedicated to extramural research grants administered through the STAR (Science to Achieve Results) grants program. The STAR program focuses on two principal areas related to global change research — science to support assessments of consequences of global change, and human dimensions research. EPA will

continue to coordinate closely with other USGCRP agencies doing human dimensions research to identify the specific topics that should be emphasized within the STAR program. This work supports the USGCRP's "human dimensions" enabling and integrating activity.

Related Research. In addition to the focused USGCRP activities, EPA conducts research that contributes to the characterization and understanding of risks to ecosystems and to human health. The ecosystem-based research is designed to understand and predict ecosystem exposure, responses, and vulnerabilities to high-risk chemicals and non-chemical stressors (*e.g.*, invasive species, genetically altered organisms) at multiple scales of biological organization and geographic scales. The research in human health is oriented toward assessing the cumulative health risks to humans (*e.g.*, cancer, reproductive, cardiovascular), including high-risk subpopulations (*e.g.*, children), from chemical stressors emanating from multiple sources. Both of these major research areas will be impacted by and are inextricably interrelated with climate change.

Mapping of Budget Request to Appropriations Legislation. In the Departments of Veterans Affairs and Housing and Urban Development, and Independent Agencies Appropriations Bill, EPA USGCRP activities are funded under the EPA section of Title III – Independent Agencies, within the Science and Technology account. Appropriations Committee report language may specify more directly the funding for global change research.

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA Program Title	FY 2001	FY 2002	FY 2003 Request
NASA Global Change Science Program			
Carbon Cycle	45.5	42.0	39.9
Ecosystems	36.0	33.0	29.3
Water Cycle	56.2	51.5	48.9
Climate Variability	63.1	64.9	64.5
Atmospheric Chemistry	55.8	51.5	53.7
Land Cover/Land Use	—	—	8.4
Global Change Science Program Total	256.6	242.9	244.7
NASA Global Change Observation Program			
Carbon Cycle	113.3	114.9	145.9
Ecosystems	84.4	92.5	90.7
Water Cycle	248.9	236.4	238.4
Climate Variability	237.3	211.8	197.9
Atmospheric Chemistry	235.6	191.4	164.2
Land Cover/land Use			27.0
Global Change Observation Program Total	919.5	847.0	864.1
NASA Global Change Research Program			
Carbon Cycle	158.8	156.9	185.8
Ecosystems	120.4	125.5	120.0
Water Cycle	305.1	287.9	287.3
Climate Variability	300.4	276.7	262.4
Atmospheric Chemistry	291.4	242.9	217.9
Land Cover/Land Use			35.4
Global Change Research Program Total	1176.1	1089.9	1108.8



Areas of Global Change Research. The mission of NASA's Earth Science Enterprise (ESE) is to develop a scientific understanding of the Earth system and its response to natural and human-induced changes to enable improved prediction of climate, weather, and natural hazards for present and future generations. NASA provides the research and technology used by Federal, state, and local agencies that provide these predictive services to the Nation. NASA has mapped out a new Research Strategy for the next decade to address the questions:

How is the Earth changing, and what are the consequences for life on Earth?

- How is the global Earth system changing?
- What are the primary causes of change in the Earth system?
- How does the Earth system respond to natural and human-induced changes?
- What are the consequences of change in the Earth system for human civilization?
- How well can we predict future changes in the Earth system?

The five component questions follow a logical scientific progression of variability, forcings, responses, consequences, to prediction. Under each of the five is a set of detailed questions, 23 in all, that reflect thematic research areas that are well-aligned with the USGCRP program elements, as described below. While in the past, NASA's Earth science programs were observation-driven, the Research Strategy is question-driven, and NASA is rebalancing its investment portfolio across observations, research, analysis & modeling, applications demonstration, and advanced technology development in order to answer the selected science questions. NASA will address the USGCRP research program elements, including Climate Variability and Change, the Global Water Cycle, and the Global Carbon Cycle, in terms of the above questions.

Recent Accomplishments: Major scientific accomplishments of NASA's Earth Science Enterprise during the past two years include:

- Demonstrating a lengthening of the growing season in much of the mid-latitude Northern Hemisphere;
- Describing how climate change might facilitate the springtime depletion of ozone in the Arctic (in spite of expected reductions in stratospheric chlorine);
- Incorporating ocean surface wind measurements from the QuikScat scatterometer into operational weather forecasts, in collaboration with partners in the National Oceanic and Atmospheric Administration (NOAA) and the European Center for Medium-Range Weather Forecasting (ECMWF);
- Providing a near factor-of-10 enhancement in the throughput of a critical data assimilation system through advances in software engineering and use of new computational hardware;
- Initiating the construction of an Earth System Modeling Framework connecting the climate modeling efforts of NASA, other government agencies, and universities to provide improved opportunities for collaboration and exchange of modules between modeling groups;
- Successfully operating a new, next-generation land remote sensing satellite (EO-1), including both a smaller and less expensive multi-spectral sensor and the first-ever space-based hyperspectral sensor;
- Successfully launching Jason, SAGE III, and GRACE payloads in collaboration with our foreign partners;
- Conducting several major national and international scientific field campaigns (TRACE-P, CAMEX-4, Cold Land Processes Experiment), including the first NASA field campaign that incorporated the use of Uninhabited Aerial Vehicles (UAVs) into the mission plan.

