OUR CHANGING PLANET

The U.S. Climate Change Science Program for Fiscal Years 2004 and 2005

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

A Supplement to the President's Budgets for Fiscal Years 2004 and 2005

Climate Change Science Program and Subcommittee on Global Change Research

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This document describes the proposed U.S. Climate Change Science Program (CCSP) for FY 2004 and FY 2005. It does not express any regulatory policies of the United States or any of its agencies, or make any findings of fact that could serve as predicates for regulatory action. Agencies must comply with required statutory and regulatory processes before they could rely on any statements in this document or by the CCSP as a basis for regulatory action.

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July 2004

Members of Congress:

We are pleased to transmit to you a copy of *Our Changing Planet: The U.S. Climate Change Science Program for Fiscal Years 2004 and 2005*. The report describes the activities and plans of the Climate Change Science Program (CCSP), which incorporates the U.S. Global Change Research Program, established under the Global Change Research Act of 1990, and the Climate Change Research Initiative, established by the President in 2001. The CCSP coordinates and integrates scientific research on climate and global change supported by 13 participating departments and agencies of the U.S. Government.

This Fiscal Year 2004 – Fiscal Year 2005 edition of *Our Changing Planet* includes a review of the key components of the *Strategic Plan for the U.S. Climate Change Science Program*, which was released in July 2003. The CCSP Strategic Plan was the first comprehensive update of a national plan for climate and global change research since the original strategy was issued at the inception of the U.S. Global Change Research Program. This report outlines how the CCSP is moving forward to implement the Strategic Plan during FY 2004 and FY 2005.

As a significant part of this implementation, the CCSP will produce 21 scientific syntheses and assessments on a wide range of topics to support informed discussion of climate variability and change and associated issues by decision makers and the public. The first nine of these products are being developed during FY 2004 and FY 2005.

The report also presents highlights of recent research supported by CCSP participating agencies on Climate Variability and Change, the Global Carbon Cycle, and other elements of the research program, and highlights of plans for FY 2004 and FY 2005. A section on International Research and Cooperation describes the Earth Observation Summit, hosted by the Secretaries of Commerce, Energy, and State, held in Washington, DC, in July 2003, as well as numerous current activities to promote cooperation between the U.S. scientific community and its counterparts worldwide. An Appendix describes principal areas of focus and program highlights for each of the CCSP participating agencies. A detailed set of CCSP budget tables is included as an insert in the report.

The CCSP is guided by the vision of our Nation and the global community empowered with the science-based knowledge to manage the risks and opportunities of change in the climate and related environmental systems. We thank the participating departments and agencies of the CCSP for their close cooperation and support and look forward to working with Congress in the continued development of this important program.

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Chair, Committee on Climate Change Science and Technology Integration

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Secretary of Energy

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THE U.S. CLIMATE CHANGE SCIENCE PROGRAM

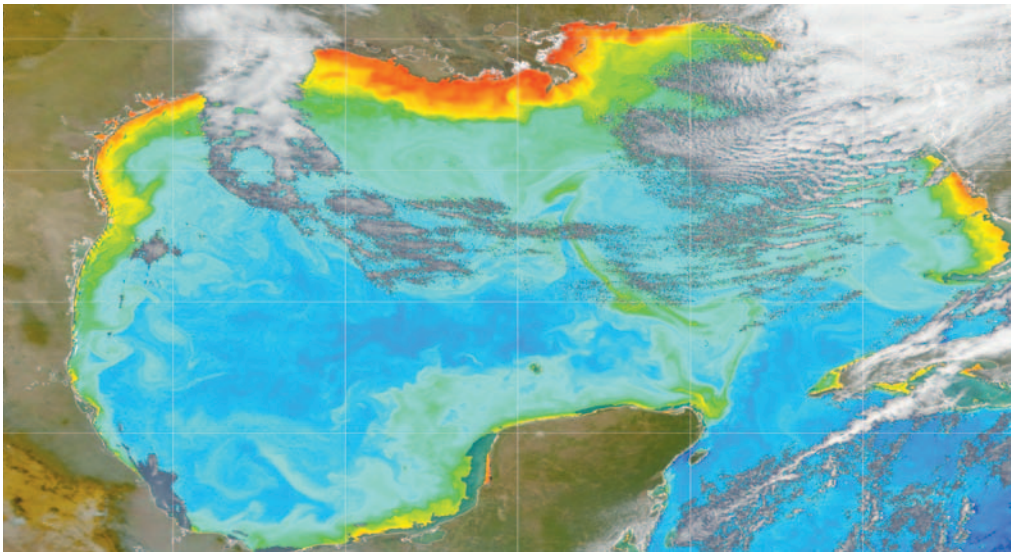
The U.S. Climate Change Science Program (CCSP) was launched in February 2002 as a collaborative interagency program, under a new cabinet-level organization designed to improve the government-wide management of climate science and climate-related technology development. The CCSP incorporates and integrates the U.S. Global Change Research Program (USGCRP) with the Administration's U.S. Climate Change Research Initiative (CCRI).

The USGCRP was established by the Global Change Research Act of 1990 to enhance understanding of natural and human-induced changes in the Earth's global environmental system; to monitor, understand, and predict global change; and to provide a sound scientific basis for national and international decisionmaking.

The CCRI builds on the USGCRP, with a focus on accelerating progress over a 5-year period on the most important issues and uncertainties in climate science, enhancing climate observation systems, and improving the integration of scientific knowledge into policy and management decisions and evaluation of management strategies and choices.

The Climate Change Science Program combines the near-term focus of the CCRI with the breadth of the long-term USGCRP. The interagency budget cross-cuts of the USGCRP and CCRI are developed and maintained separately within the CCSP, but the program management structure is identical for both the USGCRP and CCRI components.

CCSP must also integrate the products of capabilities that make essential contributions to global change research, but were outside the original USGCRP framework and



budget cross-cut. These include the operational environmental satellite system, various *in situ* ocean and atmospheric observing systems, and associated data centers. This will facilitate the transition of research observations into operational systems and the use of research products by mission agencies.

The CCSP Strategic Plan

A new *Strategic Plan for the Climate Change Science Program* was released in July 2003. This document is the first comprehensive update of a national plan for climate and global change research since the original USGCRP strategy was issued at the inception of the program. The original plan was published in the inaugural edition of *Our Changing Planet*, which accompanied the President's FY 1990 budget.

Development of the CCSP Strategic Plan

In July 2002, the CCSP undertook a year-long process to prepare a new 10-year strategic plan for the program. This planning process was designed to ensure a comprehensive examination of research and observation needs, transparent review by the national and international scientific and stakeholder communities, and establishment of defined goals for research on climate and global change.

Scientists and research program managers from the 13 participating agencies and the Climate Change Science Program Office drafted the Strategic Plan. The plan reflects a commitment by its authors to high-quality science, which requires openness to review and critique by the wider scientific community. The process by which the plan was drafted proceeded with the transparency essential for scientific credibility.

The Administration released a CCSP *Discussion Draft Strategic Plan* for public review in November 2002. The discussion draft built upon the significant investments already made in climate change science and was guided by the priority information needs identified by scientists and stakeholders, both nationally and internationally. The draft plan outlined a comprehensive, collaborative approach for developing a more accurate understanding of climate change and its potential impacts.

External comments played an important role in revising the initial draft of the plan. A Climate Change Science Program Workshop, held in December 2002 in Washington, DC, was attended by 1,300 scientists and other participants, including individuals from 47 states and 36 nations. The workshop was designed to facilitate extensive discussion and comments on the draft plan from all interested domestic and international groups

and individuals, including the scientific community, stakeholders, nongovernmental organizations, interested members of the public, and the news media.

Written comments on the *Discussion Draft Strategic Plan* were submitted during a public review period. These comments amounted to nearly 900 pages of input from hundreds of scientists, representatives of interest groups, and interested members of the lay public.

In addition, a special committee of the National Academy of Sciences' National Research Council (NRC) reviewed the discussion draft plan at the request of the CCSP. The 17-member Committee to Review the U.S. Climate Change Science Program Strategic Plan included experts in the physical, biological, social, and economic sciences. In February 2003, this committee reported its recommendations, which provided invaluable assistance in the revision of the draft plan.

The *Strategic Plan for the U.S. Climate Change Science Program*—available online at <http://www.climatescience.gov>—was released in July 2003, after consideration of all of the workshop discussions, the full range of written public review comments, and the NRC review of the discussion draft plan, as well as an extensive internal U.S. Government review process. A shorter companion document—*The U.S. Climate Change Science Program: Vision for the Program and Highlights of the Scientific Strategic Plan*—was released at the same time.

The plan will guide the conduct of research activities sponsored or conducted by the U.S. Government. It will be modified as warranted by the emergence of key findings and important new questions of public interest and scientific questions.

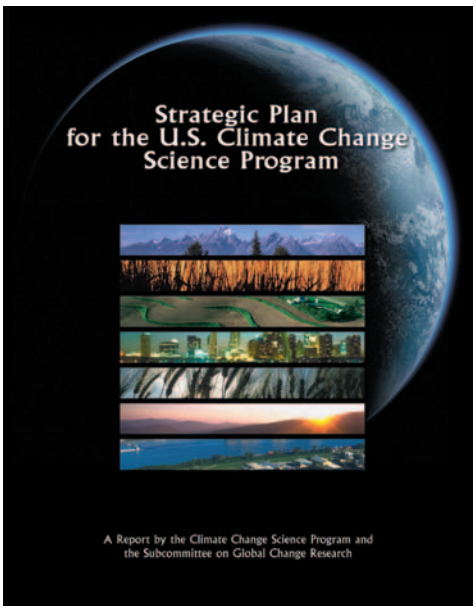
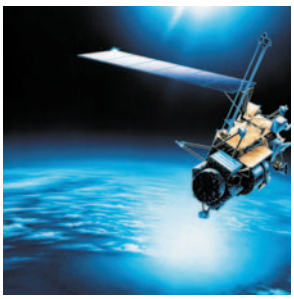


Figure 1:
The CCSP Strategic Plan.

In February 2004, the NRC review committee issued a second public report—*Implementing Climate and Global Change Research: A Review of the Final U.S. Climate Change Science Program Strategic Plan*—expressing the committee's conclusions on the content, objectivity, quality, and comprehensiveness of the updated Strategic Plan, on the process used to produce it, and on the proposed process for developing subsequent findings to be reported by the CCSP. The report made a number of recommendations on

implementing the plan. The NRC review concluded:

> "The *Strategic Plan for the U.S. Climate Change Science Program* articulates a guiding vision, is appropriately ambitious, and is broad in scope. It encompasses activities related to areas of long-standing importance, together with new or enhanced cross-disciplinary efforts. It appropriately plans for close integration with the complementary Climate Change Technology Program. The CCSP has responded constructively to the National Academies review and other community input in revising the strategic plan. In fact, the approaches taken by the CCSP to receive and respond to comments from a large and broad group of scientists and stakeholders, including a two-stage independent review of the plan, set a high standard for government research programs. As a result, the revised strategic plan is much improved over its November 2002 draft, and now includes the elements of a strategic management framework that could permit it to effectively guide research on climate and associated global changes over the next decades. Advancing science on all fronts identified by the program will be of vital importance to the nation."



Vision, Mission, and Goals of the Climate Change Science Program

Climate and climate variability play important roles in shaping the environment, natural resources, infrastructure, the economy, and other aspects of life in all countries of the world. Human-induced changes in climate and related environmental systems, and the options proposed to adapt to or mitigate these changes, may have substantial environmental, economic, and societal consequences. Because of the pervasiveness of the effects of climate variability and the potential consequences of human-induced climate change and response options, citizens and decisionmakers in public and private sector organizations need reliable and readily understood information, including a clear understanding of the reliability limits of such information, to make informed judgments and decisions.

CCSP GUIDING VISION

A nation and the global community empowered with the science-based knowledge to manage the risks and opportunities of change in the climate and related environmental systems.

Over the past 15 years, the United States has invested heavily in scientific research, monitoring, data management, and assessment for climate change analyses to build a foundation of knowledge for decisionmaking. The seriousness of the issues and the

unique role that science can play in helping to inform society's course give rise to CCSP's guiding vision.

The core precept that motivates the CCSP is that the best possible scientific knowledge should be the foundation for the information required to manage climate variability and change and related aspects of global change.

CCSP MISSION

Facilitate the creation and application of knowledge of the Earth's global environment through research, observations, decision support, and communication.

The CCSP adds significant integrative value to the individual Earth and climate science missions of its 13 participating agencies and departments, and their national and international partners. A critical role of the interagency program is to coordinate research and integrate and synthesize information to achieve results that no single agency, or small group of agencies, could attain.

In the Strategic Plan, the CCSP adopted five overarching scientific goals. By developing information responsive to these goals, the program will ensure that it addresses the most important climate-related issues. For each of the goals, the CCSP will prepare information resources that support climate-related discussion and decisions.

The five goals frame what might be termed an "end-to-end" approach to climate and global change research—including observations, understanding of processes, projections of future change, understanding potential consequences of change, and applications of knowledge to management decisions. The goals thus form a unified framework, and their ordering does not suggest an order of priority. The CCSP Goals are discussed in greater detail in the CCSP Strategic Plan.

CCSP GOALS

Goal 1: Improve knowledge of the Earth's past and present climate and environment, including its natural variability, and improve understanding of the causes of observed variability and change.

Goal 2: Improve quantification of the forces bringing about changes in the Earth's climate and related systems.

Goal 3: Reduce uncertainty in projections of how the Earth's climate and related systems may change in the future.

Goal 4: Understand the sensitivity and adaptability of different natural and managed ecosystems and human systems to climate and related global changes.

Goal 5: Explore the uses and identify the limits of evolving knowledge to manage risks and opportunities related to climate variability and change.

See Chapters 1 and 2 of the *Strategic Plan for the U.S. Climate Change Science Program* for further discussion of the CCSP Goals.

Core Approaches

The CCSP employs four core approaches in working toward its goals. Each of these components of the program is discussed in greater detail in the CCSP Strategic Plan.

CCSP CORE APPROACHES

Scientific Research: Plan, sponsor, and conduct research on changes in climate and related systems.

Observations: Enhance observations and data management systems to generate a comprehensive set of variables needed for climate-related research.

Decision Support: Develop improved science-based resources to aid decisionmaking.

Communications: Communicate results to domestic and international scientific and stakeholder communities, stressing openness and transparency.

See Chapter 1 of the *Strategic Plan for the U.S. Climate Change Science Program* for further discussion of the CCSP Core Approaches.

1. Scientific Research: Plan, Sponsor, and Conduct Research on Changes in Climate and Related Systems

The greatest percentage of the CCSP budget is devoted to continuing the essential ongoing investment in scientific knowledge, facilitating the discovery of the unexpected, and advancing the frontiers of research. The CCSP participating agencies coordinate their work through seven interdisciplinary "research elements," which together support scientific research across a wide range of interconnected issues of climate and global change. These research elements pertain to major components of the Earth's environmental and human systems, which are undergoing changes caused by a variety of natural and human-induced causes. The CCSP will encourage evolution of the research elements over the coming decade in response to new knowledge and societal needs. The CCSP research elements are:

1) Atmospheric Composition
2) Climate Variability and Change (including Climate Modeling)
3) Global Water Cycle
4) Land-Use/Land-Cover Change
5) Global Carbon Cycle
6) Ecosystems
7) Human Contributions and Responses.

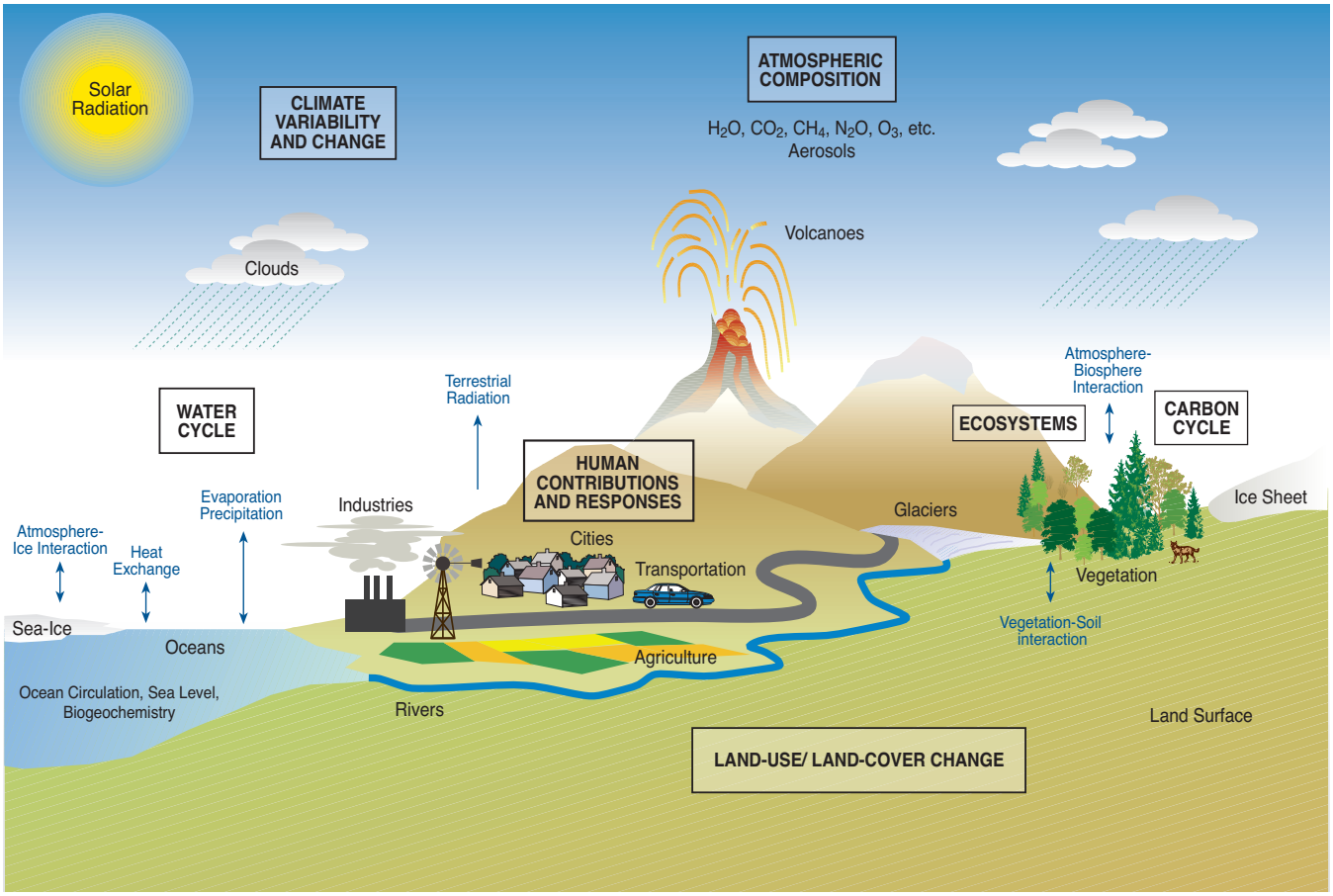
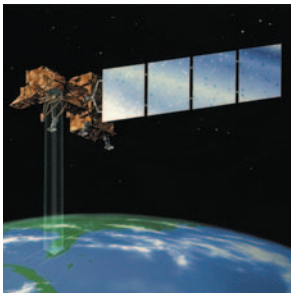


Figure 2: Major components needed to understand the climate system and climate change.



2. *Observations: Enhance Observations and Data Management Systems to Generate a Comprehensive Set of Variables Needed for Climate-Related Research*

Since the early years of the USGCRP, an expanded program of global observations has been developed to characterize climate variability and change on global and regional scales. These observations have included paleoclimatic records spanning thousands of years, satellite remote-sensing systems covering the entire planet, and numerous *in situ* observations on land (including the polar regions), in the atmosphere, and throughout the oceans.

Prior and current investments in new observations, as they come to fruition, will significantly enhance knowledge of environmental variables in the coming years. But there is also a need for enhanced global and regional integration of observation and data management systems, especially to help generate new and improved products for

supporting decisions. The CCSP will increase the capacity to prioritize, ensure the quality of, archive, and disseminate (in useful format) the large quantity of available observations.

At the Earth Observation Summit, held in Washington, DC, in July 2003, 33 nations and the European Commission made a commitment to move toward the development of a comprehensive, coordinated, and sustained Earth observation system. The Earth Observation Summit established the Group on Earth Observations (GEO) to prepare a 10-year implementation plan (see the "International Research and Cooperation" section for further discussion).

3. Decision Support: Develop Improved Science-Based Resources to Aid Decisionmaking

The available scientific record has been used for many years to address a range of questions, from detecting climate change and attributing it to particular causes, to utilizing satellite and ground-based observations and related analyses in resource management applications. The CCSP will improve interactions with stakeholders and develop resources to support public discussion and planning, adaptive management, and policymaking. The program also will encourage development of new methods, models, and other resources that facilitate economic analysis, decisionmaking under conditions of uncertainty, and integration and interpretation of information from the natural and social sciences in particular decision contexts.

4. Communications: Communicate Results to Domestic and International Scientific and User Communities, Stressing Openness and Transparency

The domestic and international communities addressing global climate change are already well-developed. This is evident in publications in the scientific literature, Intergovernmental Panel on Climate Change (IPCC) collaborations, and many other scientific forums; in policy discussions in Washington and other world capitals; and in the media throughout the world. The CCSP has a responsibility to communicate with interested partners in the United States and throughout the world, and to learn from these partners on a continuing basis. The CCSP will aim to improve dialogue with public and private sector constituencies with the end result of providing users of climate change information with adequate opportunities to help frame important scientific research activities. This dialogue is an essential component of the development of decision support.

Because of the major commitment of public resources to CCSP activities, the CCSP also has a responsibility to report its findings in the form of educational materials suitable for use at various educational and public information levels, without sacrificing

accuracy or indulging in oversimplification, so that the dissemination of its findings will be effective. As an essential part of its mission, the CCSP undertakes the significant responsibility of enhancing the quality of public discussion by stressing openness, transparency, and accuracy in its findings and reports.