FY 2003 Program Highlights. Through the end of FY 2003, ESE plans to launch ICESat, SORCE and SeaWinds (on Japan's ADEOS-2 satellite). In addition, NASA will continue implementation of its Research Strategy, consonant with the USGCRP Strategic Plan. The following describe examples of expected progress:

How is the global Earth system changing?

- Convert remotely sensed observations of Greenland ice sheet surface melting to estimates of ice mass loss, in order to quantify how much ice is lost to melting, and the variability from year to year.
- Provide continuity of calibrated data sets from ground-based, suborbital, and space-based instruments for determining long-term trends in the total column and profile abundances of stratospheric ozone with sufficient precision to enable the later assessment of expected ozone recovery.

What are the primary causes of change in the Earth system?

- Combine multiple instrument data sets on the total solar irradiance over 2 solar cycles and solar ultraviolet

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flux over one cycle in order to explore correlations between solar variation and climate without resorting to solar proxies.

- Reduce uncertainty in the retrievals of upper tropospheric and lower stratospheric water vapor abundances by 10-30% through improved laboratory spectroscopic measurements of the water vapor continuum.

How does the Earth system respond to natural and human-induced changes?

- Use near decade-long sea surface topography and *in situ* upper-ocean temperature profile measurement time series to develop a high resolution Pacific Ocean model to elucidate the mechanisms of the Pacific Decadal Oscillation and its impact on seasonal/decadal climate variations.
- Characterize the atmospheric plume from East Asia and assess its contribution to regional and global atmospheric chemical composition by completing the archival of the Transport of Chemical Evolution over the Pacific (TRACE-P) airborne mission and associated data sets, which will improve the assessment of intercontinental transport of pollution.

How well can we predict future changes in the Earth system?

- Analyze the measured trends in atmospheric trace gas concentrations using updated data sets and compare the results with those estimated from industrial production and emission data. The analysis will be used to assess the completeness of our understanding of the atmospheric persistence and degradation of industrial chemicals as well as to examine the efficiency of current regulatory agreements and international reporting on the production and emissions of regulated chemicals.

Space and Suborbital Observations and Information: NASA remains the principal supplier of global- to regional-scale observations for global change research, both through research satellites and the operational weather satellites built and launched by NASA for NOAA. Deployment of the Earth Observing System (EOS) is well underway, with Landsat-7, QuikSCAT, Terra, Aqua, and ACRIMSAT already in orbit and providing science data. The Jason mission and the SAGE III instrument were both launched early in FY 2002 and will provide important data on ocean surface topography and atmospheric ozone and aerosol distributions, respectively. Satellite data are compared with data from a variety of aircraft and balloon-borne instruments for both remote sensing and *in situ* measurements. Major scientific field campaigns using these suborbital platforms are designed to investigate long-range transport of gaseous and aerosol pollutants and their precursors, hurricane formation, and the impacts of snow cover on regional hydrology.

Terra, Aqua (May 2002 launch) and Aura (2004 scheduled launch) are the larger, multi-instrument EOS missions. They will be accompanied by a series of smaller missions, such as the Ice, Cloud, and Land Elevation Satellite (ICESat) and the Solar Radiation and Climate Experiment satellite (SORCE). ICESat is the benchmark EOS mission for the measuring of ice sheet mass balance, cloud and aerosol heights and optical densities, height of vegetation, and land topography. ICESat has a scheduled launch date of December 2002 and will carry a single instrument. SORCE will carry four instruments to measure solar radiation incident at the top of the Earth's atmosphere. These measurements are expected to be of critical importance to studies of the Sun, its effect on the Earth system, and its influence on humankind. Data obtained by SORCE will be used to model the Sun's output and to explain and predict the effect of solar radiation on the Earth's atmosphere and climate.

Complementing EOS's long-term monitoring for the study of variability and trends is a series of small, focused Earth Explorer missions to study forcings and responses in the Earth system. The first of these missions, provided through the Earth System Science Pathfinder (ESSP) program, is the Gravity Recovery and Climate Experiment (GRACE), launched in March 2002. The ultimate objective of GRACE is to improve current knowledge of the temporal and spatial variability of the gravity field by up to 1,000 times. The

GRACE data set will be used in conjunction with data from other missions to resolve the temporal and spatial variability in planetary and regional distribution of water resources, the forces driving sea-level rise, including ocean warming and glacial mass balance, and the forces driving post-glacial rebound, crustal deformation, and volcanism. Two future spacecraft under the ESSP program will be used to study the three-dimensional distributions of aerosols (CALIPSO) and clouds (CloudSat). CALIPSO will fly in formation with Aqua to provide a global set of data on aerosol and cloud properties, radiative fluxes, and atmospheric state. These measurements are designed to enable new evaluations of the radiative effects of aerosols and clouds that are expected to greatly improve the ability to project future climate change. CloudSat is a satellite experiment designed to measure the vertical structure of clouds from space. The spacecraft is designed to produce detailed, three-dimensional images of cloud structures, which are expected to contribute to better predictions of clouds.

In July, 2002, NASA selected two additional new ESSP space mission proposals that are designed to yield fresh insight into the global carbon cycle and into how the oceans affect and respond to climate change. The Orbiting Carbon Observatory (OCO), a mission that will include more than 19 universities and corporate and international partners, will provide global measurements of atmospheric carbon dioxide needed to describe the geographic distribution and variability of CO₂ sources and sinks. These measurements are expected to enable knowledge needed to improve projections of future CO₂ levels in the Earth's atmosphere. Aquarius, a mission that will involve more than 17 universities and corporate and international partners, will provide the first-ever global maps of salt concentration on the ocean surface. This is a key area of scientific uncertainty in the oceans' capacity to store and transport heat, which in turn affects the Earth's climate and water cycle. In addition to the two selected new missions, a third proposal, called HYDROS, has been selected to serve as an alternate, should the primary missions encounter difficulties during their initial development. The HYDROS mission concept calls for a spacecraft that would monitor soil moisture from space — a measurement that would be expected to improve current models used for weather and climate predictions.

EOSDIS collects, processes and distributes Earth science data to a large, diverse customer base. In FY 2001, EOSDIS and NASA's Earth Science Information Partners supported over 2.3 million customers (based on unique accesses) and distributed over 15 million data and information products. By the end of FY 2001, EOSDIS had set a new benchmark for data management when the total volume of the science data in its archives totaled over 1 Petabyte. In FY 2002, EOSDIS provided support for challenging, high data volumes from Terra and Landsat-7, and continues to support QUIKScat, ACRIMSat, SAGE-III and pre-EOS-era data, including those collected by TRMM, UARS, TOPEX/Poseidon, RADARSAT and other missions. NASA continues to plan for and prototype the evolution of data and information system services to support Earth science over the next decade.

Related Research: Outside the scope of the USGCRP, NASA's Earth Science Enterprise also conducts research and observing missions to study the solid Earth and related natural hazards. ESE also manages an applications demonstration program in partnership with other Federal agencies, State and local governments, academia, and industry to test new uses of remote-sensing data to solve practical societal problems in food and fiber production, infrastructure planning, flood hazard assessment, and other areas.

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.

Appendix A

NATIONAL SCIENCE FOUNDATION

Program Title	FY 2001	FY 2002	FY 2003 Request
Antarctic Ecosystems	1.00	1.00	1.00
Arctic System Science (ARCSS)	9.50	8.80	8.00
Carbon Cycling	8.95	17.86	22.20
Climate Modeling, Analysis & Prediction (CMAP)	14.13	14.22	16.19
Climate Variability and Predictability (CLIVAR)	20.52	21.57	25.03
Coastal Long-Term/Land Margin Ecological Research (LTER/LMER)	3.15	3.15	3.15
Earth System History (ESH)	17.53	17.54	17.54
Ecological Diversity	6.65	6.65	6.91
Ecological Rates of Change (EROC)	3.15	3.15	3.15
GEODATA	2.96	3.97	0.00
Global Ocean Ecosystems Dynamics (GLOBEC)	16.13	16.18	16.18
Global Tropospheric Chemistry Program (GTCP)	15.11	15.22	15.22
Greenhouse Gas Dynamics (GCD)	0.20	0.20	0.00
Human Dimensions of Global Change (HDGC)	13.65	13.65	15.20
Joint Global Ocean Flux Study (JGOFS)	6.54	5.04	2.50
Methods and Models for Integrated Assessment (MMIA)	2.82	2.53	0.00
Ocean Observations, Data Assimilation, & Modeling (OODAM)	6.67	7.77	7.77
Polar Ozone Depletion/UV Radiation Effects	1.50	1.50	1.50
Regional Research Institutes	3.60	3.60	3.60
Ridge Interdisciplinary Global Experiments (RIDGE)	1.33	0.03	0.00
Sea-Level Changes	3.00	0.00	0.00
Solar Influences	7.74	7.78	8.44
Water and Energy: Atmospheric, Vegetative & Earth Interactions (WEAVE)	9.71	9.72	5.39
Water Cycle	0.60	3.00	7.33
World Ocean Circulation Experiment (WOCE)	5.17	4.17	2.00
NSF Total	181.31	188.30	
President's Request			188.30



Areas of Global Change Research. NSF programs address global change issues through investments in challenging ideas, creative people, and effective tools. In particular, NSF global change research programs support research and related activities to advance the fundamental understanding of physical, chemical, biological, and human systems and the interactions among them. The programs encourage interdisciplinary activities and focus particularly on Earth system processes and the consequences of change. NSF programs facilitate data acquisition and information management activities necessary for fundamental research on global change, and promote the enhancement of models designed to improve understanding of Earth system processes and interactions and to develop advanced analytic methods to facilitate basic research. NSF also supports fundamental research on the general

processes used by organizations to identify and evaluate policies for mitigation, adaptation, and other responses to the challenge of varying environmental conditions.

FY 2003 Program Highlights. During FY2003, NSF will support research and related activities addressing all six of the USGCRP program elements and the interdisciplinary science aspects that link them. NSF will continue to invest in collaborative international programs such as the World Climate Research Programme, the International Geosphere-Biosphere Programme, and the International Human Dimensions Programme.