Each of these approaches is essential for achieving the CCSP's goals. Scientific Research and Observations will rely heavily on existing programs and mechanisms, as well as integration of capabilities developed outside the prior global change research framework. Decision Support and Communications will require the development of new capabilities and initiatives during the coming years.

Climate Change Research Initiative

President Bush launched the U.S. Climate Change Research Initiative in June 2001, "to study areas of uncertainty and identify priority areas where investments can make a difference." The 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. The CCRI has three principal aims, as described below.

1. Focus on Three Key Areas of Climate Science

Develop reliable representations of the climatic forcing resulting from atmospheric aerosols. Aerosols and tropospheric ozone play unique, but poorly quantified, roles in the atmospheric radiation budget. Proposed activities include field campaigns (including aircraft missions), *in situ* monitoring stations, improved modeling, and satellite data algorithm development.

Improve understanding of the global carbon cycle (sources and sinks). The CCRI funds will be targeted for activities to carry out the integrated North American Carbon Program, a key element of the U.S. Carbon Cycle Science Plan. This program will improve monitoring techniques, reconcile approaches for quantifying carbon storage, and elucidate key processes and land management practices regulating carbon fluxes between the atmosphere and the land and ocean.

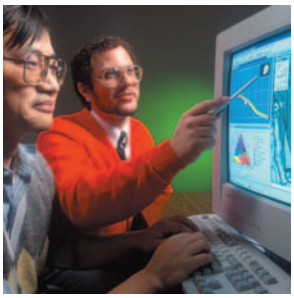
Increase knowledge of climate feedback processes. "Climate feedbacks"—such as feedbacks from clouds, water vapor, atmospheric convection, ocean circulation, ice albedo, and vegetation—can either amplify or dampen the climate system's response to changes in radiative forcing that result from changing greenhouse gas concentrations, solar

variability, or land-cover changes. Insufficient understanding of these feedbacks is responsible for large uncertainties in the ability to reliably predict climate variability and project climate change. The CCRI will focus activities to support increased understanding of feedback processes.

2. Enhance and Expand Observations of the Earth System

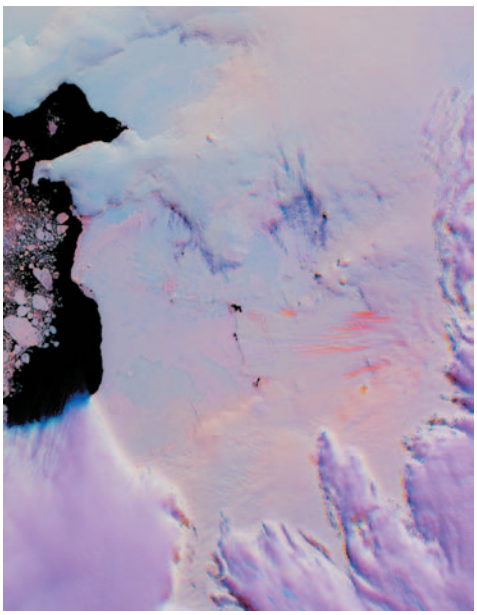
CCRI efforts will contribute to and benefit from the design and operational implementation over the next 10 years of a new international, integrated, sustained, and comprehensive global Earth observation system, designed to minimize data gaps and maximize the utility of existing observing networks.

3. Increase Climate Modeling Capacity



The CCRI will support continued development and refinement of computational climate models. Priority activities will focus on improving model physics (particularly with respect to clouds and aerosols), increasing resolution of climate model simulations, improving methods to assimilate observations into model analyses and predictions, and exploring limits to predictability of climate variability and change. The CCRI also will support development of climate modeling to provide routine model products for policy and management decision support.

The Administration also launched the parallel Climate Change Technology Program (CCTP) in June 2001, "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." Technological breakthroughs will be needed to address the long-term challenge of global climate change. The CCSP and the CCTP are closely collaborating to ensure that (a) science drives the definition of technology needs, and (b) science is used to evaluate the potential consequences of proposed technology innovations.



Implementing the Strategic Plan — The Next Stage

During FY 2004 and FY 2005 the CCSP is moving forward to implement the Strategic Plan. This section discusses CCSP management and implementation mechanisms, and criteria for setting budget and program priorities. Highlights of FY 2004 and FY 2005 program plans for each of the CCSP research elements and for each of the CCSP participating agencies are presented in greater detail in later sections of this report.

CCSP Management and Implementation Mechanisms

Several circumstances define the unique management environment of the Climate Change Science Program. Fundamentally, the CCSP integrates U.S. Government-supported research on climate and global change, as conducted and sponsored by 13 departments and agencies:

- Department of Agriculture (USDA)
- Department of Commerce / National Oceanic and Atmospheric Administration (DOC/NOAA)
- Department of Defense (DOD)
- Department of Energy (DOE)
- Department of Health and Human Services (HHS)
- Department of the Interior / U.S. Geological Survey (DOI/USGS)
- Department of State (DOS)
- Department of Transportation (DOT)
- Agency for International Development (USAID)
- Environmental Protection Agency (EPA)
- National Aeronautics and Space Administration (NASA)
- National Science Foundation (NSF)
- Smithsonian Institution (SI).

The Office of Science and Technology Policy (OSTP), the Council on Environmental Quality (CEQ), the National Economic Council (NEC), and the Office of Management and Budget (OMB) provide oversight. Planning and implementation must be coordinated across the participating departments and agencies because the capabilities required for comprehensive scientific inquiries and synthesis extend beyond the mission, resources, and expertise of any single agency.

As a U.S. Government program, CCSP budget requests are implemented within the context of the Federal budget cycle. Budget requests are coordinated through

interagency research working groups and other mechanisms, but ultimate budget accountability resides with the participating agencies and departments. As a result of its interagency composition, activities in the CCSP budget are funded by Congress through nine of the 13 annual Appropriations bills. Congressional oversight also is carried out by a number of authorizing committees, making the relationship between CCSP budgeting and the appropriations and oversight process complex.

With 14 years of experience, the U.S. Global Change Research Program has developed a solid foundation for managing a large-scale interagency research program on complex climate and global change issues.

Management of the CCSP involves five mechanisms:

- Executive direction by a cabinet-based management structure, including priority setting, management review, and accountability
- Program implementation by CCSP participating agencies
- Coordinated planning and program implementation through interagency working groups
- External interactions for guidance, evaluation, and feedback
- Coordination and management support from an interagency office accountable to the CCSP interagency governing committee.

CLIMATE CHANGE SCIENCE AND TECHNOLOGY INTEGRATION

In February 2002, the President created a new Cabinet-level management structure—the Committee on Climate Change Science and Technology Integration—to oversee the more than $3 billion annual investment in the combined Federal climate change research and technology development programs. The new management structure places accountability and leadership for the science and technology programs in the relevant cabinet departments. The relevant research continues to be coordinated through the National Science and Technology Council in accordance with the Global Change Research Act of 1990.

At the highest level, this structure includes the Executive Office of the President, with policy review provided by a combined National Security Council (NSC), Domestic Policy Council (DPC), and National Economic Council (NEC) panel. The Committee on Climate Change Science and Technology Integration (CCCSTI), consisting of cabinet secretaries and agency heads, was developed to provide management oversight to the Federal climate change science and technology programs. The Interagency Working Group on Climate Change Science and Technology (IWGCCST) reports to the CCCSTI and consists of the Deputy/Under Secretaries (or the counterparts of these positions in non-cabinet agencies and offices). The Working Group provides oversight for both the CCSP and the CCTP (which develops and reviews climate technology programs within the U.S. Government), and makes recommendations to the CCCSTI about funding and program allocations, in order to implement a coordinated climate change science and technology program that will better support policy development.

Under the new management structure, the CCSP integrates research on global climate change conducted and sponsored by the Departments of Agriculture, Commerce, Defense, Energy, Health and Human Services, the Interior, State, and Transportation, together with the Environmental Protection Agency, the National Aeronautics and Space Administration, the National Science Foundation, the Agency for International Development, and the Smithsonian Institution. The Office of Science and Technology Policy, the Council on Environmental Quality, the National Economic Council, and the Office of Management and Budget also participate. The principal areas of focus for the CCSP agencies are summarized in an Appendix to this report.

Interactions among those responsible for these five mechanisms are critical for improving the scientific planning, the effectiveness of interagency management, and the focus of climate and global change research to support governmental and nongovernmental needs. The CCSP also will employ guidance from the President's Management agenda to strengthen the implementation of this plan.

Chapter 16 of the *Strategic Plan for the U.S. Climate Change Science Program* contains a more detailed discussion of program management issues.

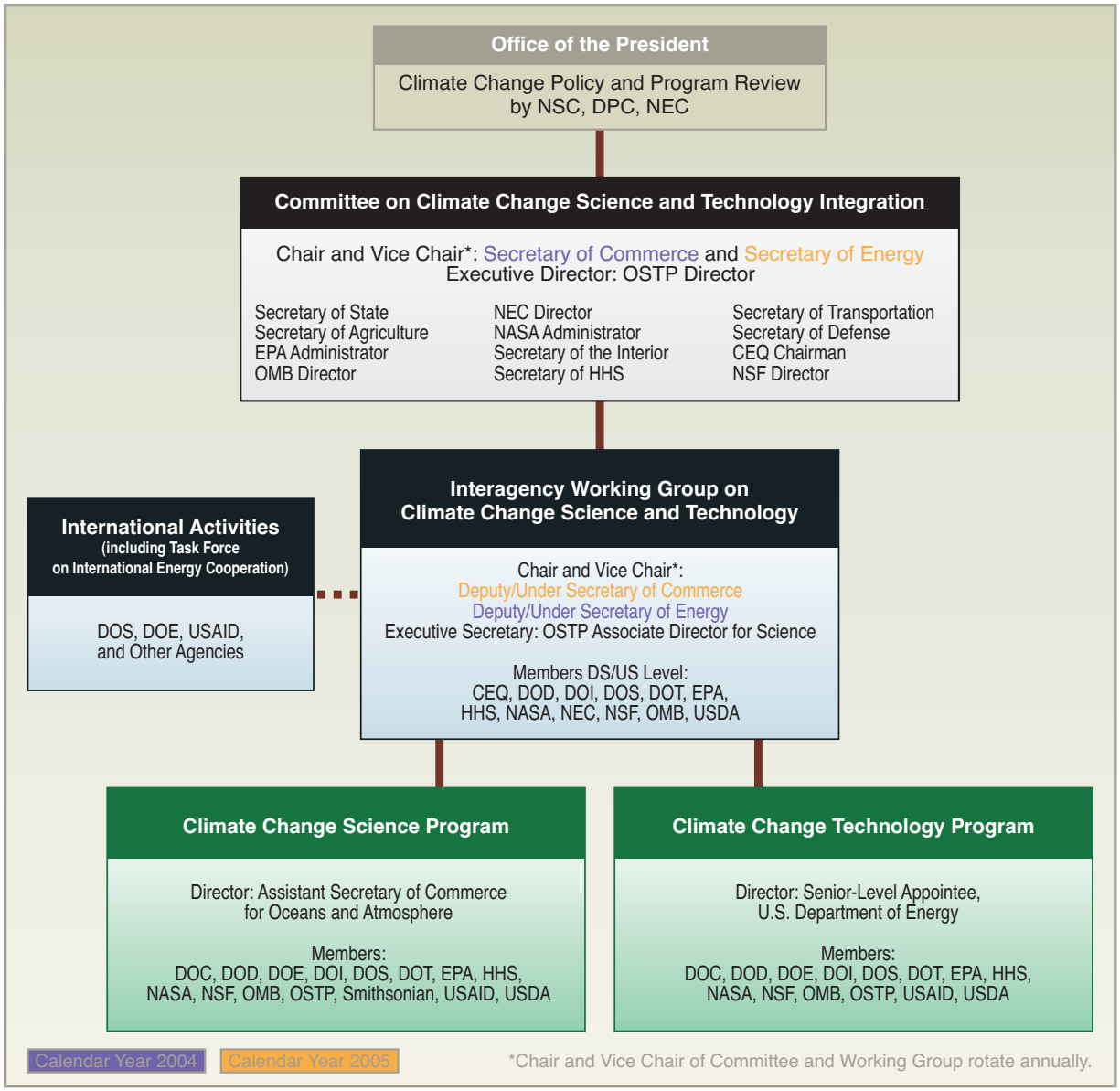


Figure 3: Climate change science and technology integration management structure.

Executive Direction by the Cabinet-Based Management Structure

The cabinet-level management structure instituted by the President in 2002 helps to focus efforts addressing the challenges of improving science-based information to manage the risks and opportunities of variability and change in climate and related systems during the coming decade. Through this structure, the CCSP also coordinates with the Climate Change Technology Program to address issues at the intersection of science and technology, such as evaluating approaches to sequestration, monitoring of anthropogenic greenhouse gas emissions, and energy technology development and market penetration scenarios.

Membership on CCSP's interagency governing body, which is chaired by the CCSP Director (a Department of Commerce appointee), is joint with the National Science and Technology Council, Committee on Environment and Natural Resources, Subcommittee on Global Change Research (SGCR)—the interagency subcommittee that coordinates the USGCRP. Its membership includes representatives from agencies that have mission responsibilities and/or funding in climate and global change research. The USGCRP and CCRI are integrated within the CCSP and responsibility for compliance with the requirements of the Global Change Research Act of 1990—including its provisions for annual reporting of findings and near-term plans, scientific reviews by the National Academy of Sciences/National Research Council, and periodic publication of a strategic plan for the program—rests with the CCSP's interagency governing body.

The CCSP interagency governing body provides overall management direction and is responsible for ensuring the development and implementation of an integrated interagency program. It oversees and directs all aspects of the program, including setting top-level goals for the program and determining what products will be developed and produced to meet those goals.

Program Implementation by CCSP Agencies

The goals and objectives of the CCSP and the plans designed by interagency working groups are carried out by the participating agencies, either individually or collaboratively. Each agency has its respective mission, capabilities, and appropriations, on the basis of which it commits to conduct research, make observations, run models, and generate products that contribute to CCSP objectives. Agency programs are aligned with CCSP implementation strategies by program managers who serve as chairs and members of interagency working groups.

Coordinated Planning and Implementation through Interagency Working Groups

At the implementation level, the CCSP draws on the strengths of many agencies and departments. A significant degree of coordination is required to ensure that the research conducted and supported by individual agencies under the umbrella of the CCSP supports program scientific objectives and that developments are effectively and efficiently synthesized and transferred into operational and sustained societal benefits. Interagency working groups of program managers who have budget authority within their agencies to implement programs oversee development of integrated science and implementation plans for each of the working groups.

External Interactions for Guidance, Evaluation, and Feedback

The science community brings essential expertise to CCSP activities. The CCSP recognizes the need to develop and utilize a variety of processes and mechanisms to provide an open and transparent process, program evaluation, and feedback. Scientific input is, and will continue to be, sought from individuals in universities, Federal research agencies, nongovernmental organizations, and industry.

The CCSP will continue to ask relevant committees of the National Academy of Sciences/National Research Council to provide scientific guidance as appropriate. Since the inception of the USGCRP, the NRC has provided a wealth of valued advice in numerous commissioned reports. Currently, four NRC standing committees provide ongoing advisory support to the CCSP: the Climate Research Committee, the Committee on the Human Dimensions of Global Change, the Committee on Geophysical and Environmental Data, and the Coordinating Committee on Global Change. Two NRC studies for the CCSP are currently underway—on Radiative Forcing Effects on Climate (scheduled for release in December 2004), and on Metrics for Documenting Progress in Global Change Research.

Additional mechanisms to seek external scientific input—such as workshops, steering committees, *ad hoc* working groups, and review boards—will be employed as needed. The research community, in cooperation with users, will develop science plans for the research elements of the program. An example of a detailed science plan is the *U.S. Carbon Cycle Science Plan*, issued in 1999. This science plan was requested by several CCSP participating agencies and was developed by a working group that drew on the expertise of the U.S. carbon cycle science community.

Coordination and Management Support by an Interagency Office

The agencies participating in the CCSP fund and supervise an interagency office, the Climate Change Science Program Office, which fosters:

- Research coordination and integration
- Development, coordination, and integration of decision support resources
- Integration of agency activities in the areas of observing, monitoring, and data management
- Development and implementation of an interagency communications plan
- Secretariat support for the CCSP Director, CCSP Principals, and CCSP interagency working groups.

Setting Budget and Program Priorities

The CCSP uses a problem-driven rather than a disciplinary approach in setting priorities and sequencing investments, identifying for early action and support those projects and activities that meet the following agreed-upon criteria:

- *Scientific or technical quality*: The proposed work must be scientifically rigorous as determined by peer review. Implementation plans will include periodic review by external advisory groups (both researchers and users).
- *Relevance to reducing uncertainties and improving decision support tools in priority areas*: Programs must substantially address one or more of the CCSP goals. Programs must respond to needs for scientific information and enhance informed discussion by all relevant stakeholders.
- *Track record of consistently good past performance and identified metrics for evaluating future progress*: Programs addressing priorities with good track records of past performance will be favored for continued investment to the extent that time tables and metrics for evaluating future progress are provided. Proposed programs that identify clear milestones for periodic assessment and documentation of progress will be favorably considered for new investment.
- *Cost and value*: Research should address CCSP goals in a cost-effective way. Research should also be coordinated with and leverage other national and international efforts. Programs that provide value-added products to improve decision support resources will be favored.

The potential scope of climate change research, observations, and scientific synthesis is so large that the CCSP must clearly identify the highest priority activities for support.

The research priorities of the CCSP are reviewed on an annual cycle through the budget process and reflect priority needs and scientific opportunities. While the CCSP Strategic Plan includes a decade-long strategy, it also establishes priorities for the near term consistent with the CCRI. These priorities are reflected in a focusing of resources and enhanced interagency coordination of ongoing and planned research that can best address major gaps in understanding of climate change. The CCSP Strategic Plan provides additional information on these priorities.

Developing Decision Support Resources

The Global Change Research Act of 1990 directs the USGCRP to support research to "produce information readily usable by policymakers attempting to formulate effective strategies for preventing, mitigating, and adapting to the effects of global change" and to undertake periodic scientific assessments. In order to fulfill the decision support and scientific assessment requirements of the Global Change Research Act and to enhance the utility of the extensive body of observations and research findings developed by the USGCRP since 1990, the CCSP is adopting a structured approach to coordinate and extend resources developed through the research activities to the support of policy and adaptive management decisionmaking.

The CCSP Decision Support Resources activities will build on the scientific foundation established by the USGCRP, the CCRI, and related international programs, as well as the lessons learned from other assessments and stakeholder interaction projects conducted during the last decade. CCSP research activities and the development of new synthesis and assessment products and other decision support resources will evolve in partnership, as scientific research progresses and as new questions related to policymaking, planning, and adaptive management arise.

THE ROLE OF DECISION SUPPORT

Prepare scientific syntheses and assessments to support informed discussion of climate variability and change and associated issues by decisionmakers, stakeholders, the media, and the general public.

Develop resources to support adaptive management and planning for responding to climate variability and climate change, and transition these resources from research to operational application.

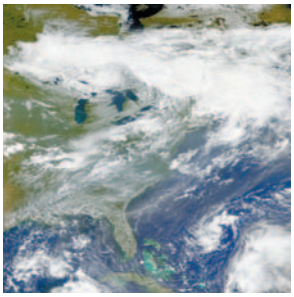
Develop and evaluate methods (scenario evaluations, integrated analyses, and alternative analytical approaches) to support climate change policymaking and demonstrate these methods with case studies.

See Chapter 11 of the *Strategic Plan for the U.S. Climate Change Science Program* for detailed discussion of decision support resources development.

Expected outcomes from the CCSP Decision Support Resources activities include:

- Improved scientific syntheses and assessments for informing public discussion of climate change issues
- Expanded adaptive management capacity to facilitate the responses of resource managers to climate variability and change
- Assessment information for evaluating options for mitigation of and adaptation to climate variability and change
- Identification of information needs to guide the evolution of the CCSP science agenda.

Syntheses and Assessments



Assessments are an effective means for integrating and analyzing CCSP research results with other knowledge, and communicating useful insights in support of a variety of applications for decision support. Assessments also help identify knowledge gaps and thus provide valuable input to the process of focusing research.

The Global Change Research Act of 1990 directs the program to prepare periodically an assessment that:

- Integrates, evaluates, and interprets the findings of the program and discusses the scientific uncertainties associated with such findings
- Analyzes the effects of global change on the natural environment, agriculture, energy production and use, land and water resources, transportation, human health and welfare, human social systems, and biological diversity
- Analyzes current trends in global change, both human-induced and natural, and projects major trends for the subsequent 25 to 100 years." (from Section 106).

To comply with the terms of Section 106, the CCSP will produce assessments that focus on a variety of science and policy issues important for public discussion and decisionmaking. The assessments will be composed of syntheses, reports, and integrated analyses that the CCSP will complete over the next 4 years. The subjects to be addressed are listed in Table 1. CCSP cooperating agencies will sponsor or carry out the analyses within the "Guidelines for Producing CCSP Synthesis and Assessment Products" (see <http://www.climatescience.gov>) to ensure that resources from the entire program are best utilized. This approach will cover the full range of CCSP goals and will provide a "snapshot" of knowledge concerning the environmental and socio-economic aspects of climate variability and change. The program has begun the process of developing the first of these reports on climate science findings.

Table 1: Summary of Synthesis and Assessment Products

CCSP GOAL 1

TOPICS FOR PRIORITY CCSP SYNTHESIS PRODUCTS	SIGNIFICANCE	COMPLETION
Temperature trends in the lower atmosphere—steps for understanding and reconciling differences.	Inconsistencies in the temperature profiles of different data sets reduce confidence in understanding of how and why climate has changed.	within 2 years
Past climate variability and change in the Arctic and at high latitudes.	High latitudes are especially sensitive and may provide early indications of climate change; new paleoclimate data will provide long-term context for recent observed temperature increases.	within 2 years
Reanalyses of historical climate data for key atmospheric features. Implications for attribution of causes of observed change.	Understanding the magnitude of past climate variations is key to increasing confidence in the understanding of how and why climate has changed and why it may change in the future.	2-4 years

CCSP GOAL 2

TOPICS FOR PRIORITY CCSP SYNTHESIS PRODUCTS	SIGNIFICANCE	COMPLETION
Updating scenarios of greenhouse gas emissions and concentrations, in collaboration with the CCTP. Review of integrated scenario development and application.	Sound, comprehensive emissions scenarios are essential for comparative analysis of how climate may change in the future, as well as for analyses of mitigation and adaptation options.	within 2 years
North American carbon budget and implications for the global carbon cycle.	The buildup of CO_2 and methane in the atmosphere and the fraction of carbon being taken up by North America's ecosystems and coastal oceans are key factors in estimating future climate change.	within 2 years
Aerosol properties and their impacts on climate.	There is a high level of uncertainty about how climate may be affected by different types of aerosols, both warming and cooling, and thus how climate change might be affected by their control.	2-4 years
Trends in emissions of ozone-depleting substances, ozone layer recovery, and implications for ultraviolet radiation exposure and climate change.	This information is key to ensuring that international agreements to phase out production of ozone-depleting substances are having the expected outcome (recovery of the protective ozone layer).	2-4 years

CCSP GOAL 3

TOPICS FOR PRIORITY CCSP SYNTHESIS PRODUCTS	SIGNIFICANCE	COMPLETION
Climate models and their uses and limitations, including sensitivity, feedbacks, and uncertainty analysis.	Clarifying the uses and limitations of climate models at different spatial and temporal scales will contribute to appropriate application of these results.	within 2 years
Climate projections for research and assessment based on emissions scenarios developed through CCTP.	Production of these projections will help develop modeling capacity and will provide important inputs to comparative analysis of response options.	2-4 years
Climate extremes including documentation of current extremes. Prospects for improving projections.	Extreme events have important implications for natural resources, property, infrastructure, and public safety.	2-4 years
Risks of abrupt changes in global climate.	Abrupt changes have occurred in the past and thus it is important to evaluate what we know about the potential for abrupt change in the future.	2-4 years

Table 1 (continued)

CCSP GOAL 4

TOPICS FOR PRIORITY CCSP SYNTHESIS PRODUCTS	SIGNIFICANCE	COMPLETION
Coastal elevation and sensitivity to sea-level rise.	Evaluation of how well equipped society is to cope with potential sea-level rise can help reduce vulnerability.	within 2 years
State-of-knowledge of thresholds of change that could lead to discontinuities (sudden changes) in some ecosystems and climate-sensitive resources.	This approach seeks to determine how much climate change natural environments and resources can withstand before being adversely affected.	2-4 years
Relationship between observed ecosystem changes and climate change.	Earlier blossoming times, longer growing seasons, and other changes are being observed, and this report will explore what is known about why these events are happening.	2-4 years
Preliminary review of adaptation options for climate-sensitive ecosystems and resources.	Understanding of adaptation options can support improved resource management—whether change results from natural or human causes—and thus helps realize opportunities or reduce negative impacts.	2-4 years
Scenario-based analysis of the climatological, environmental, resource, technological, and economic implications of different atmospheric concentrations of greenhouse gases.	Knowing how well we can differentiate the impacts of different greenhouse gas concentrations is important in determining the range of appropriate response policies.	2-4 years
State-of-the-science of socioeconomic and environmental impacts of climate variability.	This product will help improve application of evolving ENSO forecasts by synthesizing information on impacts, both positive and negative, of variability.	2-4 years
Within the transportation sector, a summary of climate change and variability sensitivities, potential impacts, and response options.	Safety and efficiency of transportation infrastructure—much of which has a long lifetime—may be increased through planning that takes account of sensitivities to climate variability and change.	2-4 years

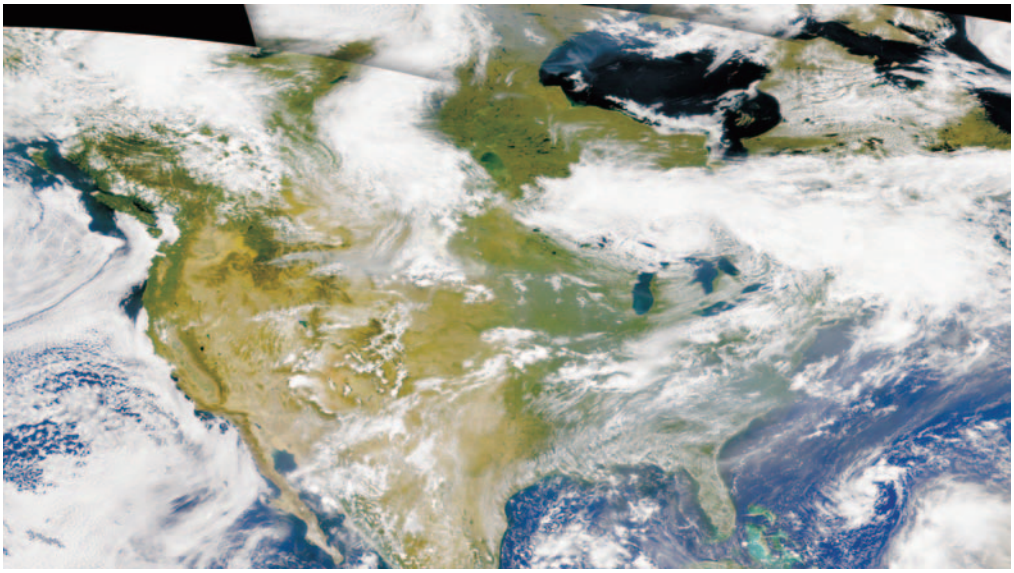
CCSP GOAL 5

TOPICS FOR PRIORITY CCSP SYNTHESIS PRODUCTS	SIGNIFICANCE	COMPLETION
Uses and limitations of observations, data, forecasts, and other projections in decision support for selected sectors and regions.	There is a great need for regional climate information; further evaluation of the reliability of current information is crucial in developing new applications.	within 2 years
Best-practice approaches to characterize, communicate, and incorporate scientific uncertainty in decisionmaking.	Improvements in how scientific uncertainty is evaluated and communicated can help reduce misunderstanding and misuse of this information.	within 2 years
Decision support experiments and evaluations using seasonal to interannual forecasts and observational data.	Climate variability is an important factor in resource planning and management; improved application of forecasts and data can benefit society.	within 2 years

The CCSP agencies and scientists funded by these agencies also will continue to participate in the principal international scientific assessments, including the Intergovernmental Panel on Climate Change assessment reports and the World Meteorological Organization (WMO)/United Nations Environment Programme (UNEP) assessments of stratospheric ozone depletion and associated environmental impacts. CCSP research programs and CCSP-supported scientists provide scientific and technical leadership in coordinating, authoring, and reviewing international assessment reports. The CCSP coordinates the U.S. Government's scientific and technical review of the products of international assessments, and in so doing, the program invites input from a wide variety of sources, both inside and outside the government.

Recent international scientific assessments include the IPCC Third Assessment Report (2001), the Scientific Assessment of Ozone Depletion (2002), and the Arctic Climate Impact Assessment (Scientific Report and Overview Report forthcoming 2004). The largest assessment program to date focused on the United States was the National Assessment of the Potential Consequences of Climate Variability and Change (Overview Report, 2000; Foundation Report, 2001; and 17 regional and sectoral reports).

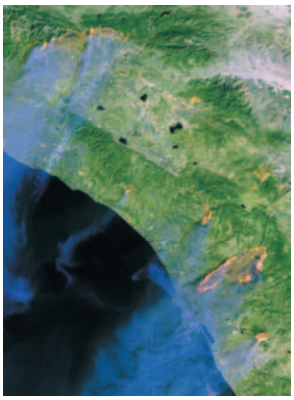
The IPCC Fourth Assessment Report is currently in the early stages of preparation and is scheduled to be completed in 2007. A U.S. scientist at NOAA serves as co-chair of the IPCC Working Group I on the scientific aspects of the climate system and climate change. The CCSP provides resources to support this working group. CCSP participating agency representatives also have played a significant role in nominating



U.S. experts for various roles as authors and reviewers for the IPCC Fourth Assessment Report.

During the next decade, the CCSP will continue to support assessment analyses. Given the broad set of policy, planning, and operational decisions that would benefit from climate and global change information, there are a wide variety of candidates for CCSP assessments. The decision support approach adopted by the CCSP builds upon the "lessons learned" from earlier USGCRP-supported assessments, as well as other sectoral, regional, national, and international assessments. The CCRI will place enhanced emphasis on the extraction of mature, peer-reviewed scientific knowledge from the core research program for use in assessment and decision support.

Resources to Support Adaptive Management and Planning



Adapting to climate variability and change and their potential impacts poses challenges and opportunities for management of resources, infrastructure, and the economy. The pressures of increased population densities and intensified land use, common throughout much of the United States and other nations, increase the demand for effective management of resources sensitive to climate in many regions. For example, information on short-term climate variability (i.e., weekly, monthly and seasonal forecasts) is relevant for the development of state and regional drought action plans, agricultural operations management, water resource system management, and fishery management.

CCSP decision support resource activities will play an important role in the "transition from research to operations" for major elements of the underlying research. CCSP research results, data products, forecasts, and model results are already being applied to adaptive management decision support in a limited number of regional and sectoral case studies. Elements of climate and associated ecosystem observations from satellite, ground-based, and *in situ* platforms are also being synthesized into useful data products for decisionmakers. Examples include a variety of maps for crop management, water quality management, and urban planning, and integrated products illustrating snowpack, precipitation, streamflow, and potential for drought conditions.

Observations and increased understanding of El Niño-Southern Oscillation (ENSO) have led to useful predictions of El Niño events at lead times of up to several months. These climate forecasts have provided information for state and local emergency preparedness organizations; water resource management plans for the western regions; agricultural planning for the U.S. Southeast; and fire management for

drought-stricken regions. Decision support tools are also employed by federal agencies to serve the public in local and regional decisionmaking and include applications in the management of carbon, water, disasters, invasive species, and coastal ecosystems along with information on public health, agriculture efficiency, and energy use. All of these products have been co-developed by scientists and users after extensive dialogues.

The CCSP will play an important role in generating improved processes and products relevant to adaptive management decisionmaking. Decision support for adaptive management requires advances in basic knowledge and progress in applying scientific information within adaptive management settings. Conducting research within a decision support framework is intended to provide multiple benefits for both managers and scientists. Ideally, users of research information are served so that new options exist for minimizing negative impacts or pursuing opportunities, and researchers benefit from refinement and prioritization of research agendas through the identification of the uncertainties most relevant to decisionmaking.

Methods to Support Climate Change Policymaking

Policy-related questions regarding climate change typically arise from numerous sources, for example from:

- Consideration of climate change policy within the Federal government
- Proposals advanced by private and nongovernmental organizations
- Preparation for international negotiations
- Consideration of legislative proposals
- Priority setting processes for science and technology programs.

The CCSP will work in close collaboration with the Climate Change Technology Program to develop evaluations of relevant policy questions that incorporate up-to-date knowledge of both scientific and technology issues. The CCSP will focus on two objectives in this area: (1) developing scientific syntheses and analytical frameworks ("resources") to support integrated evaluations, including explicit characterization of uncertainties to guide appropriate interpretation; and (2) initially conducting a limited number of case studies with evaluation of the lessons learned, to guide future analyses.

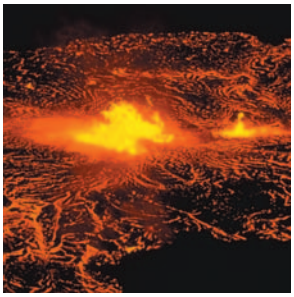
HIGHLIGHTS OF RECENT RESEARCH AND PLANS FOR FY 2004 AND FY 2005

HIGHLIGHTS OF RECENT RESEARCH AND PLANS FOR FY 2004 AND FY 2005

The CCSP participating agencies coordinate scientific research through a set of seven linked interdisciplinary research elements, which together support scientific research across a wide range of interconnected issues of climate and global change. These research elements pertain to major components of the Earth's environmental and human systems, which are undergoing changes caused by a variety of natural and human-induced causes. The CCSP Strategic Plan (Chapters 3-9) contains a more detailed discussion of the research elements and the set of strategic research questions associated with each element. This report will focus primarily on highlights of recent research and program plans for FY 2004 and FY 2005.

The research elements include:

Atmospheric Composition—CCSP-supported research focuses on how the composition of the global atmosphere is altered by human activities and natural phenomena, and how such changes influence climate, ozone, ultraviolet radiation, pollutant exposure, ecosystems, and human health. Specific objectives address processes affecting the recovery of the stratospheric ozone layer from reduced ozone levels observed in recent decades; the properties and distributions of greenhouse gases and aerosols; long-range transport of pollutants and implications for regional 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 stratospheric water vapor and ozone, or the potential effects of global climate change on regional air quality—are of particular interest at present.



Climate Variability and Change—CCSP-supported research on climate variability and change focuses 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. Specific objectives include improved predictions of seasonal to decadal climate variations (such as predictions of El Niño and La Niña events); 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 development of approaches (including characterization of uncertainty) to inform national dialogue and support public and private sector decisionmaking.

Global Water Cycle—CCSP-supported research on the global water cycle focuses on how natural processes and human activities influence the distribution and quality of water within the Earth system, whether changes are predictable, and on the effects of variability and change in the water cycle on human systems. 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 time scales of months to years and longer; and modeling physical/biological and socioeconomic processes to facilitate efficient water resources management.

Land-Use/Land-Cover Change—CCSP-supported research on land-use and land-cover change will focus on: (1) the processes that determine the temporal and spatial distributions of land cover and land use at local, regional, and global scales, and how and how well land use and land cover can be projected over time scales of 5 to 50 years; and (2) how changes in land use, management, and cover may affect local, regional, and global environmental and socioeconomic conditions, including economic welfare and human health, taking into consideration socioeconomic factors and potential technological change. Specific foci will identify and quantify the human drivers of land-use and land-cover change; improve monitoring, measuring, and mapping of land use and land cover, and the management of these data; and develop projections of land-cover and land-use change under various scenarios of climate, demographic, economic, and technological trends.

Global Carbon Cycle—CCSP-supported research on the global carbon cycle focuses on identifying the size, variability, and potential future changes to reservoirs and fluxes of carbon within the Earth system; and providing the scientific underpinning for evaluating options to manage carbon sources and sinks. Specific programs and projects focus on North American and oceanic 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.

Ecosystems—CCSP-supported research on ecosystems focuses on: (1) how natural and human-induced environmental changes interact to affect the structure and function of ecosystems (and the goods and services they provide) 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 may have to ensure that desirable ecosystem goods and services will be sustained, or enhanced, in the context of still uncertain regional and global environmental changes. Among the specific focus areas are the cycling of nutrients such as nitrogen and how these nutrients

interact with the carbon cycle; key processes that link ecosystems with climate; and options for managing agricultural lands, forests, and other ecosystems to sustain goods and services essential to societies.

Human Contributions and Responses—CCSP-supported research on human contributions and responses to global change focuses on the interactions of changes in the global environment and human activities. The current focus of this research is on the potential effects of climate variability and change on human health and welfare; human influences on the climate system, land use, and other global environmental changes; analyses of societal vulnerability and resilience to global environmental change; decisionmaking under conditions of significant complexity and uncertainty; and integrated assessment methods.

1 Atmospheric Composition

Strategic Research Questions

3.1 What are the climate-relevant chemical, microphysical, and optical properties, and spatial and temporal distributions, of human-caused and naturally occurring aerosols?

3.2 What are the atmospheric sources and sinks of the greenhouse gases other than CO_2 and the implications for the Earth's energy balance?

3.3 What are the effects of regional pollution on the global atmosphere and the effects of global climate and chemical change on regional air quality and atmospheric chemical inputs to ecosystems?

3.4 What are the characteristics of the recovery of the stratospheric ozone layer in response to declining abundances of ozone-depleting gases and increasing abundances of greenhouse gases?

3.5 What are the couplings and feedback mechanisms among climate change, air pollution, and ozone layer depletion, and their relationship to the health of humans and ecosystems?

See Chapter 3 of the *Strategic Plan for the U.S. Climate Change Science Program* for detailed discussion of these research questions.

The composition of the atmosphere—its gases and particles—plays a critical role in connecting human welfare with global and regional changes because the atmosphere links all of the principal components of the Earth system. The atmosphere interacts with the oceans, land, terrestrial and marine plants and animals, and the cryosphere (regions of ice and snow). Because of these linkages, the atmosphere is a conduit of change.

Emissions from natural sources and human activities enter the atmosphere at the surface and are transported to other geographical locations and often higher altitudes.

Some emissions undergo chemical transformation or removal while in the atmosphere or interact with cloud formation and precipitation. Some natural events and human activities that change atmospheric composition also change the Earth's radiative (energy) balance. Subsequent responses to changes in atmospheric composition by the stratospheric ozone layer, the climate system, and regional chemical composition (air quality) create multiple environmental effects that can influence human health and natural systems.

Changes in atmospheric composition are indicators of many potential environmental issues. Observations of trends in atmospheric composition are among the earliest harbingers of global changes. For example, the decline of the concentrations of ozone-depleting substances, such as the chlorofluorocarbons (CFCs), has been the first measure of the effectiveness of international agreements to end production and use of these compounds.

A principal feature of the atmosphere is that it acts as a long-term "reservoir" for certain trace gases that can cause global changes. The long removal times of some gases, such as CO_2 (more than 100 years) and perfluorocarbons (more than 1,000 years), imply that any associated global changes could persist over decades, centuries, and millennia—affecting all countries and populations.

The overall research approach for understanding the role of atmospheric composition is an integrated application of long-term systematic observations, laboratory and field studies, and modeling, with periodic assessments of understanding and significance to decisionmaking. Most of the activities related to atmospheric composition research are part of national and international partnerships. Such partnerships are necessitated by the breadth and complexity of current issues and because the atmosphere links all nations. Current research on atmospheric composition is based on the substantial body of knowledge and understanding available from the work of many scientists.

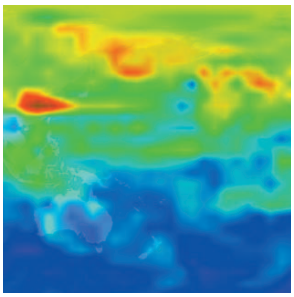
Highlights of Recent Research

Highlights of recent research supported by CCSP participating agencies follow.

Global atmospheric methane levels constant. Increases in methane are the second most important contribution to the radiative forcing of climate from human activities. Methane has a relatively short lifetime in the atmosphere. The globally averaged abundance of methane is monitored using an extensive network of surface sampling sites. Methane growth rates in the atmosphere have been steadily decreasing

since 1985. Recent analysis now shows that global methane abundances have been constant from 1999 through 2002. This lack of change strongly suggests that methane may have reached a steady state in the atmosphere determined by a balance between methane emissions and removal processes. The annual averages also show an abrupt drop in the early 1990s in the difference between methane values in the Northern and Southern Hemispheres. This change is attributed to reductions in emissions from the former Soviet Union, which might have accelerated the approach to steady state conditions. Future global measurements will continue to be of great importance to improve our understanding of the global methane budget.

Global aerosol measurements. Observational studies have identified chemical markers for distinct aerosol sources such as smoke from forest fires and African dust. These markers can be used to identify aerosol transported over continental and intercontinental scales. Ground-based measurement stations in California and in the Azores—two key aerosol observing sites in an emerging global network—have been of particular value in recent studies. Data from ground-based sites obtained during the Intercontinental Transport and Chemical Transformation (ITCT-2K2) field campaign suggest that the springtime background aerosol found in the western United States was Asian in origin.



The ability to characterize and understand the nature and origins of atmospheric aerosols is rapidly improving. In an intensive field campaign, detailed investigations were undertaken of the composition, size, shape, and mixing state of individual particles of mineral dust and urban aerosols originating from East Asia—a region that is the source of substantial emissions, dust storms, and pollution plumes. The optical properties (important for understanding the role of aerosols in climate change) varied significantly depending on the mixture of components, and a range of shapes of elemental carbon-containing aerosols was observed.

In addition, models for aqueous and gas-phase chemistry are being coupled with thermodynamic models for an improved description of aerosol-gas-cloud interactions.

New techniques for aerosol measurements. Rapid progress in new techniques for aerosol measurements promises to improve the ability to characterize aerosols in future field and laboratory studies. NOAA, NASA, and NSF have supported several new analytical techniques developed to probe aerosol composition that are proving effective in identifying aerosol sources and changes in composition. Examples include aerosol sampling with mass spectrometers, liquid surfaces, improved rotating drum impactors, and relative-humidity-controlled samplers, and an aerosol analytical method based on synchrotron spectroscopy.

Efforts at the National Institute of Standards and Technology (NIST) have also focused on improving the accuracy of thermal-optical analysis, a method widely used

for monitoring black carbon levels. In another NIST effort to study the effect of soot on radiative transport in the atmosphere, quantitative measurements were performed on the extinction coefficient of soot in the infrared region.

Scientific assessment of ozone layer depletion. In the 2002 *Scientific Assessment of Ozone Depletion*, published in 2003, the world's leading scientists defined the current understanding of the ozone layer and the phenomenon of stratospheric ozone depletion. This global, multiagency effort was led by NOAA, NASA, the European Commission, the UN Environment Programme, and the World Meteorological Organization. Scientists in several agencies and in academia played leading roles in authoring the report, as well as carrying out its review and final publication. The Ozone Assessment plays a particularly unique role as a "bridge" between the scientific community and decisionmakers and is designed to underpin future international decisions about ozone-depleting substances and the protection of the ozone layer.