A major focus on atmospheric composition and chemistry will continue through programs in tropospheric chemistry. Studies of atmospheric transport of aerosols will continue to provide insights into how aerosols affect the radiative and cloud nucleating properties of the atmosphere, and ultimately the climate.

In concert with its agency partners, NSF will continue its emphasis on climate variability and change. This is a major activity for the Agency and consists of support for observational campaigns and numerous analytical and modeling activities, as well as paleoclimate studies. A number of ocean and atmospheric science projects will address topics identified in the CLIVAR implementation plans. Ocean science studies will address changes in ocean structure, ocean circulation and ocean-atmosphere coupling to improve the present understanding of the role of the ocean in climate, and will lead to the development of better climate models. In addition, improved coupled atmosphere/ocean models will incorporate land-surface processes and biogeochemistry. Continued support of the Community Climate System Model will provide opportunities for U.S. climate scientists to understand better the climate and its variability.

NSF is increasing its support for studies of the carbon cycle. In FY 2003 NSF will begin implementation of a globally integrated carbon cycle research effort to encourage cooperative research among atmospheric, marine, geological, and ecological scientists to understand the key processes underlying carbon cycling. As an element of the effort, ocean sciences will support the JGOFS Synthesis and Modeling Project and the Southern Ocean Iron (Fe) Experiment, a complex mesoscale fertilization experiment, and continue several CO₂ observational time-series activities (Hawaii and Bermuda ocean stations, and atmospheric CO₂ and O₂ observational programs).

Water pervades nearly all environmental issues and clearly requires a comprehensive approach. NSF is one of the several agencies supporting global water cycle research and will focus on key aspects with its available resources. NSF programs will emphasize the development of hydrologic and atmospheric models to simulate the water cycle and to understand the processes that control it.

Several programs will address aspects of land-use and land-cover change as important aspects of global change. Ecological rates of change and related species diversity, Arctic systems and their temporal variability, water and energy influences on vegetative systems, and diverse human influences exemplify program components related to land use and land cover.

Several NSF programs will focus on terrestrial and marine ecosystems through observational and laboratory studies. NSF will continue to support the collection of terrestrial and marine ecosystem data through its Long-Term Ecological Research programs. In addition, studies will continue in terrestrial ecosystem functions and landscape ecology. The Global Ocean Ecosystem Dynamics program will continue to study the impact of the global ocean environment on marine ecosystems. In FY 2003 field research will continue to focus on the Northwest Pacific and Southern Ocean, and work on the Northwest Atlantic will concentrate on synthesis and modeling activities.

Appendix A

Related Research. NSF will continue to support research on broader topics that are closely related to global change. These include, *inter alia*, studies of the atmosphere, ocean, land surface, ecosystems, and human dimensions that add substantively to the specific programs supporting USGCRP objectives. Thus, much NSF research support may be considered “contributing research.”

In addition, projects that integrate research with education on global climate change are being supported to demonstrate that scientific visualization, incorporated into inquiry-based learning, can enable students to develop an understanding of complex global change phenomena. Students address these issues by evaluating multimedia data at various spatial and temporal resolutions, reviewing scientific evidence, and considering social concerns that contribute to the global change debate.

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

SMITHSONIAN INSTITUTION

SI	Program Title	FY 2001	FY 2002	FY 2003 Request
NMNH/STRI	Long-Term Environmental Change	1.6	1.6	1.6
NASM/SERC	Monitoring Natural Environmental Change	1.2	1.2	1.2
NZP/NMNH/ SERC/STRI	Biological Responses	4.2	4.2	4.2
Smithsonian Institution 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, global change research is conducted at the Smithsonian Astrophysical Observatory, the National Air and Space Museum, the Smithsonian Environmental Research Center, National Museum of Natural History, Smithsonian Tropical Research Institute and National Zoological Park. Research is organized around themes of atmospheric processes, ecosystem dynamics, observing natural and anthropogenic environmental change on daily to decadal time scales, and defining longer-term climate proxies present in the historical artifacts and records of the museums as well as in the geologic record at field sites. The Smithsonian Institution program strives 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 conducting to observations on sufficiently long (*e.g.* decadal) timescales to resolve human-caused modification of natural variability.

FY 2003 Program Highlights.

Climate Variability and Change: 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.

Atmospheric Composition: At SERC, measurements will be made of spectral UV-B in Maryland (>25 year record), Florida, Arizona, and other sites in the U.S. These data will be electronically disseminated to meet the needs for assessing the biological and chemical impact of varying UV exposure.

Terrestrial and Marine Ecosystems: Several Smithsonian programs will examine biological responses to global change. At SERC, research will be conducted on the responses of global ecosystems to increasing CO₂ (also a contribution to the Global Carbon Cycle program), exotic species introduc-

Appendix A

tions, and solar UV. Biodiversity education and research 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.

Human Dimensions of Global Change: The general public and research community will be informed of global change research conducted by Smithsonian and other USGCRP agencies via exhibits, such as the planned “Forces of Change: Global Links” display at NMNH, educational programs, and a global change information web page.