Findings of the 2002 Ozone Assessment include an update on atmospheric processes underlying ozone abundance at the poles and globally, observations of ozone-depleting substances in the atmosphere, expectations for recovery of the ozone layer, and approaches to evaluating the ozone-layer impacts of very short-lived halogen-containing substances. Antarctic ozone depletion has been found to be large throughout the last decade. The size of the Antarctic ozone hole in September 2003 is the largest on record. It is not yet possible to say whether the annual peak in the area of the ozone hole has reached its maximum. The abundance of ozone-depleting compounds controlled by the Montreal Protocol continues to decline slowly in the lower atmosphere. The assessment concludes that the global ozone layer is expected to begin

Figure 4:
Covers of three 2002 Ozone Assessment reports.

recovery within the next decade or so, assuming continued international compliance with the Montreal Protocol. The ozone layer will remain particularly vulnerable during the next decade because halogen-containing gases in the stratosphere will be at their greatest values.

Splitting of the 2002 Antarctic ozone hole. The Antarctic ozone hole is a springtime fixture in southern high latitudes, occurring every year in the stratosphere as the result of high chlorine and bromine levels and low winter temperatures. In late September 2002, a major sudden warming occurred in the Southern Hemisphere stratosphere (see Figure 5). This unusual event split the polar vortex and the associated Antarctic ozone hole into two distinct parts. An unexpected major warming such as that observed in 2002 likely occurs only once a century and, hence, does not change the predictions of ozone recovery in the next decades as chlorine and bromine levels decline in the global stratosphere. Year-to-year changes in ozone hole area (or depth) are more likely to reflect changes in stratospheric "weather" conditions, rather than longer term changes in chlorine and bromine levels. NASA, NOAA, and NSF are supporting model evaluations of this unusual event to further our understanding of stratospheric transport and dynamics.

Observations and modeling of Asian pollution outflow. Emission inventories for atmospheric constituents are essential inputs to models used for simulating and projecting changes in air quality and climate. These inventories are constructed in what is known as the 'bottom up' method by using current knowledge of consumption

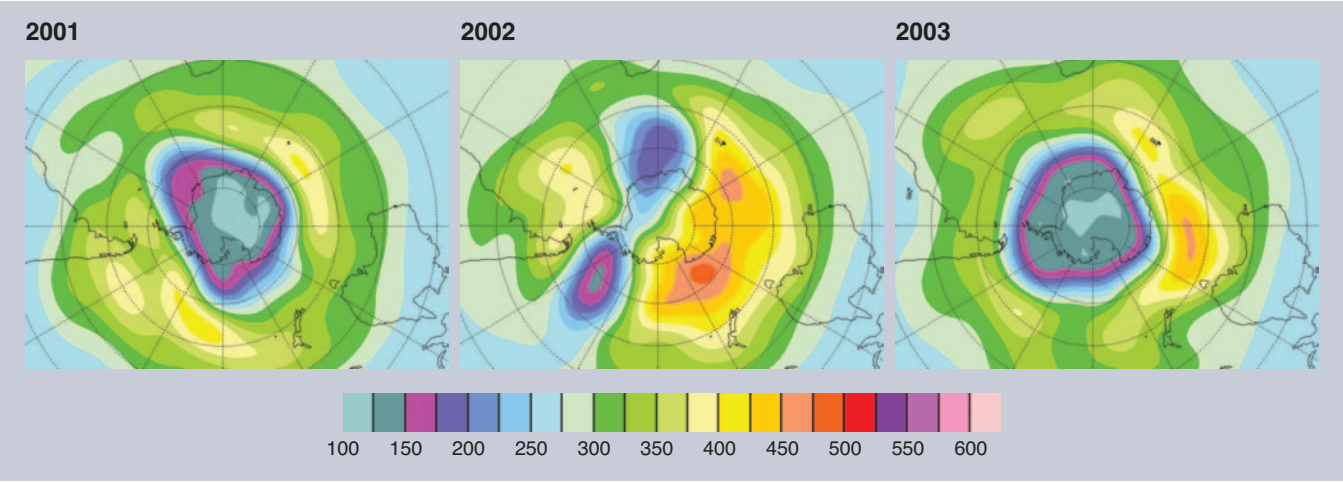
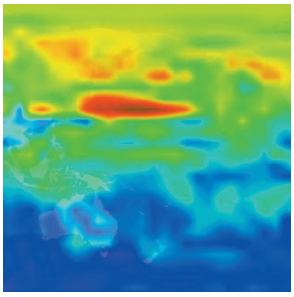
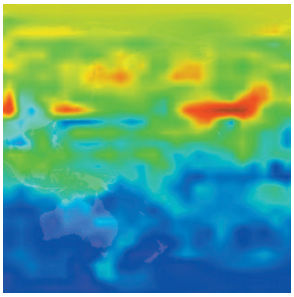


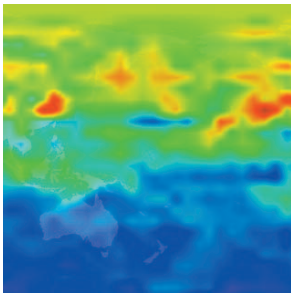
Figure 5: Satellite maps of total ozone over Antarctica on 24 September 2001, 2002, and 2003. The color scale shows the amount of ozone in Dobson units, indicating the depth of the hole. The images are based on multiple satellite records and analyses.
*Credit: Susan Solomon, "The hole truth." Nature, **427**, 22 January 2004. World Ozone and Ultraviolet Radiation Data Centre, Toronto, Canada.*

and practices in various nations, regions, and economic sectors. Recently, much progress has been made in demonstrating the value of global satellite and airborne observations for improving knowledge of emissions inventories, through combining the bottom-up derived information with 'top-down' data derived from observations. NASA's Transport and Chemical Evolution over the Pacific (TRACE-P) mission integrated aircraft and satellite data with chemical transport models (CTM) to analyze Asian carbon monoxide (CO) sources. A central objective of TRACE-P was to improve knowledge of Asian emission inventories through the addition of top-down constraints derived from observations in airmass outflow from Asia. Asian emissions for the period of the TRACE-P mission, based on the best bottom-up data sets, were generated prior to the mission. These emission estimates were used by five different CTMs to forecast the location of pollution plumes and to direct the observing aircraft toward this Asian outflow, thereby optimizing the testing of the model forecasts. Validation of the satellite-based CO observations was conducted during the mission to provide a seamless aircraft-satellite CO data set. These TRACE-P CO data were then assimilated into the models and used to derive the emission inventories with a method known as inverse modeling. Major conclusions were that the bottom-up estimates of anthropogenic emissions from China were 50% too low, biomass burning emissions from southeast Asia were 60% too high, and Japan and Korean emissions were roughly correct. The advantage of the combined bottom-up and top-down approach has been demonstrated for other important atmospheric constituents, such as tropospheric ozone precursors and also for absorbing aerosols.





Effects of regional pollution on the global atmosphere. Substantial progress is being made in describing the fate of anthropogenic emissions in the global atmosphere. New measurement techniques and observational studies addressing regional pollution were supported by NOAA, NSF, and other agencies. Rapid airborne measurements of formaldehyde (CH_2O) provided new insight into the reactive intermediate products of volatile organic carbon (VOC) oxidation in petrochemical plumes. Since VOC oxidation drives ozone production in the polluted boundary layer, this is a valuable new tool to evaluate the effect of regional pollution on the global atmosphere. A new chemical ionization mass spectrometry technique is now available for organic nitrogen species, which will improve understanding of how nitrogen oxide emissions are chemically transformed and transported globally. Regional- and global-scale models have been linked to capture intercontinental transport of regional emissions and the results are being compared with observations from multiple ground-based sites.



Anthropogenic emissions in megacities. The growth of pollution sources in the world's megacites has reduced air quality for millions of inhabitants. A broad-based initiative has been developed for the Mexico City Metropolitan Area to address the

Figure 6:
Aerial photo taken during Mexico City Metropolitan Area (MCMA) 2003 Field Measurement Campaign.
Credit: MCMA 2003 Field Measurement Campaign.

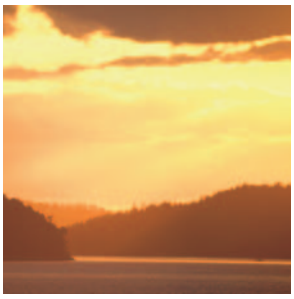
causes and possible solutions of the local and regional pollution that affects the area's large population. NSF and DOE supported deployment of state-of-the-art instruments near Mexico City in an April 2003 study in order to improve understanding of the space- and time-dependent nature of emissions and atmospheric composition in a developing megacity. Enhanced understanding of these emissions will lead to better assessment of the role of megacities in influencing regional and global air quality (see Figure 6).

Regional hydrocarbon pollution in the southwestern United States. Research in the southwestern United States has revealed significant quantities of light alkane hydrocarbons in the near-surface atmosphere of Texas, Oklahoma, and Kansas during both autumn and spring seasons. The levels are attributed to direct emissions from the oil and natural gas industries in the southwestern states. Observed alkyl nitrate mixing ratios in north-central Texas (maximum 34 ppbv ethane, 20 ppbv propane, and 13 ppbv n-butane) were comparable to urban smog values, with abundant formation of tropospheric ozone. Ozone production adversely affects human health and plant growth, and contributes to climate forcing. An estimated 4-6 teragrams of methane are released annually within the region, representing a significant fraction of the estimated total U.S. emissions. This result suggests that total U.S. natural gas emissions may have been previously underestimated. These measurements will lead to a more comprehensive understanding of U.S. greenhouse gas emissions and the role of fossil fuel hydrocarbon emissions in regional air quality.

Cirrus cloud study. A unique data set of properties of cirrus clouds was obtained in 2002 from a field campaign conducted in southern Florida. The Cirrus Regional Study of Tropical Anvils and Cirrus Layers - Florida Area Cirrus Experiment (CRYSTAL-FACE) was an interagency effort involving NASA, NOAA, NSF, DOE, and the Naval Research Laboratory. More than 60 *in situ* and remote measurements operated onboard six aircraft. Aircraft flights were coordinated with overpasses of instruments on the Terra and Aqua satellites in order to validate cloud and aerosol retrieval algorithms. Scientists are analyzing the multi-instrument data set to enhance understanding of the properties of cirrus clouds and their role in the climate system. CRYSTAL-FACE results published to date address the role of Saharan dust in cloud systems, the use of water isotope measurements to constrain the stratospheric dehydration process, the composition of cloud condensation nuclei, and the role of nitric acid in affecting relative humidity in low-temperature cirrus clouds.

Highlights of Plans for FY 2004 and FY 2005

The CCSP 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 2004 and FY 2005 are described below.



Tropospheric aerosols and climate. Atmospheric aerosols play a significant role in modifying the amounts of solar radiation absorbed at the surface and in the atmosphere. Changes in absorbed radiation can influence climate change, which can, in turn, affect the concentration of aerosols, especially on regional scales. The role of aerosols in climate processes will be examined as part of an international, interagency intensive field campaign based in the eastern United States in mid-2004. A joint NASA, NOAA, and DOE mission, using multiple instrumented aircraft, will make measurements focused on the properties and distribution of aerosols; processes affecting distribution; source-strength estimates; and radiative impact, with specific emphasis on regional and continental scales. Study objectives include using observations to diagnose the indirect effect of anthropogenic aerosols on cloudiness. Coordination with the NASA Aura and Terra satellites and the European Envisat satellite will facilitate connection with global data sets and provide validation to several satellite instruments. In separate studies, regular vertical profiling of aerosol parameters will be made from light aircraft. Data from these campaigns will be used to improve aerosol chemistry and transport models, and will address the CCSP aerosol transport/transformation and radiative impact priorities, as well as provide information that is common to a better understanding of both climate and air quality processes.

These activities will address Question 3.1 of the CCSP Strategic Plan.

CCRI PRIORITY - AEROSOLS

The Climate Change Research Initiative (CCRI) will accelerate research on aerosols and leverage existing USGCRP research to address major gaps in understanding climate change. Uncertainties related to the effects of aerosols on climate are large, with both warming and cooling effects possible depending on the nature and distribution of the aerosol.

Research has demonstrated that atmospheric particles (aerosols) can cause a net cooling or warming tendency within the climate system, depending upon their physical and chemical characteristics. Sulfate-based aerosols, for example, tend to cool, whereas black carbon (soot) tends to warm the system. In addition to these direct effects, aerosols can also have indirect effects on radiative forcing (e.g., changes in cloud properties). When climate models include the effects of sulfate aerosol, the simulation of global mean surface temperatures is improved. One of the largest uncertainties about the net impact of aerosols on climate is the diverse warming and cooling influences of the very complex mixture of aerosol types and their spatial distributions. Further, the poorly understood impact of aerosols on the formation of both water droplets and ice crystals in clouds also results in large uncertainties in the ability to project climate changes. More detail is needed globally to describe the scattering and absorbing optical properties of aerosols from regional sources and how these aerosols impact other regions of the globe.

The CCRI will advance the understanding of the distribution of all major types of aerosols and their variability through time, the different contributions of aerosols from human activities, and the processes by which the different contributions are linked to global distributions of aerosols. The CCRI will support research to improve understanding of the processes by which trace gases and aerosols are transformed and transported in the atmosphere. Studies of how atmospheric chemistry, composition, and climate are linked will be emphasized, including those processes that control the abundance of constituents that affect the Earth's radiation budget, such as tropospheric methane, ozone, and aerosols.

The global distributions of a limited number of atmospheric parameters (including climatically relevant parameters such as ozone and aerosols) and their variabilities will be obtained from satellite observations over long periods of time along with more comprehensive suites of observations over briefer time periods. Satellite data recently obtained and to become available for the first time for methane, tropospheric ozone, and tropospheric aerosols will be analyzed and interpreted in the context of global models and assimilation systems.

The studies will provide an observational- and model-based evaluation of the radiative forcings associated with aerosol direct and indirect effects. These forcing results will contribute to the CCSP climate projections for research and assessment.

Following the 2004 field mission, a major activity within NOAA, DOE, and NASA will be to analyze and interpret the field data set, with an emphasis on modeling. These efforts are expected to yield substantial information on the fate and transport of pollutants emitted from North America and how their chemical and radiative properties evolve as they move across the Atlantic Ocean. The data interpretation will demonstrate how combining information from multiple sampling platforms (e.g., aircraft and satellites) allows a more complete description of the transport and transformation processes. Innovative approaches to studying the radiative effects of aerosols will also have been part of the 2004 mission, with the results expected to decrease the uncertainty in understanding of aerosol climate effects. The results will make substantial contributions to national (CCSP 2006 products) and international (IPCC Fourth Assessment Report) assessments. Tangible results in the form of reports and peer-reviewed publications are expected to begin appearing by the end of 2005.

These activities will address Questions 3.1 and 3.3 of the CCSP Strategic Plan.

Investigations of aerosol-cloud-climate interactions will continue beyond 2004, with novel instruments, techniques, and approaches developed to study aerosol indirect effects. Studies already planned include, for example, using an aerosol-gas-cloud chemical model, newly coupled with a thermodynamic model, to investigate the effects of organic aerosols on cloud microphysical properties.

These activities will address Question 3.1 of the CCSP Strategic Plan.

In 2005, regular vertical profiling of aerosols also will continue, with the ultimate goal of developing an aerosol 'climatology' of North America. This continuous information will not only give scientists a comprehensive understanding of U.S. aerosol emissions, fate, and transport, but also will establish a baseline against which effects of policy measures to reduce human-induced aerosol emissions may be measured.

These activities will address Question 3.1 of the CCSP Strategic Plan.

Aura satellite launch. Researchers will begin examining data from the new Aura satellite scheduled to be launched in mid-2004. The satellite will carry four instruments designed to measure trace gases and aerosols in the troposphere and stratosphere. Aura measurements made in the troposphere using infrared emissions will provide an unprecedented data set from space on tropospheric composition. Using the measurements of tropospheric ozone, carbon monoxide, nitric acid, water vapor, and other trace gases, the transport and chemical transformation of anthropogenic pollution can be investigated from the local to global scale. Also measurements of stratospheric ozone, ozone-depleting gases, and other stratospheric gases will improve detection and attribution of ozone layer recovery in the coming years.

In 2005, the Aura satellite will be operational, producing large global data sets of trace gases and aerosols in the troposphere and stratosphere. The subsequent analysis and interpretation of these data sets by NASA, NOAA, NSF, and other agencies will be used to address a wide variety of research questions as noted above.

These activities will address Questions 3.2, 3.3, and 3.4 of the CCSP Strategic Plan.

Global transport of atmospheric pollutants. A 2004 study supported by NOAA and NASA will explore the processes governing the formation, transport, and fate of tropospheric ozone over northeastern North America and the North Atlantic Ocean. The instrumented aircraft and ship platforms involved in this study will be able to diagnose the sources of pollutants that increase regional ozone levels and follow the trajectories of emissions as they move eastward over the continental United States and ultimately offshore into the North Atlantic. With participation of European airborne platforms, the tracking of polluted air masses will continue across the Atlantic Ocean. This field research will address the need to quantify North American outflow of reactive

and long-lived gases and aerosols and to understand the balance between long-range transport and transformation of pollutants.

In 2005, a major activity within NOAA and NASA will be to analyze and interpret the field data sets obtained in the 2004 field mission. The results of these activities will yield insight into the effects of regional pollution on the global scale. The results will also form part of a detailed global survey of tropospheric ozone and its precursor species and provide valuable data for employing atmospheric chemistry models coupled with general circulation models to improve understanding of the feedbacks between regional air pollution and global climate change.

These activities will address Questions 3.2 and 3.3 of the CCSP Strategic Plan.

Megacity modeling studies. Data acquired in the Mexico City measurement-intensive study in April 2003 will be used to address the fate and impact of anthropogenic emissions from a megacity population. The study provided an unprecedented data set of emissions from the most polluted metropolitan area in the world. With NSF support, model studies will use the observations to constrain estimates of local and regional pollution transport and transformation. Of interest is the production of ozone and the formation of aerosols in the urban center and the export of ozone precursors and aerosols to the regional and global scale. Models are now able to incorporate emission sources on the subgrid scale in regional and global analysis.

These activities will address Questions 3.1, 3.2, and 3.3 of the CCSP Strategic Plan.

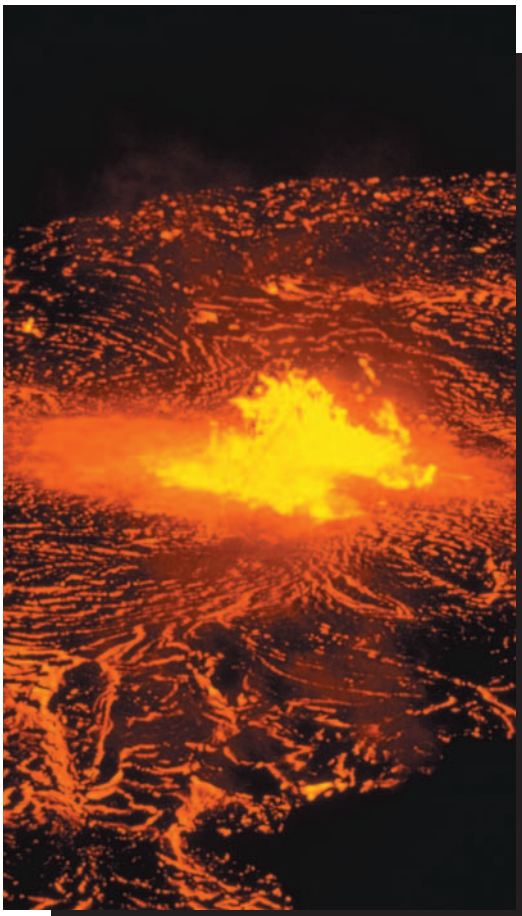
Consequences of climate change for U.S. air quality. A scenario-based assessment of the potential consequences of global change for regional U.S. air quality is being conducted, focusing on fine particles and ozone. The climate, emissions, and underlying socioeconomic scenarios are intended to provide a plausible depiction of future conditions, rather than predictions of what actually will happen. Research and assessment activities will focus on developing regional-scale inputs for air quality simulations, using the Community Multiscale Air Quality modeling system. The impacts of potential increases in transported pollutants due to further global industrialization, population growth, and increases in economic activity are also being assessed. The continuing research in FY 2004 and FY 2005 will build toward a 2007 assessment of changes in U.S. air quality due to climate change, which includes direct meteorological impacts on atmospheric chemistry and transport, and the effect of changes in temperature, cloud cover, and precipitation on air pollution emissions. Further research will result in a 2010 assessment that adds the emission impacts from technology, land use, and demographic changes to construct plausible scenarios of U.S. air quality 50 years into the future.

These activities will address Questions 3.3 and 3.5 of the CCSP Strategic Plan.

Figure 7:
The High-performance Instrumented Airborne Platform (HIAPER) aircraft.
Credit: University Corporation for Atmospheric Research.

Instrumenting the HIAPER research aircraft. In late FY 2004, a new platform for atmospheric research will be delivered. This new aircraft, a Gulfstream V (G-V), is designated as the High-performance Instrumented Airborne Platform (HIAPER, see Figure 7). The G-V's combination of payload capacity, altitude, and range make it an important new national resource for the study of meteorology and chemistry in the troposphere and lower stratosphere. Modifications specified by a scientific users group that will make the aircraft suitable for atmospheric research will be completed before delivery. In FY 2004, NSF will begin supporting the development and construction of new instrumentation for HIAPER. In FY 2005, the HIAPER aircraft will be fully flight tested, facility instrumentation will be evaluated, and one or more progressive science missions will be flown in preparation of the aircraft becoming formally available to the scientific community by the end of FY 2005.

The development of this platform and its instruments will potentially support a wide range of activities needed to address the Atmospheric Composition research element of the CCSP Strategic Plan.



2 Climate Variability and Change

Strategic Research Questions

4.1 To what extent can uncertainties in model projections due to climate system feedbacks be reduced?

4.2 How can predictions of climate variability and projections of climate change be improved, and what are the limits of their predictability?

4.3 What is the likelihood of abrupt changes in the climate system such as the collapse of the ocean thermohaline circulation, inception of a decades-long mega-drought, or rapid melting of the major ice sheets?

4.4 How are extreme events, such as droughts, floods, wildfires, heat waves, and hurricanes, related to climate variability and change?

4.5 How can information on climate variability and change be most efficiently developed, integrated with non-climatic knowledge, and communicated in order to best serve societal needs?

See Chapter 4 of the *Strategic Plan for the U.S. Climate Change Science Program* for detailed discussion of these research questions.

Climate variability and change can profoundly influence social and natural environments throughout the world, with consequent impacts on natural resources and industry that can be large and far-reaching. For example, seasonal to interannual climate fluctuations strongly affect agriculture, the abundance of water resources, and the demand for energy, while long-term climate change may alter agricultural productivity, land and marine ecosystems, and the goods and services that these ecosystems supply. Recent advances in climate science are providing information for decisionmakers and resource managers to better anticipate and plan for potential impacts of climate variability and change. Further advances will serve the nation by providing improved knowledge to enable more scientifically informed decisions across a broad array of climate-sensitive sectors.

Research on climate variability and change focuses on two overarching questions:

- How are climate variables that are important to human and natural systems affected by changes in the Earth system resulting from natural processes and human activities?
- How can emerging scientific findings on climate variability and change be further developed and communicated in order to better serve societal needs?

Addressing these questions requires recognition that the problems of climate variability and change cannot be cleanly separated, and that the success of understanding each will require improved understanding of both. Future changes in climate variability—for example, a variation in the frequency and nature of ENSO events or the severity and duration of droughts—will depend partly on changes in global (and regional) mean conditions. Conversely, climate variations influence global and regional heat and moisture distributions, and hence can substantially alter the global and regional mean response of the climate system to either natural or anthropogenic forcing. Further, demands for improved climate information span a broad range of time scales, ranging from assessments of current conditions and seasonal forecasts of climate variability that support resource management decisions, to longer term decadal- to centennial-scale projections of climate change that help inform infrastructure planning and policy development.

Current research activities on climate variability and change are directed toward understanding and, to the extent possible, reducing uncertainties in climate model projections; improving climate predictions on seasonal to interannual time scales; improving capabilities to detect, attribute, and project longer term climate changes; advancing understanding on the causes of past abrupt climate changes and the potential for future rapid changes; determining whether and how climate variations alter the frequencies, intensities, and locations of extreme events; and improving the development and communication of climate information to better the needs of the public and decisionmakers. Over the past year, significant advances have been made in several of these areas. Some of the research highlights are summarized below.

Highlights of Recent Research

Highlights of recent research supported by CCSP participating agencies follow.

Observed Arctic warming trend over the last 20 years. Observations of Arctic-wide surface temperatures using satellite data have shown that, over the period 1981-2001, the Arctic region warmed at an annual average rate of 0.3°C per decade over sea ice (considering those portions of the Arctic Ocean where 80% of ocean surface is covered by ice), 0.5°C per decade over the high latitude (poleward of 60°N) region of Eurasia, and 1.0°C over the high latitude region of North America. Temperature trends derived from surface data are similar over much of the Arctic, but differ in some sub-regions. In comparison, during the last 20 years the global annual average surface temperature has increased by about 0.2°C per decade. At the high northern latitudes, the warming trends are more pronounced in the spring and are also evident in summer and fall, resulting in a longer melt season for snow and ice on land and for annual sea ice.

Satellite data also show that the portion of the Arctic Ocean covered by perennial sea ice has declined by about 9% per decade since 1978. The longer melt season and loss of perennial sea ice cover can have large-scale climate consequences. They permit an increase in the amount of energy absorbed in the previously ice- or snow-covered

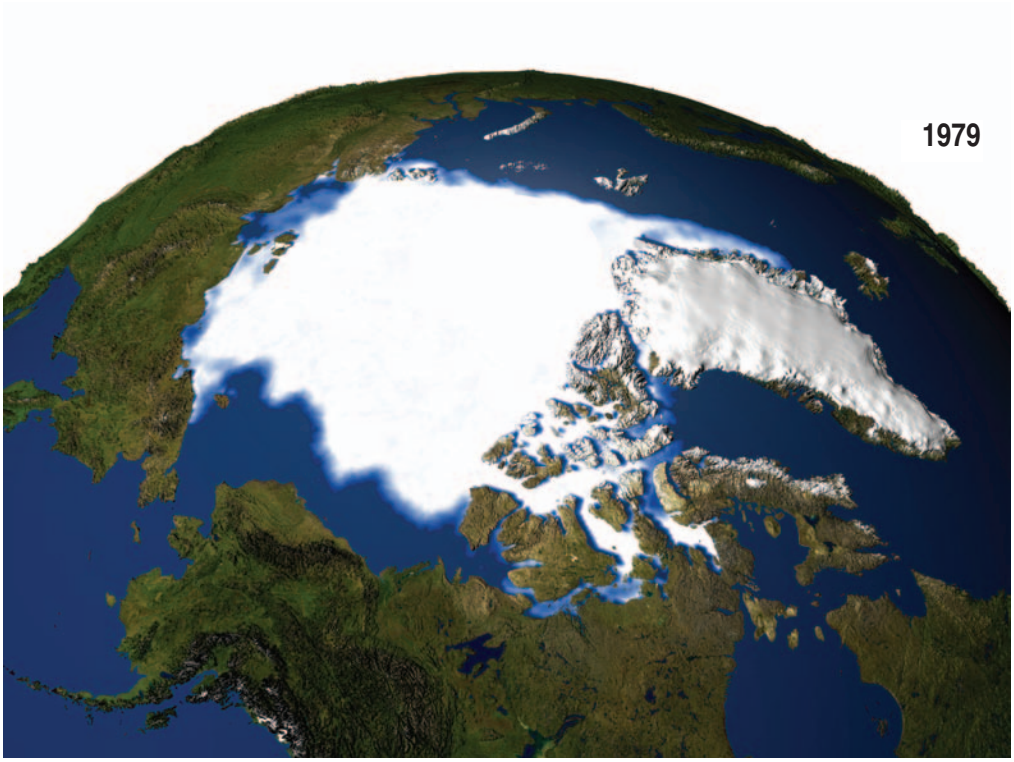


Figure 8: Between 1979 (left panel) and 2003 (right panel), Arctic perennial sea ice has been decreasing at a rate of 9% per decade. The lefthand image shows the minimum sea ice concentration for the year 1979, and the righthand image shows the minimum sea ice concentration in 2003. The data used to create these images were collected by the Defense Meteorological Satellite Program (DMSP). *Credit: NASA Goddard Space Flight Center.*

areas and, on land, permit increased growth of vegetation that also has a lower albedo (lower light reflectivity) than snow covered areas.

Climate models project that the high latitude regions are particularly sensitive to climate change because of the positive albedo feedback effects associated with reduction of ice and snow cover, and the reduction of thermal insulation of the ocean that sea ice cover provides, allowing increased heat transfer from the ocean to the atmosphere. However, there is as yet no direct evidence that greenhouse gas forcing, which drives the climate models, is responsible for the melting of sea ice and snow cover in the Arctic region.

The data also show regional differences that suggest there are other influences in addition to global-scale climate warming. A natural weather pattern called the North Atlantic Oscillation/Northern Annular Mode (NAO/NAM) may have contributed to regional variations as well as the overall decrease in Arctic sea ice cover over the last 20 years. Whether the ice cover as a whole will continue to exhibit the decreases that it experienced over the 1979 to 2003 period (see Figure 8) might depend on the strength and phase of the NAO/NAM, as well as on long-term trends in the climate system.

Increasing ocean heat storage. Simulations with an improved version of the NASA/GISS Global Climate Model indicate that the rate of heat storage by the world's oceans has increased from about 0.2 Wm^{-2} in 1951 to a present value of

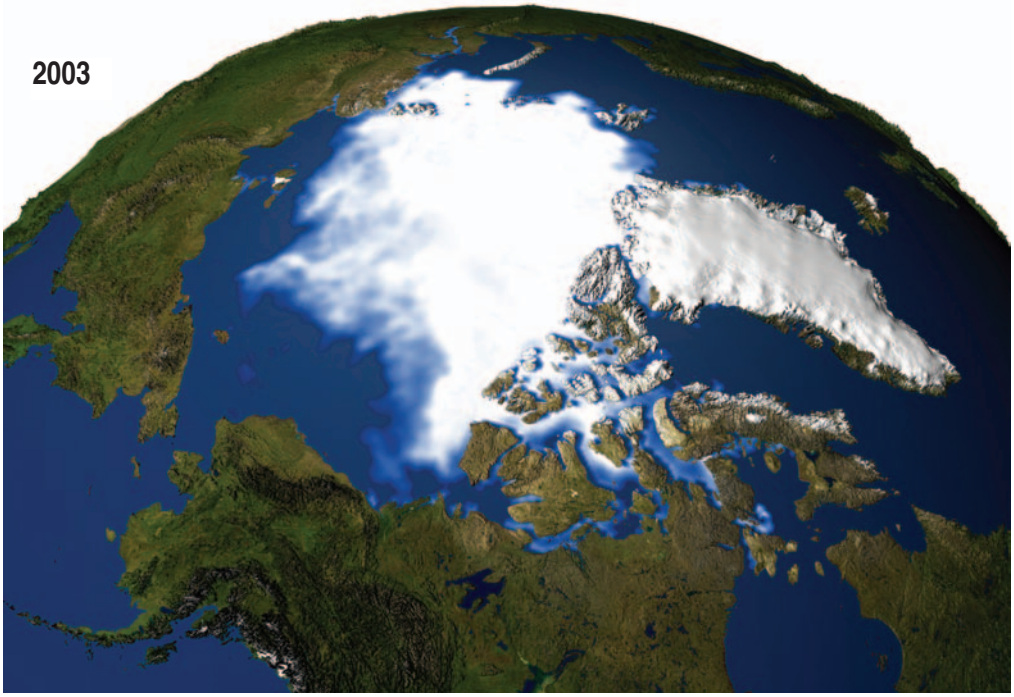
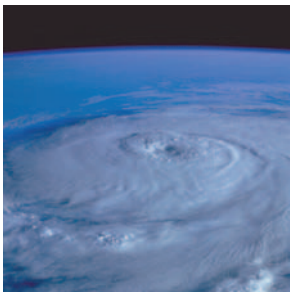


Figure 8 (continued):
Arctic sea ice cover, 1979 and 2003.



about 0.7 Wm^{-2} net downward flux (convergence) of heat into the ocean surface. This is the third independent climate model to produce such an increase, and compares well with observational analyses of changes in ocean heat storage. Since the ocean stores a large portion of the excess heat due to the imbalance of the radiation budget of the Earth's climate system, this work indicates that careful monitoring of the global distribution of ocean heat storage will be a key indicator for identifying changes in the climate system.

Change in the freshwater balance of the Atlantic Ocean. The distribution of salinity in the Atlantic Ocean has been sampled over a broad area during the last half-century. These historical data can be used to diagnose rates of surface freshwater fluxes, freshwater transport, and local ocean mixing—important components of climate. Recent research comparing observed salinities on a long transect through the western basins of the Atlantic Ocean between the 1950s and the 1990s found systematic increases in freshwater at high latitudes (at both poleward ends), contrasted with large increases of salinity at low latitudes. Although the observational record is insufficient to quantify a number of factors that may have contributed to these long-term trends, a growing body of evidence suggests that shifts in the oceanic distribution of fresh and saline waters are occurring in ways that may be linked to global warming and possible change in the global water cycle. Parallel changes in ocean salinity and temperature are occurring in other oceans as well.

20th century global sea-level rise. The rate and causes of 20th century global sea-level rise are subjects of intense debate. Direct observations, based on tide gauge records, suggest that the rate of sea-level rise is between 1.5 and 2.0 mm yr^{-1} (0.6 to 0.8 inches per decade). The two largest contributors to sea-level rise are thought to be volume changes due to ocean warming (thermal expansion) and the addition of mass due to the melting of polar ice sheets, although the magnitudes of these contributions are not well known. Scientists at NOAA's Laboratory for Satellite Altimetry analyzed tide gauge records, which reflect both volume and mass changes, and ocean temperature and salinity data, which reflect only volume changes, in the North Pacific and North Atlantic Oceans. They found that measurements of sea-level rise from tide gauges are two to three times higher than those from temperature and salinity measured regionally and near gauge sites. The data support earlier estimates of the 20th century rate of sea-level rise and, more importantly, also provide the first evidence suggesting that addition of mass due to the melting of polar ice sheets can play an important, perhaps dominant, role in sea-level rise.

Simulating 20th century climate. Multiple ensemble simulations of the 20th century climate have been conducted using climate models that include new and

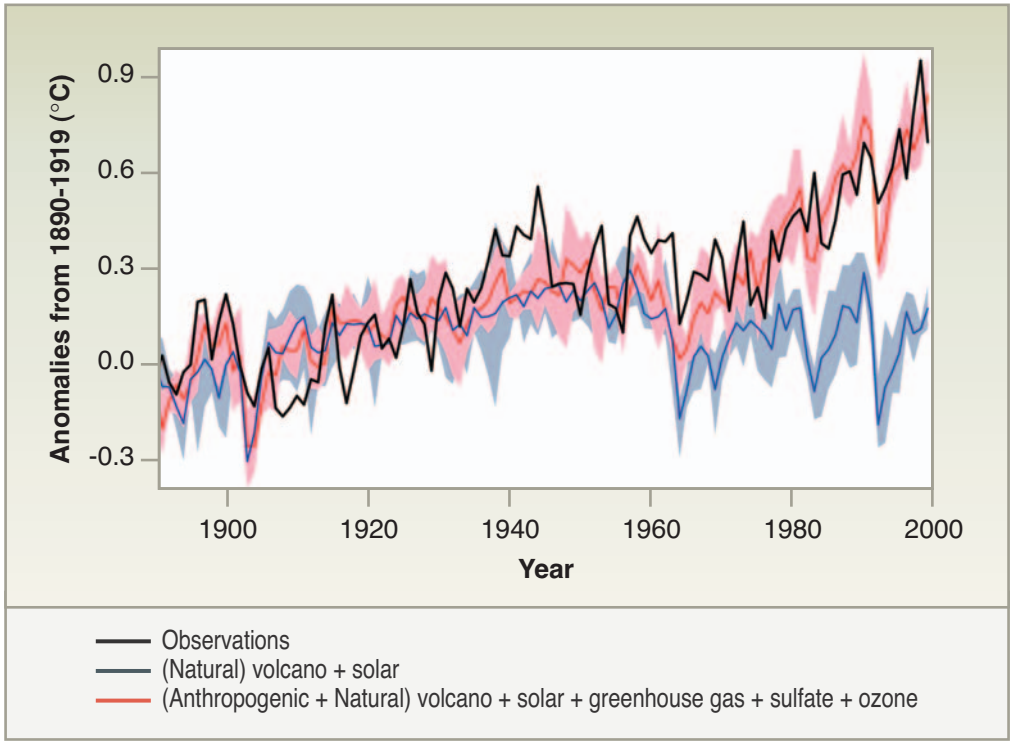


Figure 9:
Climate model simulations of the Earth's temperature variations compared with observed changes. Ensemble simulations were run with the global fully coupled DOE Parallel Climate Model (PCM) employing five forcing agents that influence the time evolution of globally averaged surface air temperature during the 20th century. Two of the forcings are natural (volcanoes and solar) and the others are anthropogenic [greenhouse gases, ozone (stratospheric and tropospheric), and direct effect of sulfate aerosols]. The figure shows global average temperature, relative to the 1890-1919 mean, over the time period 1890-1999. The black line shows observed temperature; the blue line shows ensemble mean temperature based on simulations using natural forcings only; and the red line shows ensemble mean temperature based on simulations using both natural and anthropogenic forcings. The shadings denote the ensemble ranges.
Credit: Meehl, G.A., et al., 2004: Combinations of natural and anthropogenic forcings and 20th century climate. J. Climate, in press. Observed temperature data (black line) from Folland, C.K., et al., Geophys. Res. Lett., ***28****, 2621-2624.*

improved estimates of natural and anthropogenic forcing. The simulations show that observed globally averaged surface air temperatures can be replicated only when both anthropogenic forcings—for example, greenhouse gases—as well as natural forcings such as solar variability and volcanic eruptions are included in the model. These simulations improve on the robustness of earlier work. Comparisons of model results with observations indicate that regionally concentrated increases in precipitation can occur as a function of variability in solar forcing (see Figure 9).

Detecting a human influence on North American climate. A recent study shows that the average global results reported above also pertain over the North American region. Several indices of large-scale patterns of surface temperature variation were used to investigate climate change in North America over the 20th century. The observed variability of these indices was simulated well by several climate models. Comparison of index trends in observations and model simulations shows that North American temperature changes from 1950 to 1999 were unlikely to be due only to natural climate variations. Observed trends over this period are consistent with simulations that include anthropogenic forcing from increasing atmospheric greenhouse gases and sulfate aerosols. However, most of the observed warming from 1900 to 1949 was likely due to natural climate variation.

Long-term drought reconstructions for North America. Tree-ring paleo-proxy records have been used to develop an animated atlas of North American drought for the last ~1,000 years. The data show annual (and even within-year) resolution of drought/wetness conditions across the United States and parts of Mexico and Canada. This synthesis provides a dramatic visual representation of changing climatic and environmental conditions over the region, including an indication that significantly more arid conditions existed in parts of the western United States prior to AD 1500. Such paleoclimate data help aid the understanding of climate mechanisms and impacts.

Origins of recent severe droughts in the Northern Hemisphere. Recent work provides compelling evidence that severe droughts that affected the United States, the Mediterranean region, and Southwest Asia simultaneously during 1998-2002 were part of a persistent climate state that was strongly influenced by the tropical oceans. The oceanic conditions of importance were unusually cold sea surface temperatures (SSTs) in the eastern tropical Pacific (i.e., persistent La Niña conditions) that occurred together with sustained above normal SSTs in the western tropical Pacific and Indian Oceans. The persistence of this abnormal tropical SST pattern was unprecedented in the instrumental record. A large suite of model simulations showed that this SST pattern was ideally suited to force atmospheric circulation anomalies that

CCRI PRIORITY - CLOUD AND WATER VAPOR FEEDBACKS AND OCEAN CIRCULATION AND MIXING PROCESSES

The Climate Change Science Program will address targeted climate processes known to be responsible for large uncertainties in climate predictions and projections. A new paradigm for conducting the research—Climate Process and Modeling Teams (CPTs)—will be used and evaluated.

Important processes that are inadequately represented in climate models include atmospheric convection, the hydrological cycle, and clouds and their net radiative forcing. Water vapor is the most important of the greenhouse gases, and clouds affect both vertical heating profiles and geographic heating patterns. Results from climate models suggest that there will be an overall increase in water vapor as the climate warms. However, scientists know neither how the amounts and distributions of water vapor and clouds will change as the total water vapor in the atmosphere changes, nor how the associated changes in radiative forcing and precipitation will affect climate. Improved representation of the distribution of and processes involving water vapor in climate models is therefore critical to improving climate change projections.

Ocean mixing plays a pivotal role in climate variability and change, and is a primary source of uncertainty in ocean climate models. The highly energetic eddies of the ocean circulation are not well resolved and cannot be sustained for the multiple thousands of years of simulations required to assess coupled climate sensitivity. This leaves the problem of parameterization of eddy fluxes as a key issue for improving coupled model simulations.

Accelerating improvements in climate models requires observational, process, and modeling programs coordinated by teams of scientists—that is, CPTs, an approach first proposed by the U.S. elements of the program on Climate Variability and Predictability (CLIVAR). A complete description of CPTs can be found on the U.S. CLIVAR website, <http://www.usclivar.org>. CPTs will rapidly identify, characterize, and ultimately reduce uncertainties in climate model projections as well as determine observational requirements for critical processes. For problems that are generic to all climate models (e.g., cloud processes and ocean mixing), CPTs will consist of teams of climate process researchers, observing system specialists, and modelers working in partnership with designated modeling centers.

were conducive to producing abnormally dry conditions in those regions where severe and sustained drought was observed.

Causes of the 1930s Dustbowl. A NASA atmospheric general circulation model was used to investigate the North American dustbowl drought during the 1930s. Ensemble simulations using observed sea-surface temperatures show that principal causes of the Great Plains drought were the anomalous tropical SSTs during the 1930s in the Pacific and, to a lesser extent, the Indian and Atlantic Oceans. Land-surface feedbacks were also essential to the development and maintenance of the severe drought conditions.

Role of stratosphere. Recent observational analyses suggest that, together with the tropical oceans, the stratosphere increases the 'memory' of the climate system, and also may influence long-term variations in the polar ice pack, sea surface temperatures, and the deep ocean circulation. This stratosphere-troposphere connection has important implications for the prediction of the response of tropospheric climate under increasing concentrations of greenhouse gases. Currently, sophisticated climate models differ as to whether the stratospheric polar vortex, a key part of the connection, will strengthen or weaken with increasing concentrations of greenhouse gases.

Role of aerosol infrared forcing. A crucial factor limiting the predictability of global climate is the large uncertainty about the precise effects of aerosols on Earth's radiation balance. Most large-scale global climate models include the direct radiative effects of aerosols at higher wavelengths, but few consider aerosol radiative properties in the infrared (IR) region. Measurements of clear-sky IR spectra, performed during a cruise across the western Pacific Ocean, revealed aerosol forcings of up to 10 Wm^{-2}. These values are quite large compared to the 1-2 Wm^{-2} forcing estimated for greenhouse gas accumulations since the beginning of the industrial revolution. Based on these measurements and analyses, aerosol IR effects will be included in the next version of the National Center for Atmospheric Research (NCAR) Community Climate System Model.