Related Research. Much of the global change research performed at Smithsonian is not supported by direct Federal appropriation (i.e. USGCRP crosscut) and instead is supported by other public and private sources (including other USGCRP agencies). These projects are nonetheless organized around the USGCRP program elements and thus amplify the scope and impact of research supported directly by the USGCRP. These include programs at SAO studying stratospheric trace species that play an important role in ozone photochemical cycles as well as studies of solar activity and irradiance. SERC and STRI receive agency support via competitive grants programs to perform studies of the ecosystem responses to increased CO₂, UV-B and invasive species. Other contributing activities include 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 researchers around the world, 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 Smithsonian 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 B

ADDITIONAL INFORMATION ON FIGURES

Atmospheric Composition

2.1 Spring dust storm smothers Beijing

In March 2002, a few days earlier than usual, a large, dense plume of dust blew southward and eastward from the desert plains of Mongolia — seriously affecting air quality for the residents of Beijing and surrounding areas. Citizens of northeastern China call this annual event the “shachenbao,” or “dust cloud tempest.” The dust storm hit Beijing on March 15 and began coating everything with a fine, pale brown layer of grit. The region is quite dry, a problem some believe has been exacerbated by decades of deforestation. According to Chinese government estimates, roughly one million tons of desert dust and sand blow into Beijing each year.

This true-color image was made using data from the Sea-viewing Wide Field-of-view Sensor (SeaWiFS), flying aboard the OrbView-2 satellite, on March 17, 2002. The massive dust storm (brownish pixels) can easily be distinguished from clouds (bright white pixels) as it blows across northern Japan and eastward toward the open Pacific ocean.

Reducing uncertainty about the role of atmospheric aerosol particles in the Earth’s climate system is one of the highest priorities of research on atmospheric composition. The Aerosol Characterization Experiment-Asia (ACE-Asia) program is making substantial progress toward its goal of characterizing the aerosol particles leaving Asia and moving out over the the North Pacific Ocean. Several large dust storms, as well as pollution plumes and regional dust layers, were studied during an intensive field campaign in spring, 2001, in which NSF, DOD, and NOAA collaborated.

[Credit: NASA Goddard Space Flight Center, SeaWiFS Project; and ORBIMAGE]

2.2 Air pollution plume from Southeast Asia moving over the Pacific Ocean and Reaching North America (March 2000).

Concentrations of carbon monoxide at 15,000 feet: (a) March 10, 2000; (b) March 12, 2000; (c) March 13, 2000; (d) March 15, 2000. Measurements were taken by the Measurements of Pollution in the Troposphere (MOPITT) instrument, onboard the Terra satellite. MOPITT is now operating well in orbit, and global maps of carbon monoxide (CO), an important tropospheric pollutant, are being produced.

[Credit: NASA Goddard Space Flight Center, Scientific Visualization Studio]

Climate Variability and Change

3.1 1997-98 El Niño event, water temperature and sea-surface topography in the equatorial Pacific Ocean – (a) January 1997; (b) June 1997; (c) November 1997; (d) March 1998

The images show a combined perspective of the El Niño-induced change in sea temperature below the surface as measured by NOAA’s Tropical Atmosphere/Ocean (TAO) moorings, the sea-surface topography as viewed from space by the NASA Ocean Topography Experiment (TOPEX) radar altimetry satellite, and sea-surface temperature observed by NOAA’s Advanced Very High-Resolution Radiometer (AVHRR) sensor, for the period from January 1997 to March 1998.

The sea temperature below the surface as measured by NOAA’s TAO moorings illustrates how the thermocline (the boundary between warm and cold sea water at 20° C) is flattened out by El Niño. The three-dimensional relief map shows a sea-level rise along the Equator in the eastern Pacific Ocean of up to 34 centimeters, with the red colors indicating an associated change in sea-surface temperature of up to 5.4° C. Also shown is a combined perspective of the the weakening of the trade winds across the Pacific Ocean and the associated increase in sea-surface temperature. The convergence of the surface wind field into the anomalous warm water regions indicates a continued strengthening of this El Niño event.

[Credit: NASA Goddard Space Flight Center, Scientific Visualization Studio; NOAA Pacific Marine Environmental Laboratory]

Appendix B

3.2` Changes in cold season extreme precipitation (left) and mean annual snowpack (right) based on ensemble regional climate simulations of current and mid-21st century climate conditions

This figure shows the difference between three future (2040-2060) regional climate simulations based on the Penn State/National Center for Atmospheric Research (NCAR) Mesoscale Model (MM5) and a control simulation with concentrations of greenhouse gases kept constant at the 1995 level. Results show that, by the mid-21st century, the projected average regional warming of 1-2.5°C would strongly affect snowpack in the western U.S. Along coastal mountains, reduction in annual snowpack is above 50 percent. Snowpack increases slightly over the Northern Rockies, because precipitation is found to increase while temperature remains mostly below freezing, even under these simulated future climate conditions. In addition to changes in mean temperature, precipitation, and snowpack, cold season extreme precipitation is projected to increase by 5-15 mm/day (15-20 percent) along the Cascades and Sierra Nevada ranges. Changes in snowpack and extreme precipitation suggest higher likelihood of wintertime flooding and reduced water supply in the summer. Such changes could have significant impacts on water resources in the western U.S. A pilot project is currently investigating the the potential for adapting to these changes by using alternative water management strategies in the Columbia River and Sacramento-San Joaquin Basins.