Effects of Indo-Pacific ocean mechanisms. A new multi-year assimilation of *in situ* and satellite data into an ocean model highlighted the importance of the interior ocean mechanisms (as compared to boundary currents such as the Gulf Stream) on time scales of weeks to months. Investigators found these mechanisms in the interior ocean play a critical role in altering the water mass exchanges between the midlatitude eastern Pacific Ocean and the the tropical Pacific where El Niño develops, suggesting that remote effects on El Niño should be more carefully considered by prediction models. Further, these relatively fast mechanisms were found to govern more generally

CCRI PRIORITY - POLAR FEEDBACKS

The Climate Change Research Initiative will leverage existing USGCRP research to address major gaps in understanding climate change. Polar systems may be especially sensitive to climate change and might provide early indications of climate change as well as interact with climate variability and change through several important feedback processes.

The CCRI will support research to improve understanding of processes that determine the behavior of slowly varying elements of the physical climate system, especially the oceanic and cryospheric portions. Particular foci include the processes by which the ice-covered regions of the high latitude Earth behave, the processes by which the distribution of sea ice varies, and the way in which knowledge of ocean circulation can be enhanced through use of global observations of ocean state and forcing parameters. The development and testing of new capabilities for measuring climatic properties, such as ocean surface salinity, mixed layer depth, and ice sheet thickness also will be carried out.

The CCRI will support the obtaining of systematic data sets for a limited number of Earth system parameters such as ice thickness, extent, and concentration in the case of sea ice, and mass balance and surface temperatures in the case of land ice and snow cover. It will shortly enable the initiation of regular observations of ice sheet thickness. Data assimilation systems using satellite data that provide for accurate, geophysically consistent data sets will also be carried out through this program. The polar feedbacks research will contribute to decision support through cryospheric observations and associated models that enable the initialization and verification of climate models, and the reduction in uncertainty of model output. The models also will provide real-time information for use by the U.S. Navy and commercial maritime interests in high latitude regions.

the transports and exchanges between the tropical and midlatitude ocean and thus could be an important factors for observing and modeling the longer term changes (e.g., interannual to decadal variability) of the Pacific Ocean.

Diagnostic for evaluating climate model performance. Scientists developed the Broadband Heating Rate Profile (BBHRP), a new model diagnostic that will help reduce a significant obstacle to improving the predictive accuracy of climate models—the ability to accurately quantify the interaction of the clouds, aerosols, and gases in the atmosphere with radiation. Because direct observation of these interactions is extremely difficult, there has been no observation standard with which to compare and judge the accuracy of climate model simulations. The BBHRP, which is based on an assimilation of detailed field measurements from the Atmospheric Radiation Measurement program, provides a realistic estimate of radiative heating or cooling impact of clouds, aerosols, and gases. This diagnostic can be directly compared to the model-predicted impacts, thus enabling model uncertainties to be evaluated.

CCSP CLIMATE MODELING STRATEGY

The CCSP strategy to accelerate climate model development and increase climate modeling capacity has three goals:

1) Improve the scientific basis of climate and climate impacts models.
2) Provide the infrastructure and capacity necessary to support a scientifically rigorous and responsive U.S. climate modeling activity.
3) Coordinate and accelerate climate modeling activities and provide relevant decision support information on a timely basis.

See Chapter 10 of the *Strategic Plan for the U.S. Climate Change Science Program* for detailed discussion of the CCSP modeling strategy.

Highlights of Plans for FY 2004 and FY 2005

The CCSP will continue to enhance observational and modeling capabilities for improved understanding, prediction, and assessment of climate variability and change on all time scales. Climate Variability and Change modeling activities will be linked with the CCSP climate modeling strategy.

Key Climate Modeling Research Plans for FY 2004 and FY 2005

Continue development of next generation climate models. Work is underway to develop the next generation of global climate models at the major modeling centers in the United States. The research will produce improved representation of physical processes (e.g, convection and clouds) and more complete and improved representations of coupled interactive atmospheric chemistry, terrestrial and marine ecosystems, biogeochemical cycling, and middle atmospheric processes. This work is being initiated in FY 2004 and will be ongoing in FY 2005.

These activities will address Goal 1 of the CCSP modeling strategy.

Improve climate model evaluation and modeling infrastructure. Infrastructure for major model evaluation and improvement will be provided, coordination of model intercomparisons will be conducted, and model testbeds for parameterization testing will be maintained by the DOE Program for Climate Model Diagnosis and Intercomparison. A major effort will be dedicated to providing a robust and extensible software engineering framework for the Community Climate System Model, a code used by hundreds of researchers on many different high-end computing platforms. This work is now underway and will continue in FY 2005.

These activities will address Goal 1 of the CCSP modeling strategy.

Enhance computer capabilities at the Geophysical Fluid Dynamics Laboratory (GFDL) to support the Climate Change Technology Program. The NOAA GFDL supercomputing capability will be enhanced in FY 2004 to enable additional climate projections for research and assessment based on emissions scenarios developed through the CCTP. Likely case studies will include exploring the range of plausible future environmental consequences of different emission rates resulting from combinations of new technologies.

These activities will address Goal 2 of the CCSP modeling strategy.

Perform multi-century simulations and projections for the IPCC Fourth Assessment Report. Scientists at GFDL, NCAR, and six DOE National Laboratories will complete the production of ensemble multi-century global simulations and projections of climate variability and change for use in the Intergovernmental Panel

on Climate Change Fourth Assessment Report. Some of these simulations will be modeled at twice the resolution used in the past in order to provide more useful information for downscaling results to regional scales. This, in turn, can enhance the capability of climate impacts scientists and other researchers to produce environmental information to support informed resource management and policymaking. This work will begin in FY 2004 and continue through FY 2005.

These activities will address Goal 3 of the CCSP modeling strategy.

Further implement the Earth System Modeling Framework. The Earth System Modeling Framework project will be enhanced and will produce initial climate simulation experiments in FY 2004, continuing through FY 2005. Several existing ocean and atmospheric models from NASA, NOAA, NSF, DOE, and university labs will be connected and coupled to produce new prototype modeling systems. This is a major milestone to enable full interoperability among atmosphere, land, ocean, and other models to improve the fidelity and predictive capability of the models.

These activities will address Goal 3 of the CCSP modeling strategy.

Key Observations and Process Studies Research Plans for FY 2004 and FY 2005

Continue research by Climate Process and Modeling Teams. DOE, NASA, NOAA, and NSF have jointly initiated three CPTs. These CPTs are focusing their research on cloud feedbacks and ocean mixing—high-priority climate processes that are responsible for climate model deficiencies and thus uncertainties in climate change projections. This work will continue through FY 2005.

These activities will address Question 4.1 of the CCSP Strategic Plan, and Goals 1 and 3 of the CCSP modeling strategy.

Assess aerosol impact on cloud and water vapor feedbacks and climate change. A focused research effort on the aerosol impact on cloud-radiation feedback and climate change will be initiated by coupling atmospheric chemistry, radiation science, and global modeling. The focused effort, which will continue through FY 2005, will develop improved representations of the aerosol impact on cloud and water vapor feedback processes in climate models. This is a collaborative effort with the CCSP Global Water Cycle research element.

These activities will address Question 4.1 of the CCSP Strategic Plan.

Assess impact of climate forcings on long-term climate change. NASA's Goddard Institute for Space Studies (GISS) will systematically change the climate forcings in its modeling experiments to evaluate the relative impact on long-term climate change and to understand the climate sensitivities to the various forcings. This research, initiated in FY 2004 and continuing until at least FY 2006, is an important

step in building capability to provide answers to "if…then" questions relevant to resource management and environmental policy.

These activities will address Questions 4.1 and 4.2 of the CCSP Strategic Plan.

Improve subsurface ocean observations. The international Argo collaboration will establish a global network of free-drifting floats equipped with sensors for measuring the temperature and salinity of the upper 2000 meters of the oceans. Argo will allow, for the first time, continuous monitoring of the climate state of the oceans, with all data being relayed and made public within hours after collection. Data from the Argo floats will be used both operationally and in climate research programs. Argo float deployments began in 2000 and will continue during FY 2004 and FY 2005, with completion of the full array to be achieved over the next several years.

These activities will address Questions 4.1 and 4.2 of the CCSP Strategic Plan.

Obtain new high-density global observations of atmospheric temperature and water vapor. The United States—with participating agencies NSF, DOD (Space Test Program, U.S. Air Force, U.S. Navy), NASA, and NOAA—in partnership with Taiwan will launch six low Earth orbit (LEO) satellites, each carrying a set of instruments designed to measure high-resolution vertical profiles of atmospheric temperature and water vapor. This Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) project will provide approximately 3,000 vertical soundings per day, uniformly distributed over the globe. This will be an improvement over the current global radiosonde network of balloon-borne instruments, especially over the oceans and polar regions. The current system, which is the mainstream observational network for operational weather and climate prediction and research, obtains about 600 soundings twice a day. COSMIC will complement rather than replace the current system. Launch is scheduled for September 2005.

These activities will address Questions 4.1 and 4.2 of the CCSP Strategic Plan.

Develop an assimilated long-term global ocean circulation data set. Researchers working on the Estimating the Circulation and Climate of the Ocean (ECCO) project, formed under the National Ocean Partnership Program (NOPP), will initiate the production of an assimilated decadal ocean data product at near-eddy-resolving scale (1/4 degree) in FY 2004. Data analysis will continue into FY 2005.

These activities will address Question 4.2 of the CCSP Strategic Plan.

Continue research on thinning and acceleration of sensitive glaciers in Antarctica. Satellite radar data have shown that the area around the Thwaites and Pine Island Glaciers—known as the "weak underbelly of the West Antarctic Ice Sheet"—has experienced thinning in recent years in a manner that is consistent with observed glacier acceleration. This thinning appears to be contributing to sea-level

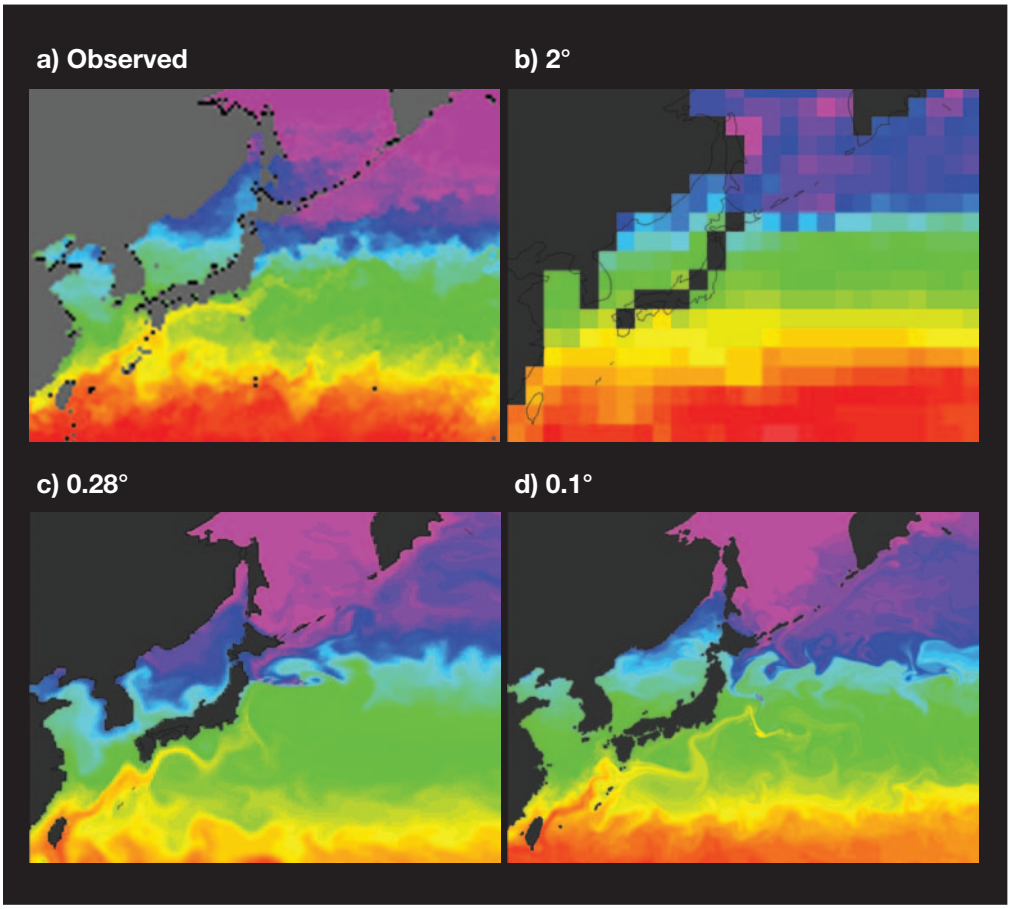


Figure 10: Sea surface temperature in the northwest Pacific Ocean from (a) satellite data, (b) a 2x2-degree non-eddy-resolving simulation, (c) a 0.28-degree eddy-permitting simulation, and (d) a 0.1-degree eddy-resolving simulation. All simulations were performed using the Parallel Ocean Program (POP). The detail is much more realistic in the two high-resolution cases, but only the eddy-resolving case can simulate the Kuroshio current separation—the point at which the warm Kuroshio current separates from the coast of Japan and extends into the Pacific. Currents like the Kuroshio and the Gulf Stream are responsible for transporting heat and other quantities to high latitudes and strongly affect the climate in regions including northern Europe. Accurate simulations of these current systems are required for understanding how climate change would affect global ocean circulation and how ocean circulation changes would affect climate in northern Europe and other regions. *Credit: Mathew Maltrud, Los Alamos National Laboratory, DOE Climate Change Prediction Program.*

rise, but the extent to which the ice sheet as a whole is influencing sea level has yet to be accurately assessed (given the large spatial variability of this thinning and observed thickening of ice in other regions). NASA's Ice Cloud and Land Elevation Satellite (ICESat), which was launched in January 2003, is expected to help provide a reliable estimate of these changes. Analysis will continue through FY 2005.

These activities will address Question 4.2 of the CCSP Strategic Plan.

Provide new Arctic paleoclimate products. Based on a new synthesis of data from the Holocene Thermal Maximum (~9,000 years ago), warming is asynchronous and asymmetric across the North America Arctic region. Warming begins in the west and sweeps eastward. A georeferenced database of annually resolved records of Arctic temperature over the past 1,000 years is under development and is scheduled for completion and on-line availability in late FY 2004. Such maps, data, and manuscript references will provide spatially detailed information about Arctic temperature trends over the last millennium, which can be used to compare more recent changes with the patterns of change from the mid-Holocene geologic epoch.

These activities will address Questions 4.2 and 4.3 of the CCSP Strategic Plan.

Perform deep time paleoclimate research. Researchers supported by NSF, along with researchers at NASA and USGS, have begun a multi-year data analysis and climate modeling effort to create three-dimensional global data sets of middle Pliocene epoch (~3 million years ago) ocean temperature and salinity. This will create the most comprehensive global reconstruction for any warm period of Earth's climate prior to the most recent past. Estimates of middle Pliocene global warming suggest that temperatures were approximately 2°C greater than today. This level of warming is within the range of projected global temperature increase in the 21st century. No other time period in the past 3 million years approaches this level of warming. Analysis of this period challenges the science community's understanding of the sensitivity of key components of the climate system and how the system is simulated—that is, polar versus tropical sensitivity, the role of ocean circulation in a warming climate, the hydrological impact of altered storm tracks, and the regional climate impacts of modified atmospheric and oceanic energy transport systems.

These activities will address Question 4.2 and 4.3 of the CCSP Strategic Plan.

Key Decision Support Resources Development Activities for FY 2004 and FY 2005

Report on understanding of vertical temperature trends. A CCSP synthesis report on understanding and reconciling differences in observed temperature trends in the lower atmosphere will be produced for publication in FY 2005. In October 2003, 55 scientists from academia, the U.S. Government, and several other countries participated in a workshop at the National Climatic Data Center on the current state of knowledge and scientific uncertainties on this subject. Follow-on activities will include coordination with a workshop to be held at the UK Hadley Centre in June 2004. A solid foundation has been laid to proceed with the delivery of a synthesis report, with NOAA as the lead CCSP agency and DOE, NASA, and NSF contributing.

This activity will address Questions 4.1 and 4.5 of the CCSP Strategic Plan.

Develop, evaluate, and provide new probability forecasts of seasonal climate anomalies resulting from ENSO. In FY 2004 and FY 2005 major R&D efforts will continue on improving probabilistic intra-seasonal to interannual climate forecasts, and on developing new and improved climate forecasting products with regional and sectoral applications to water resource management and agriculture.

This activity will address Questions 4.4 and 4.5 of the CCSP Strategic Plan.

Provide improved climate information products for resource management. Regional integrated research will develop climate information products in FY 2004 and FY 2005 for the agricultural, wildfire, and water management sectors.

These activities will address Questions 4.4 and 4.5 of the CCSP Strategic Plan.

3 Global Water Cycle

Strategic Research Questions

5.1 What are the mechanisms and processes responsible for the maintenance and variability of the water cycle; are the characteristics of the cycle changing and, if so, to what extent are human activities responsible for those changes?

5.2 How do feedback processes control the interactions between the global water cycle and other parts of the climate system (e.g., carbon cycle, energy), and how are these feedbacks changing over time?

5.3 What are the key uncertainties in seasonal to interannual predictions and long-term projections of water cycle variables, and what improvements are needed in global and regional models to reduce these uncertainties?

5.4 What are the consequences over a range of space and time scales of water cycle variability and change for human societies and ecosystems, and how do they interact with the Earth system to affect sediment transport and nutrient and biogeochemical cycles?

5.5 How can global water cycle information be used to inform decision processes in the context of changing water resource conditions and policies?

See Chapter 5 of the *Strategic Plan for the U.S. Climate Change Science Program* for detailed discussion of these research questions.

The water cycle is essential to life on Earth. As a result of complex interactions, the water cycle acts as an integrator within the Earth/climate system, controlling climate variability and maintaining a suitable climate for life. The water cycle manifests itself through many processes and phenomena, such as clouds and precipitation; ocean-atmosphere, cryosphere-atmosphere, and land-atmosphere interactions; mountain snow packs; groundwater; and extreme events such as droughts and floods.

Inadequate understanding of and limited ability to model and predict water cycle processes and their associated feedbacks account for many of the uncertainties associated with our understanding of long-term changes in the climate system and their potential impacts, as described by the IPCC. For example, clouds, precipitation, and water vapor produce feedbacks that alter surface and atmospheric heating and cooling rates, and the redistribution of the associated heat sources and sinks leads to adjustments in atmospheric circulation, evaporation, and precipitation patterns.

Clean water is an essential resource for human life, health, economic growth, and the vitality of ecosystems. From social and economic perspectives, the needs for water supplies adequate for human uses—such as drinking water, industry, irrigated agriculture, hydropower, waste disposal, and the protection of human and ecosystem health—are critical. Water supplies are subject to a range of stresses, such as from population growth, pollution, and industrial and urban development. These stresses can be affected by climate variations and changes that alter the hydrologic cycle in ways that are currently not predicted with sufficient accuracy for decisionmakers.

Advances in observing techniques, combined with increased computing power and improved numerical models, now offer new opportunities for significant scientific progress. Recently, for example, credible predictions of seasonal variations in the water cycle have been produced for the western United States and Florida. Along with the growing ability to provide advance notice of extreme hydrologic events, this forecast capability provides new options for social and economic development and resource and ecosystem management. In addition, recently launched NASA satellites such as Terra, Aqua, GRACE, and ICESat, among others, will substantially increase the detailed data needed to better understand and model global and regional water cycle processes.

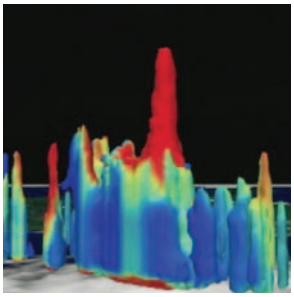
Highlights of Recent Research

Highlights of recent research supported by CCSP participating agencies follow.

Cloud feedback effects. A combination of improved models and better measurement technology is closing the gap between observed and modeled quantification of radiative fluxes in the atmosphere (flows of incoming solar radiation and outgoing radiation from the Earth through the atmosphere). These new results are helping to improve the radiative transfer calculations in climate models being developed for the start of the next international assessment by the IPCC.

The radiative transfer components of climate models account for how water vapor, other gases, and cloud droplets scatter and absorb solar radiation and absorb

and reradiate infrared radiation. Studies in the mid-1990s indicated that clouds absorbed roughly 40% more sunlight than calculated by climate models, suggesting that the inaccuracy of model calculations of radiation absorption by clouds was undermining the ability of the models to simulate climate correctly. However, new model calculations of cloud absorption, using state-of-the-art radiative transfer models, closely match recently analyzed cloud observation data from DOE's Atmospheric Radiation Measurement Enhanced Shortwave Experiment-II, which was conducted at a site in Oklahoma. This data set was unique in its redundant measurements and high quality control. In addition, studies have shown that, by modifying models to account for radiation absorbed by microscopic aerosol particles such as dust and soot, the gap between models and observations can be narrowed even further.



Multi-scale simulation of cloud effects on climate. The global circulation of the atmosphere has been simulated using a radically new kind of mathematical model that simulates cloud processes directly. A high-resolution cloud model is run "inside" the lower resolution global model to create a "multi-scale modeling framework" (MMF). Results from the MMF show major improvements, relative to earlier models, for the simulation of many kinds of weather and climate systems, including the most powerful cloud systems in the tropics. Particularly encouraging is the improved representation of the diurnal cycle of precipitation. This modeling tool is one of several important research components being applied to achieve a better quantitative understanding of climate feedbacks related to atmospheric convection and hydrologic and cloud processes. The ever-increasing availability of new computational advances as well as high-quality observational data from field programs is making such advances possible (see, for example, Figure 11).

Water vapor measurement. Because water vapor is by far the most abundant of the greenhouse gases, accurate water vapor measurements are essential for understanding atmospheric processes and representing and evaluating them in regional and global climate models. Instruments and observational protocols are needed to measure water vapor accurately. Researchers have succeeded in reducing measurement uncertainties in water vapor concentrations from greater than 25% to less than 3% using ground-based instrumentation, such as Raman lidar and microwave radiometer (see Figure 12).