The Accelerated Climate Prediction Initiative (ACPI) was funded by DOE to develop the scientific and computational infrastructures needed to carry through a full assessment of the possible effects of human-induced climate change. This information forms the scientific basis for showing how climate change might affect the U.S. and for developing strategies for adapting to such change. As part of the ACPI, this ensemble of global climate simulations was produced by NCAR, using the NCAR/DOE Parallel Climate Model (PCM). The simulations were initialized at 1995 using observed ocean conditions. Four independent simulations were obtained. Three were transient simulations of future climate conditions (1995-2100), driven by increasing greenhouse gas concentrations that followed the IPCC “business as usual” scenario. These simulations were compared to a control simulation. Two regional climate models were used to downscale the PCM control and future climate simulations. These down-scaled results were then used to drive various process models to study mid-century effects of climate change on water resources in the western United States.

Uncertainty in the projected climate changes was investigated using the ensemble simulation approach with the global and regional climate models, which accounts for the effects of climate variability. However, the effects of model biases and uncertainty related to the relationship of projected greenhouse gas concentrations to the projected future climate conditions were not evaluated in the ACPI pilot study. As pointed out in the IPCC Third Assessment Report, large uncertainties still exist in projecting future climate, more so for precipitation than temperature, based on different climate models. Future studies need to adopt multiple models and emission scenarios to estimate uncertainty in the projected future climate, and evaluate the effects of model biases, error propagation, and scaling in climate impact assessment.

[Credit: L. Ruby Leung, Pacific Northwest National Laboratory. More information on the ACPI pilot study is available at <http://www.pnl.gov/ccpp/acpi.htm>.]

3.3 Modeling the climate system

Models are an essential tool for synthesizing observations, theory, and experimental results to investigate how the Earth system works and how it is affected by human activities. Such models can be used in both a retrospective sense, to test the accuracy of modeled changes in Earth system forcing and response by comparing model results with observations of past change, and in a prognostic sense, for calculating the response of the Earth system to projected future forcing. Models provide the only objective, quantitative means to integrate scientific understanding of the many components of the climate system and, thus, are the only tools available for making rigorous quantitative projections. Comprehensive climate models represent the major components of the climate system (atmosphere, oceans, land surface, cryosphere, and biosphere) and the transfer of water, energy, organic chemicals, and mass among them, but are still in their formative stages.

[Credit: *National Assessment of the Potential Consequences of Climate Variability and Change for the United States — Overview Report.*]

3.4 The development of climate models: Past, present, and future

The figure illustrates the development of comprehensive climate models over the last 25 years, showing how different components are first developed separately and later coupled together.

[Credit: Intergovernmental panel on Climate Change, Third Assessment Report, Technical Summary of Working Group I Report, 2001]

Global Carbon Cycle

4.1 North American terrestrial carbon sink: Contribution of increasing CO₂ and changes in climate to carbon storage by ecosystems in the United States

Estimates from three biogeochemical models of net carbon storage for different bioclimatic regions of the United States, for the period 1980-1993. Histograms show results from the Biome-BioGeochemical Cycles (Biome-BGC) model, the Century model, and the Terrestrial Ecosystem Model (TEM), and the mean of the three results (with 95 percent confidence interval).

The effects of increasing carbon dioxide and changes in climate on net carbon storage in terrestrial ecosystems of the conterminous United States were modeled using new, detailed historical climate information from the NOAA Historical Climate Network database. For the period 1980-1993, results from an ensemble of three models agree within 25 percent, simulating a land carbon sink from CO₂ and climate effects of 0.08 gigaton (1 gigaton=1 billion tonnes) of carbon per year. The best estimates of the total sink from inventory data are about three times larger, suggesting that processes such as regrowth on abandoned agricultural land or in forests harvested before 1980 have effects as large as or larger than the direct effects of CO₂ and climate. The modeled sink varies by about 100 percent from year to year as a result of climate variability. Estimates from all three models were used for natural ecosystems; the Century model results were used for agricultural areas. These results were part of the Vegetation/Ecosystem Modeling and Analysis Project (VEMAP) aimed at understanding the contribution of ecosystem physiological mechanisms to terrestrial sinks in the conterminous United States.

[Schimel, et al., *Science*, 287 (5460): 2004 (March 17, 2000)]

4.2 Carbon dioxide measurements and experiments –(a) AmeriFlux tower; (b) Free Air CO₂ Enrichment (FACE); (c) Elevated CO₂ concentration experiment

AmeriFlux: The AmeriFlux network, established in 1996, includes more than 40 independently funded sites operating across North, Central, and South America. AmeriFlux sites include tundra, grassland, agricultural crops, tropical forests, and temperate coniferous and deciduous forests. AmeriFlux sites are an infrastructure for making long-term measurements CO₂, water, and energy exchanges from a variety of ecosystems. These data have provided a wealth of information on how diverse ecosystems respond to changes in their physical environment, and how they affect their environments in turn. Contributions to carbon cycle science include understanding variation in net carbon uptake with interannual variation in climate, and the influence of disturbance on carbon storage and fluxes.