ICESat launched. The Ice, Clouds, and Land Elevation Satellite (ICESat) was successfully launched in January 2003. This Earth Observing System mission—covering the Arctic, the Antarctic, continental high elevations, and the oceans—measures water cycle variables, including ice sheet mass balance, cloud and aerosol heights, and land topography and vegetation characteristics. ICESat provides, primarily, land-ice and sea-ice altimetry products, with cloud/aerosol lidar and land/vegetation altimetry as secondary products. ICESat will provide multi-year elevation data needed to determine

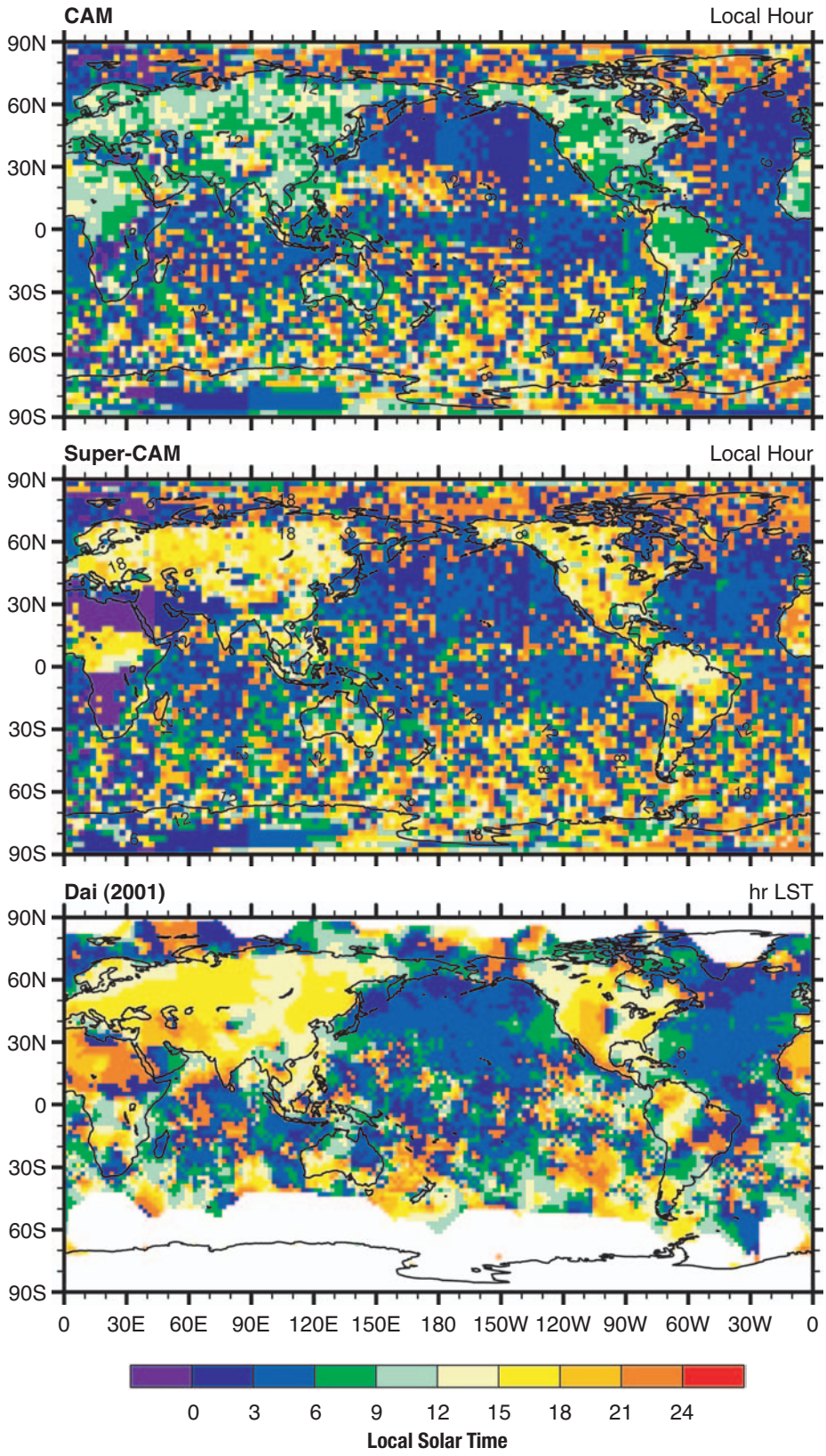


Figure 11:
Modeling the diurnal cycle of precipitation. The mean June-July-August local solar time of non-drizzle precipitation frequency maximum has been simulated with the standard Community Atmosphere Model (CAM) (upper panel); super-parameterization CAM (middle panel); and from observational data set by Dai (bottom panel). Non-drizzle precipitation was defined as producing mean precipitation rate in excess of 1 mm per day over a 3-hour interval.
Source: From Khairoutdinov et al. 2004, J. Atmos. Sci., submitted.

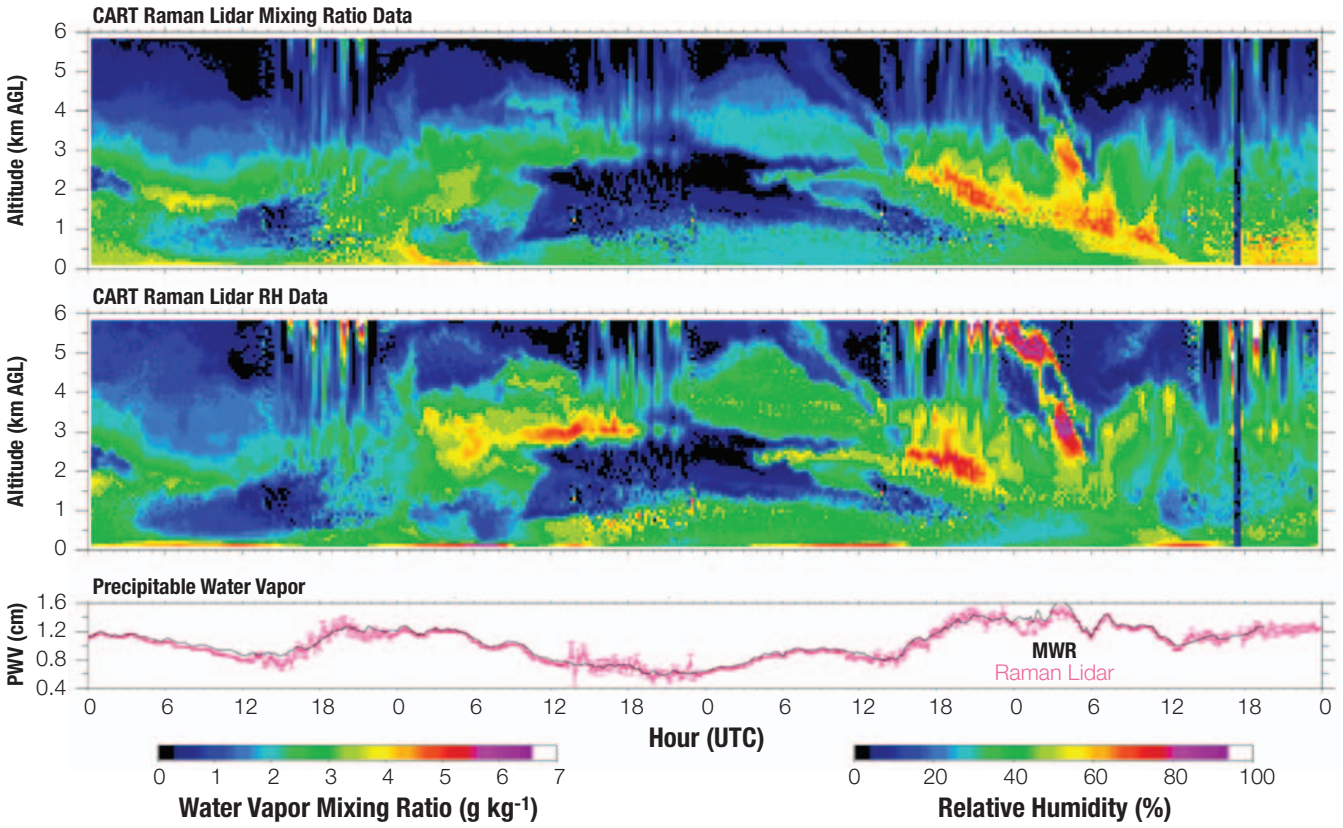


Figure 12: Laser technology captures continuous, vertical distributions of water vapor over the Atmospheric Radiation Measurement's Southern Great Plains Site for the 29 November - 2 December 2002 time frame. The figure represents three measurements that are important for climate studies: (a) ratio of water vapor to dry air (CART Raman Lidar Mixing Ratio Data); (b) relative humidity (CART Raman Lidar RH Data); and (c) the total atmospheric water vapor contained in a vertical column of unit cross-sectional area extending from the surface to the top of the atmosphere (precipitable water vapor). *Credit: David Turner, University of Wisconsin.*

ice sheet mass balance around the globe, in addition to the polar-specific coverage over the Greenland and Antarctic ice sheets. ICESat observations, together with those of the Terra and Aqua satellites, will more accurately quantify the changes in the Greenland ice sheet and the interannual changes of Arctic ice. These regions, identified by models to be highly sensitive to climate warming, already show signs of a strong climate change signal with a shrinking of perennial ice-covered regions.

Enhanced sea ice observations. Data from the EOS Aqua satellite are providing the research community with sea ice data products at a higher spatial resolution and a greater spectral range than previously possible. To make these data products a useful research tool, a comprehensive sea ice validation program is currently underway. An Arctic field campaign with the NASA P3 aircraft was completed in March 2003. Enhanced calibration of satellite microwave sensors will permit a more accurate monitoring of sea ice variability and provide data for the validation of coupled models

that require improved sea ice component models in order to better understand and predict polar responses to global climate change.

Water cycle observation from space. NASA's Gravity Recovery and Climate Experiment (GRACE) satellite—successfully launched in March 2002, to measure both the static and time-variable components of the Earth's gravity field—has delivered (in mid-2003) the first global analysis of data showing the distribution of gravity variations around the world. Due to an uneven distribution of mass inside the Earth, the Earth's gravity field is not uniform. The gravity variations that GRACE will study include changes due to surface and deep currents in the ocean; runoff and groundwater storage on land masses; exchanges between ice sheets or glaciers and the oceans; and variations of mass within the Earth.

Future data analysis and applications based on measurements from GRACE will provide information on changes in the extent and volume of water stored in continental water bodies (large reservoirs, lakes, and groundwater), as well as other physical changes, such as movement of warm water zones in the Pacific Ocean (El Niño) and shifting tectonic plates. Simulations of GRACE observations show that the time variations in the water budget of the Mississippi River basin, for example, are well-captured. Remote sensing of changes in water storage has potential applications to monitoring and management of regional water supplies, as well as national and international resource assessment and planning activities.

Water cycle-carbon cycle interactions. A number of recent studies demonstrated intimate links between the water cycle, the carbon cycle, and climate. A combination

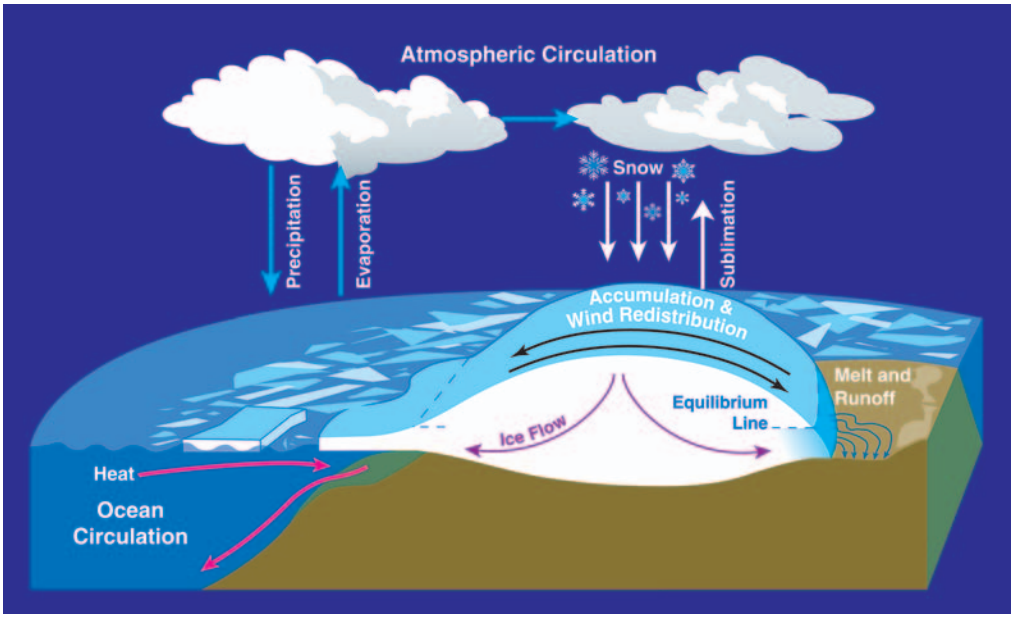


Figure 13:
Future changes in ice sheet mass balance will be a complex function of accumulation and melting as well as dynamic ice sheet behavior. Sea level response is still not well understood. ICESat observations will help answer important questions about trends that affect the ice mass balance and sea level change. *Credit: NASA.*

of data analysis and model integrations and diagnostics suggests that approximately 60% of the increase in terrestrial carbon sequestration in North America may be attributable to increases in rainfall over the North American continent. Previously, most of the increased carbon sequestration in the Northern Hemisphere was thought to be due to a combination of increases in temperature and the direct fertilization effect of increased atmospheric CO_2 concentration. This study's results indicate that changes in precipitation may be at least as important.

A recent study of chemical weathering, using a combination of precipitation, streamflow, and alkalinity measurements from USGS, showed that carbon export, in the form of alkalinity, has increased along with levels of streamflow and precipitation in the Mississippi River basin. Chemical weathering converts CO_2 into dissolved bicarbonate or carbonate that is then transported by rivers to the ocean. River transport of alkalinity from land to ocean is a major source of oceanic alkalinity and thus is a regulator of the carbonate saturation state of the oceans. This has implications for the global carbon cycle and the function of oceans as carbon sinks.

A third study by a multidisciplinary group from government agencies, universities, and the private sector analyzed the fires associated with the 1997-1998 El Niño drought conditions using satellite observations, together with output from biogeochemical and atmospheric chemistry transport models and observed carbon concentrations at flask stations. The study found that during the 1997-1998 El Niño event, fire emissions of carbon increased significantly (2.1 ± 0.8 PgC, or $66 \pm 24\%$ of the CO_2 growth rate anomaly). The study suggests that the variability and intensity of the water and energy cycle on interannual time scales may be among the most critical factors regulating carbon budgets. For example, when conditions support fires, regions that have long served as carbon sinks may suddenly become carbon sources.

Modeling the global water and energy cycles and their regional components. The Global Energy and Water Cycle Experiment (GEWEX) Continental-scale International Project successfully completed water and energy budget studies for the Mississippi River Basin. Results indicate that the water and energy budgets over the Mississippi River Basin can be closed to within 15%. Water and energy budgets account for the amount of water and energy entering a region, how they are partitioned among their various components (e.g., evaporation, runoff, groundwater), and the amount leaving the region. To close a budget, it is necessary to understand the processes that control inflow, partitioning, and outflow, and to have sufficient data on key variables. In addition to establishing benchmarks for future modeling studies, data and results of these studies will be used in initializing and validating regional climate models.

Prediction of warm season rain. In order to better understand the processes influencing warm season rain in the southwestern United States, process and modeling

studies have been carried out that explore the role of the North American Monsoon system in the water budget stores over the region. These studies relied upon fine-resolution precipitation data products and improved representations of land processes in models during the monsoon period, and examined the effects of model resolution on the simulation of summer mountain region precipitation processes. New process understanding that results from these studies will improve simulation and monthly to seasonal prediction of the monsoon and regional water resources.

Evaluation of water cycle prediction products for decision support. A joint NOAA/NASA project on improving water demand analysis and prediction for U.S. Bureau of Reclamation water managers is designed to improve estimates of evapotranspiration (loss of water from the soil) in New Mexico. The project uses satellite remote sensing, radar, and surface-based observations, and numerical forecasts and surface modeling, to integrate Land Data Assimilation System information into water operations decision support systems, and displays decision data on the Web. Bureau of Reclamation water managers, water conservancy districts, and farmers may access the information daily to help them conserve the State's extremely limited water resources.

Highlights of Plans for FY 2004 and FY 2005

The CCSP 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 FY2004 and FY2005 follow.

Integrated hydrologic database development. A major obstacle to research on the water cycle is the wide range in the types of data sets. Data sets are created by a variety of agencies for a variety of purposes. Integrating these data would extend and expand their usefulness for addressing important scientific, management, and policy-related questions that cross traditional disciplinary boundaries. Disparities in existing data that present challenges to integration include scale, both temporal and spatial, and type, whether continuous or discrete. A new effort will be initiated in FY 2004 to integrate these disparate data sets for general use in hydrologic research and water resources management.

These activities will address all five strategic research questions on the Global Water Cycle in the CCSP Strategic Plan, particularly Questions 5.3, 5.4, and 5.5, and will lay the groundwork for implementation of many products.

Integrated global observing strategy and coordinated data sets. Several U.S. agencies will cooperate in an international effort to establish an integrated global

observing strategy for water cycle variables as a component of the world climate research agenda. Observation of water cycle variables has been identified as an important weakness in climate prediction, particularly with respect to regional manifestations of variability and change. A coordinated strategy for observing these variables will enable more effective deployment of observational resources. The strategy will provide input to the Group on Earth Observations (GEO) to promote consistency with the Earth observation system under development by GEO. In FY 2004, a Water Cycle Theme report will be published and an international management structure for the program will be created. The Coordinated Enhanced Observing Period (CEOP) will be the program's first focus, and an initial report on results will be published in FY 2005.

Participants in the Coordinated Enhanced Observing Period, which include national weather centers, space agencies, other government agencies, and university research centers, will release integrated global data sets, covering the period 1 October 2001 to 31 December 2004. The preliminary data set (October to December 2001) is being used now in process studies, model comparisons, and related research. A second set (2002 to 2003) is being processed and archived for release in FY 2004, and a third set (2003 to 2004) is planned for release in FY 2005. Data include satellite observations, measurements made at more than 60 globally distributed GEWEX reference sites, and Model Output Time Series (MOLTS) data from various global modeling centers. The data sets will be useful in a wide range of applications, including improving predictions associated with the North American Monsoon System.

These activities will address Questions 5.1 (first product), 5.2 (fourth product), 5.3, and 5.4 of the CCSP Strategic Plan.

Characterizing atmospheric water vapor. A new satellite, scheduled for launch in 2004, will provide a platform for measuring upper tropospheric water vapor profiles—information that is essential for understanding climate and water cycle variability. In FY 2005, the Microwave Limb Sounder (MLS) on NASA's EOS-Aura will begin transmitting its first streams of data on lower stratospheric and upper tropospheric temperature and water vapor, in addition to measurements of atmospheric chemistry. Before MLS, water vapor profiles in the lower stratosphere and upper troposphere were difficult to observe reliably on a global scale, but the Upper Atmosphere Research Satellite (UARS) demonstrated that MLS is capable of measuring upper troposphere water vapor profiles, even in the presence of cirrus clouds. In addition, MLS is unique in its ability to measure cirrus ice content. The HIRDLS (High-Resolution Dynamics Limb Sounder) on EOS-Aura will complement MLS by profiling the upper troposphere, stratosphere, and mesosphere to determine temperature and concentrations of ozone, water vapor, and various chemical species. The simultaneous measurements of upper tropospheric water vapor, ice content, and temperature,

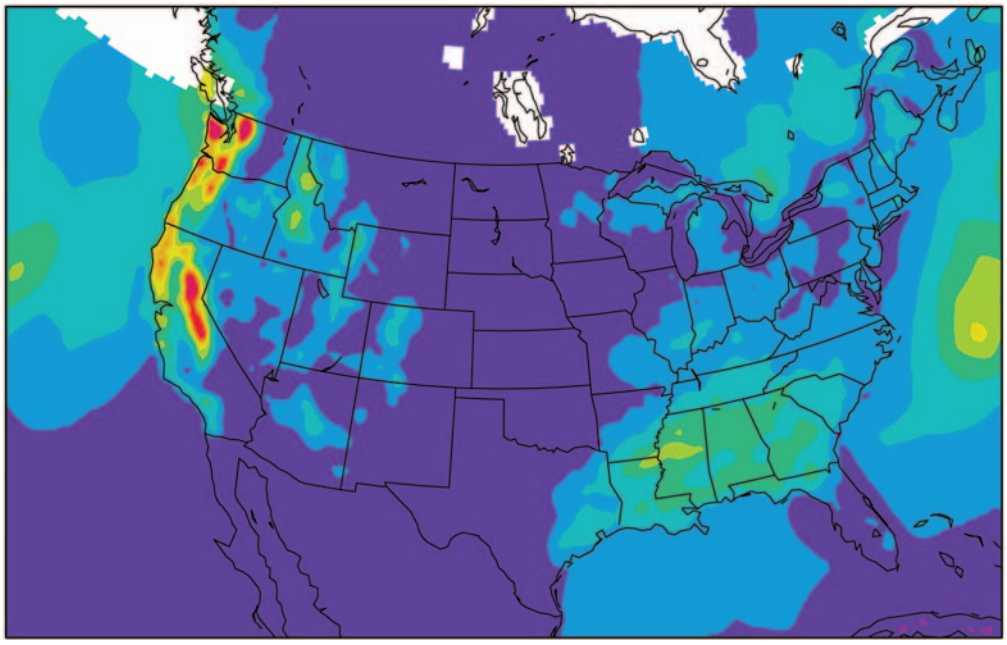
under all conditions and with good vertical resolution, will be of great value for improving understanding of processes (such as El Niño) affecting the distribution of atmospheric water, climate variability, and tropospheric-stratospheric exchange.
These activities will address Questions 5.1 (second product) and 5.2 of the CCSP Strategic Plan.