Free Air CO₂ Enrichment (FACE): Reducing uncertainties in estimates of atmospheric CO₂ and carbon sequestration requires narrowing errors in estimates of present and future biosphere-atmosphere CO₂ gross fluxes. FACE facilities can tell us how increasing atmospheric CO₂ will change terrestrial ecosystem behavior. FACE provides a technology by which the microclimate around growing plants may be modified to simulate climate change conditions. Typically, CO₂-enriched air is released from a circle of vertical pipes into plots up to 30 m in diameter, and as tall as 20 m. FACE field data represent plant and ecosystem responses to concentrations of atmospheric CO₂ expected in the mid-21st century.

The Smithsonian Environmental Research Center (SERC) is conducting a series of innovative experiments that expose portions of salt marsh and forest ecosystems to elevated CO₂ concentrations in outdoor chambers. SERC has established two sites for studying the impacts of elevated CO₂ on plants and ecosystem processes: a wetland study on Chesapeake Bay and a scrub oak site on Merritt Island Wildlife Refuge, Cape Canaveral, Florida.

[Credits: AmeriFlux – Oak Ridge National Laboratory; FACE – Brookhaven National Laboratory; Smithsonian Environmental Research Center]

Appendix B

Global Water Cycle

5.2 The “Blue Marble” – Global water and energy cycles

(a) Western Hemisphere; (b) Eastern Hemisphere

The most detailed true-color images of the Earth to date depict the global interactions between the atmosphere, oceans, land surfaces, and snow/ice surfaces, which together comprise the global water and energy cycles of the Earth system.

A collection of satellite-based observations, combined with data from months of observations of the land surface, was blended together into a seamless, true-color mosaic of every square kilometer of the planet. Most of the information contained in these images came from the Moderate Resolution Imaging Spectroradiometer (MODIS) flying at about 700 km above the Earth on-board the NASA's Terra satellite. The land and coastal ocean portions are based on surface observations collected from June through September 2001 and combined or composited every eight days to compensate for clouds that might block the sensor's view of the surface on any single day. Two different types of ocean data were used in these images: shallow water true color data, and global ocean color (or chlorophyll) data. Topographic shading is based on the GTOPO 30 elevation data set compiled by the USGS' EROS Data Center. MODIS observations of polar sea ice were combined with observations of Antarctica made by the NOAA Advanced Very High Resolution Radiometer (AVHRR) sensor. The cloud image is a composite of two days of imagery collected in visible light wavelengths and a third day of thermal infrared imagery over the poles.

[Credits: NASA Goddard Space Flight Center. Image by Reto Stöckli (land surface, shallow water, clouds). Enhancements by Robert Simmon (ocean color, compositing, 3D globes, animation). Data and technical support: MODIS Land Group; MODIS Science Data Support Team; MODIS Atmosphere Group; MODIS Ocean Group. Additional data: USGS EROS Data Center (topography); USGS Terrestrial Remote Sensing Flagstaff Field Center (Antarctica)]

5.3 North Carolina coast after Hurricane Floyd

The global water cycle plays a pivotal role in the transport of sediment and nutrients through the Earth system, as exemplified in this Landsat-7 image of the North Carolina coast. The image was taken on September 23, 1999, one week after Hurricane Floyd hit the continent. Along with soil swept away by the flood waters, the estuaries were filled with human and animal waste, fertilizers, and pesticides. The slow degradation of the deposited organic waste and soil is expected to worsen greatly the eutrophic conditions in the estuaries as oxygen is depleted and as increased nutrient concentrations stimulate algal blooms. The pulse of organic-rich sediments from the flood represents a persistent ecological impact threatening sport and commercial fisheries in this large productive estuary,

[Credit: Image: Brian Montgomery, NASA Goddard Space Flight Center. Text: Water Cycle Study Group, *A Plan for a New Science Initiative on the Global Water Cycle* (2001)]

Ecosystems

6.1 Trends in surface temperature, vegetation greenness, and duration of growing season, North America and Eurasia, 1982-1999

(a) Temperature and greenness; (b) Changes in growing season duration

An analysis of two decades of satellite data confirms that the growing season in the Northern Hemisphere is getting longer and plant life is becoming more lush as well. Ground-based temperature data and satellite-based vegetation data indicate that year-to-year changes in growth and duration of the growing season of northern vegetation are tightly linked to year-to-year changes in temperature. The greening trend is more pronounced in Eurasia than in North America, particularly throughout the forests and woodlands in central Europe, Siberia, and far-east Russia.

The study used a global data set from the period 1981-1999, based on measurements by the AVHRR sensor onboard a series of NOAA satellites, and the Normalized Difference Vegetation Index (NDVI), which is expressed on a scale from -1 to +1, with values increasing for increasing amounts of vegetation.

Temperature and greenness: The northern latitudes (poleward of 23.6° N) have warmed by about 0.8° C since the early 1970s, but not all areas have warmed uniformly. The warming rate in the U.S. is smaller than in

most of the world. The figure shows a time series of NDVI and land temperature anomaly between 40° N-70° N. On both continents, NDVI is positively correlated with the temperature anomaly during the growing season at the 1% significance level. These results suggest that warmer temperatures may have promoted plant growth in the north during the 1980s and 1990s.

Changes in growing season duration: Researchers defined growing season as the number of days with NDVI greenness level greater than a threshold value, and assessed changes in the duration of photosynthetic activity. The data indicate that the beginning of spring advanced and the termination of photosynthetic activity was delayed in both continents. The duration of the active growing season increased by about 12(+/-5) in North America and 18(+/-4) days in Eurasia.

[Credit: Boston University Climate and Vegetation Research Group; NASA Goddard Space Flight Center]

Land Use and Land Cover Change

7.1 Land Cover Change in Eastern U.S. Ecosystems, 1973-2000

An analysis of land use and land cover change in nine ecological regions provides evidence of distinctive regional variation in the rates and characteristics of changes. The USGS, in cooperation with EPA and NASA, used Landsat images from five years (1973, 1980, 1986, 1992, and 2000) to map the rates of ecoregion change in each time interval (portrayed in ecoregion color and through the graph insert), and the primary land cover transformations (portrayed in the pie charts).

The land cover of approximately 20 percent of the land in the Mid-Atlantic Coastal Plain and Southeastern Plain was affected during the nearly 30-year period from about 1970-2000 due to the rapid, cyclic harvesting and replanting of forests. The adjacent Piedmont region also showed substantial change in forest cover. Urbanization was the dominant conversion in the Northern Piedmont and Atlantic Coast Pine Barrens. The two Appalachian regions studied (Blue Ridge and North Central Appalachia) had comparatively low overall change, with the primary transformations being urban development and forest conversion, respectively.

[Credit: USGS EROS Data Center]

7.2 Forest cover increase and abandonment of marginal agricultural lands in the Upper Midwest

See D.G. Brown, B.C. Pijanowski, and J.D. Duh, "Modeling the relationships between land use and land cover on private lands in the Upper Midwest, USA," *Journal of Environmental Management* (2000).

Human Contributions and Responses

8.1 Urban Population Density of North America

Based upon satellite measurements of city lights, this image is a map of the urban population density of North America. Red, yellow, and green are urban areas, and blue is peri-urban. The city light data is laid over elevation data (black is sea level, light gray is over 10,000 feet). Most major cities are in level areas along an ocean, bay, large lake, or navigable river.

[Credit: Marc Imhoff, NASA Goddard Space Flight Center; Flashback Imaging Corporation, Ontario, Canada]

8.2 Groundwater Overdraft in Response to Drought in Arizona's Urban Areas, 2025

A team from the University of Arizona analyzed the water budgets of several Arizona cities to determine how severe the drought impacts would be from the deepest one-year (1900), five-year (1900-1904), and ten-year (1946-1955) droughts on record. Case study sites included two of the fastest growing areas in the U.S. —the Phoenix and Tucson Active Management Areas (AMAs). In these AMAs, stringent groundwater management is mandated under the 1980 Arizona Groundwater Management Act. The study showed that, even under assumptions of continuing "average" climate conditions, the possibility of achieving "safe yield," as articulated in the Act, (i.e., supply and demand are in balance), remains uncertain. Thus, future severe droughts have the potential to cause significant economic and social impacts, particularly where groundwater pumping is the sole source of supply.

[Credit: University of Arizona project]

USGCRP WEB SITE: www.usgcrp.gov

To meet the need for accurate and useful information on global change, the USGCRP maintains a Web site that helps connect scientists, government officials, educators, the private sector, and the general public to information they are seeking.

Regular updates to the site's "New" page provide many links to recent Internet postings related to USGCRP research program elements. Links are selected from hundreds of monitored sites – including especially those maintained by the government agencies that participate in the USGCRP. For those seeking background information on the USGCRP, the site provides concise online descriptions. Users who wish to focus on any of the USGCRP agencies will find many postings conveniently organized by agency. The site lists the specific programs included by each agency in the USGCRP and, in most cases, includes a link to a Web page for additional information on that program. Visitors looking for information by topic will find many links organized by USGCRP research element, ranging from Climate Variability and Change to the Global Carbon Cycle to the Human Dimensions of Global Change. The site also contains links specifically collected and organized for teachers in elementary and secondary schools.

Other useful links on the site provide access to key Web sites and other current and archived material, including:

- Editions of *Our Changing Planet*, the USGCRP annual report
- The USGCRP Global Change Data and Information System
- The U.S. National Assessment of the Potential Consequences of Climate Variability and Change and associated regional and sectoral assessments
- USGCRP-related international scientific research programs
- The Intergovernmental Panel on Climate Change
- The Global Change Research Information Office (GCRIO)
- Press releases announcing recent scientific advances, and audio segments
- Image collections from USGCRP participating agencies and other sources
- Lists of upcoming events
- Research opportunities, including calls for proposals
- Archived material dating back to 1990, including background papers for USGCRP-sponsored events.

Each page on the site contains an e-mail link to the USGCRP Office, for additional inquiries.

GCRIO was established pursuant to the Global Change Research Act of 1990. The GCRIO Web site at <http://www.gcrio.org/> serves as a gateway to a wide range of global change information for the general public in the United States and internationally. GCRIO provides access to data and information on global environmental change research, adaptation and mitigation strategies and technologies, and global-change-related educational resources.

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