Reprocessing of global climate data. In FY 2005, the retrospective global time series of key water and energy cycle parameters will be extended by reprocessing data using new algorithms. For example, an extended global precipitation data time series will be produced using algorithms derived from experience with the Tropical Rainfall Measuring Mission (TRMM) satellite and other experimental platforms.
These activities will address Questions 5.1 (fourth product) and 5.3 of the CCSP Strategic Plan.

Reanalysis of regional climate data. Regional reanalysis of historical observations, covering the period 1979 through 2003, will be completed in FY 2004. The period 1979 through 2001 is already finished. The regional reanalysis produces a wide range of high-resolution, daily water cycle analysis products at 3-hourly intervals, such as precipitation, relative humidity, moisture flux, soil moisture, and snowpack fields at 32-km spatial resolution over North America, as well as Central America. These analysis products provide opportunities to analyze climatological features of spatial and temporal variability in the water cycle and improve characterization of land states for initializing predictions at seasonal to interannual time scales. The North American regional reanalysis represents advances in regional models and data assimilation that include assimilation of precipitation, direct assimilation of radiances, additional observation types, and recent developments in modeling, particularly land-surface components. When completed, the North American data set will be the best available for a variety of studies and applications regarding climate, water resources, weather prediction, predictability, and other applications. Regional reanalysis will continue in real-time after the 25-year data set is complete, and will produce forecasts at regular intervals for use in predictability studies.
These activities will address Questions 5.1 and 5.3 (first product) of the CCSP Strategic Plan.

Launch of Cloudsat and CALIPSO satellites. Two Earth System Science Pathfinder (ESSP) satellites addressing global three-dimensional distributions of aerosols and clouds are currently scheduled for launch in mid-FY 2005. These are the joint NASA-French CALIPSO mission to study aerosols and thin clouds, and the joint NASA-U.S. Air Force-Canadian Cloudsat mission to study a broader range of clouds. These satellites will fly as part of a constellation of satellites in polar orbit, with equatorial crossing times within approximately 15 minutes of each other and a number of other NASA satellites measuring atmospheric properties. The integrated impact of this constellation—known as the "A-train" because of the names of other satellites in

Observed Precipitation (in) January 1997



NARR Precipitation (in) January 1997

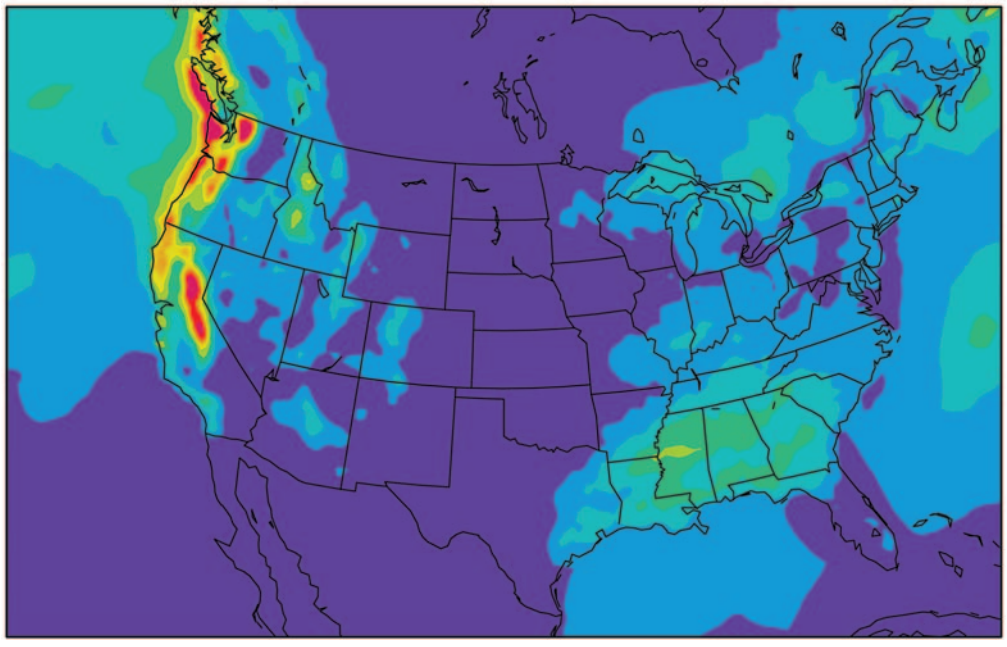
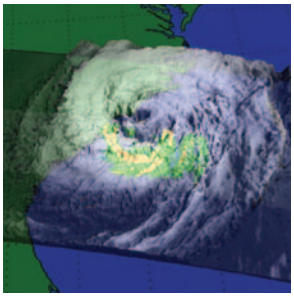


Figure 14: Assimilation of observed precipitation is the most important data addition to the North American Regional Reanalysis (NARR), because successful assimilation of these observations enables more realistic modeling of the hydrological cycle than otherwise would be possible. This figure shows a comparison, during a strong El Niño event (January 1997), over North America of analyzed precipitation based on observations (top panel) and the NARR precipitation output (bottom panel). The color scale indicates inches per month. The comparison shows extremely high agreement over land, even over the complex western topography. The regional reanalysis provides coupled atmospheric and land water cycle components that include preciptation fields in much better agreement with observed precipitation fields than previously available over North America. *Credit: NOAA/National Weather Service/National Centers for Environmental Prediction.*

the constellation (Aqua, Aura)—will be to improve significantly understanding of the relationship between atmospheric temperature, water vapor, aerosols, and clouds.

These activities will address Questions 5.1 and 5.2 of the CCSP Strategic Plan.



Global precipitation monitoring. Planning will continue toward the design and implementation of a Global Precipitation Mission (GPM) satellite. The GPM will be the forward, and more advanced and comprehensive, replacement to the present suite of precipitation measurements by TRMM and SSM/I, among others. TRMM is likely to be de-orbited in 2004 because of a lack of fuel; however, the satellite has already successfully exceeded its planned life span by a substantial margin. The current vision—by NASA and its international partners in Japan and Europe—calls for a constellation of eight satellites carrying some form of passive microwave radiometer (likely a combination of new lightweight satellites and operational/experimental satellites) and a ninth "core" satellite, carrying a dual frequency radar and an advanced, multi-frequency passive microwave radiometer. The constellation is designed to provide at least 3-hour sampling at any spot on the globe for relevant measurements of internal cloud-precipitation microphysical processes and the "training and calibrating" information for retrieval algorithms. The GPM program will involve other international partners, scientific agencies and institutions in the United States, and individual scientists from academia, government, and the private sector to fulfill mission goals and establish a foundation for eventual development of an internationally organized, operational global precipitation observing system. The United Nations has identified this mission as a foremost candidate for its Peaceful Uses of Space Program.

These activities will address Questions 5.1 and 5.3 (seventh product) of the CCSP Strategic Plan.

Cloud feedback processes. Cloud feedback processes will be examined in studies using satellite and *in situ* data (e.g., from Atmospheric Radiation Measurement sites), and results will be incorporated into global climate models to improve the representation of these processes. The very different response of subtropical boundary layer clouds to the doubling of CO_2 in two global climate models (GCMs) will be examined by using observational constraints and by closely examining the various physical parameterizations involved. In addition, cloud feedbacks in tropical convective cloud regimes will be studied. Diagnostic studies based on regional and global observations, single-column model analysis and modeling efforts, GCM sensitivity studies, and interchanges of parameterization schemes between models will be carried out. Better representation of cloud feedback processes in climate models should reduce uncertainties in climate projections.

These activities will address Question 5.2 (first product) of the CCSP Strategic Plan.

Impacts of climate-related hydrologic and water temperature changes. Changes in precipitation and temperature associated with climate change may have direct effects on the concentrations of pollutants and pathogens in surface and ground waters. These changes could have ramifications for aquatic ecosystems, drinking water, human recreational uses, and the cost of environmental protection. In 2004, a project will be completed evaluating how climate-related hydrologic and water temperature changes may affect the costs of attaining water quality standards at publicly owned sewage treatment works in the Great Lakes region. Results from this project will include: 1) identification of water quality-limited watersheds in the Great Lakes and evaluation of their vulnerabilities to climate change; and 2) estimates of changes in treatment efficiency required, and associated costs, for continued compliance under different water quality standards and climate change scenarios. In FY 2005, a report will be completed to evaluate the effects of global changes on drinking water infrastructure, wastewater treatment, and surface water/groundwater characteristics.

These activities will address Questions 5.4 (fourth product) and 5.5 of the CCSP Strategic Plan.

Moisture monitoring tool for land management. An experimental surface and subsurface moisture-monitoring product for land resource management is being developed and tested. As part of the effort to build a national drought monitoring system, researchers in California are developing a technique, based on a moisture index, for estimating the likelihood of drought-related threats, such as forest fires and loss of agricultural crops. In FY 2004, the new tools will be incorporated into regional and national drought monitoring systems.

These activities will address Question 5.5 (first product) of the CCSP Strategic Plan.

Climate predictions in water management. Water managers need more accurate and timely forecasts of water supplies and demands to manage limited, and often over-allocated, water resources in the semi-arid West. Thus, an experimental on-line decision support tool designed to provide users with a description of streamflow conditions and their accompanying probabilities in the Pacific Northwest, from near-term climate predictions and long-term projections, is being developed, demonstrated, and deployed in the Columbia River Basin. Data assimilation systems and land surface models developed under the CCSP by NASA, NOAA, and other agencies and universities will be integrated with river system management decision support systems developed by the Bureau of Reclamation and used by water managers to make daily to seasonal water operations decisions. Tests of prototype systems in FY 2004 will be followed by routine integration of forecasts in FY 2005, depending upon the range of uncertainty associated with the streamflow forecasts and water demand forecasts. If

successful, the integrated forecasting and decision support system will be extended to other major river systems of the West.

These activities will address Question 5.5 (second product) of the CCSP Strategic Plan.

Forecast tools on the Web. Web-based tools will be refined to improve communication and usability of climate and water forecasts. One of the major barriers to the effective use of forecasts in policy and resource management decisions is the failure of forecast products to communicate to potential users the nature of their associated uncertainty, its meaning and value. In FY 2004, tools designed to help users of predictions over a range of time scales understand and evaluate forecast uncertainties will be enhanced on the basis of tests that have been carried out with users in Arizona.

These activities will address Question 5.5 (third product) of the CCSP Strategic Plan.

4 Land-Use and Land-Cover Change

Strategic Research Questions

6.1 What tools or methods are needed to better characterize historic and current land-use and land-cover attributes and dynamics?

6.2 What are the primary drivers of land-use and land-cover change?

6.3 What will land-use and land-cover patterns and characteristics be 5 to 50 years into the future?

6.4 How do climate variability and change affect land use and land cover, and what are the potential feedbacks of changes in land use and land cover to climate?

6.5 What are the environmental, social, economic, and human health consequences of current and potential land-use and land-cover change over the next 5 to 50 years?

See Chapter 6 of the *Strategic Plan for the U.S. Climate Change Science Program* for detailed discussion of these research questions.

Land use and land cover are linked to climate and weather in complex ways. Key links between changes in land cover and climate include the exchange of greenhouse gases (such as water vapor, carbon dioxide, methane, and nitrous oxide) between the land surface and the atmosphere, the radiation (both solar and longwave) balance of the land surface, the exchange of sensible heat between the land surface and the atmosphere, and the roughness of the land surface and its uptake of momentum from the atmosphere.

Because of these strong links between land cover and climate, changes in land use and land cover can be important contributors to climate change and variability. Reconstructions of past land-cover changes and projections of possible future land-cover changes are needed to understand past climate changes and to project possible future climate changes. Land-cover characteristics are important inputs to climate models. In addition, changes in land use and land cover, especially when coupled with

climate variability and change, are likely to affect ecosystems and the many important goods and services they provide to society. The combination of climate and land-use change may have profound effects on the habitability of the Earth in more significant ways than either acting alone. While land-use change is often a driver of environmental and climatic changes, a changing climate can, in turn, affect land use and land cover. Climate variability alters land-use practices differently in different parts of the world, highlighting differences in regional and national vulnerability and resilience.

The interaction between land use and climate variability and change is poorly understood and will require the development of new models linking the geophysics of climate with the socioeconomic drivers of land use. Providing a scientific understanding of the process of land-use change, the impacts of different land-use decisions, and the ways that decisions are affected by a changing climate and increasing climate variability are priority areas for research. In addition to being a driver of Earth system processes affecting the climate, carbon cycle, and ecosystems, land-use and land-cover change is a global change in its own right, requiring its own research foundation.

Highlights of Recent Research

Highlights of recent research supported by CCSP participating agencies follow.

Projections of land-use and land-cover change. National projections of changes in land use and land cover were updated as part of a national renewable resources assessment, designed in part to support global climate change analyses. In this assessment, future climate was assumed to reflect current trends. Projected land-use changes include deforestation due to pressures to develop rural land as the human population expands—a larger area than that converted from other rural lands (e.g., agriculture) to forestry. More than 70 million acres of U.S. rural land are projected to be converted to urban and developed uses between the present and 2025. The majority of the 70 million acres is projected to come from forestland, thereby reducing the carbon storage potential of terrestrial ecosystems. Substantial shifting of agricultural and other lands to forest use is also projected, which would significantly reduce the net effect on total forest area. On remaining forestland, investment is projected to increase in certain areas, with a 14-million-acre increase in planted pine area in the South during the next 50 years. This investment is expected to result in a significant increase in sequestered carbon per acre for such treated lands. The amount of gross area changes in land uses and land covers is a multiple of net area changes, which is important for carbon accounting.

New Enhanced National Land Cover Database. The USGS, with significant support from EPA, NASA, NOAA, and USDA, is developing a new National Land Cover Database (NLCD). The 2001 NLCD, slated for completion in 2005, is being developed using circa-2001 Landsat 7 remote-sensing data. The 2001 NLCD will complement the recently completed 1992 NLCD, but will be enhanced through the generation of additional land-cover attributes and will have expanded geographic coverage (all 50 States). The new database includes significant advances over the 1992 data set. It includes land cover, percent tree cover, and percent impervious surface cover data layers. In a parallel effort between USGS and the USDA Forest Service, the same Landsat data and NLCD layers are being further interpreted into natural vegetation data layers. The collective set of NLCD land-cover data products is a crucial input to regional hydrology, climatology, biogeochemistry, and ecosystem functioning investigations (see Figure 15).

Land-Use/Land-Cover Change in the Amazon Region. The Amazon Basin contains the largest intact tropical forest biome in the world. It is a region undergoing

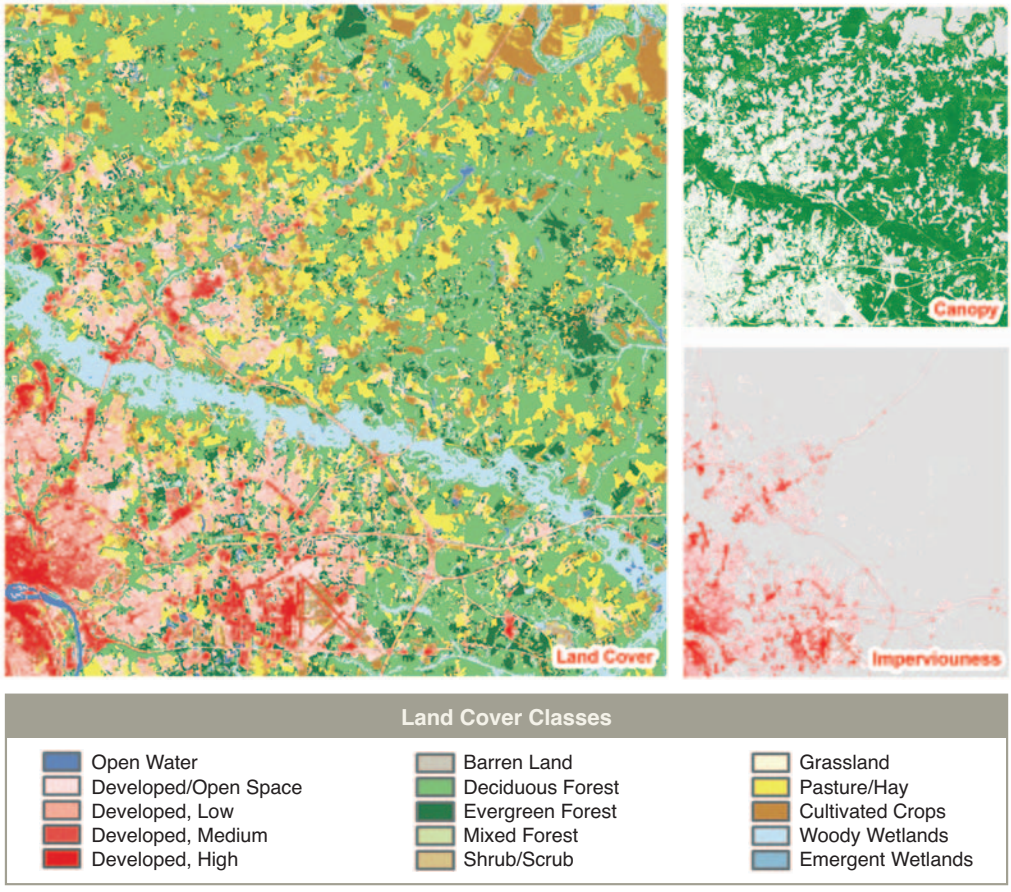


Figure 15: The development of the 2001 National Land Cover Database (NLCD) is underway and data sets are being released to researchers as they are completed. This Richmond, Virginia, example illustrates the data layers being produced. The map of land cover categories depicts the complex matrix of developed and natural lands on the fringe of Richmond. The map is used for assessments of consequences of land-cover patterns for ecosystem goods and services and climate variability. The 2001 NLCD also includes maps of canopy density, which are important for biogeochemistry studies, and surface imperviousness, which is needed for studies of hydrological processes and investigations of urban heat island issues. *Credit: USGS.*

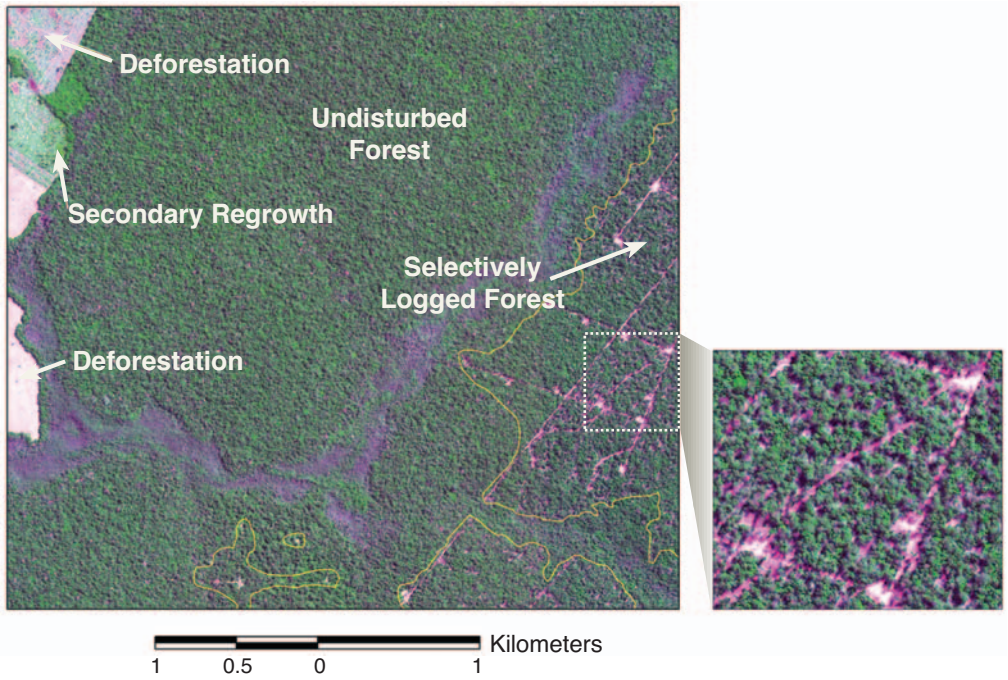


Figure 16:
Remotely sensed image identifying areas of undisturbed forest, selectively logged forest, deforestation (clear cut), and secondary regrowth. The image of Amazon forest degradation was acquired by the Space Imaging Ikonos satellite over Mato Grosso, Brazil (11o°34'S and 54°39'W), on 13 June 2000. It was band-sharpened to 1-m resolution and the display is color composite (3,4,1). *Credit: David Skole, Michigan State University.*

rapid transformation via land-use and land-cover change, with potentially profound effects on climate change, the hydrologic cycle, and ecosystem structure and biodiversity. Research underway has been utilizing the assets of Earth Observing System satellites and associated data and information systems to measure and assess these changes.

Findings to date confirm that forest degradation from fragmentation and logging has become an important disturbance in addition to deforestation. The area under selective logging is now 10-fold higher than it was in 1992. While not a significant disturbance prior to 1999, as some reports that did not use Earth observations had suggested, logging now represents roughly 30-40% of the total annual disturbance in Amazonian forests. This trend toward degradation as an important form of ecosystem disturbance is also being seen in other parts of the tropics, such as Southeast Asia, and presents new methodological and observation challenges. Future research will focus on refining the use of continuous field measurements of forest density, using the vastly improved detection capabilities of instruments aboard the Landsat and Terra satellites. Additional work is underway to extend the work in the Amazon to a prototype global monitoring system in support of the United Nations Tropical Forest Assessment.

Assessment of Global Forest Extent. Through the use of global measurements obtained by the Terra satellite, data products have been derived assessing the extent of forests and other properties of the Earth's land cover. The data provide consistent estimates of the extent of tree cover, independent of varying definitions of "forest."

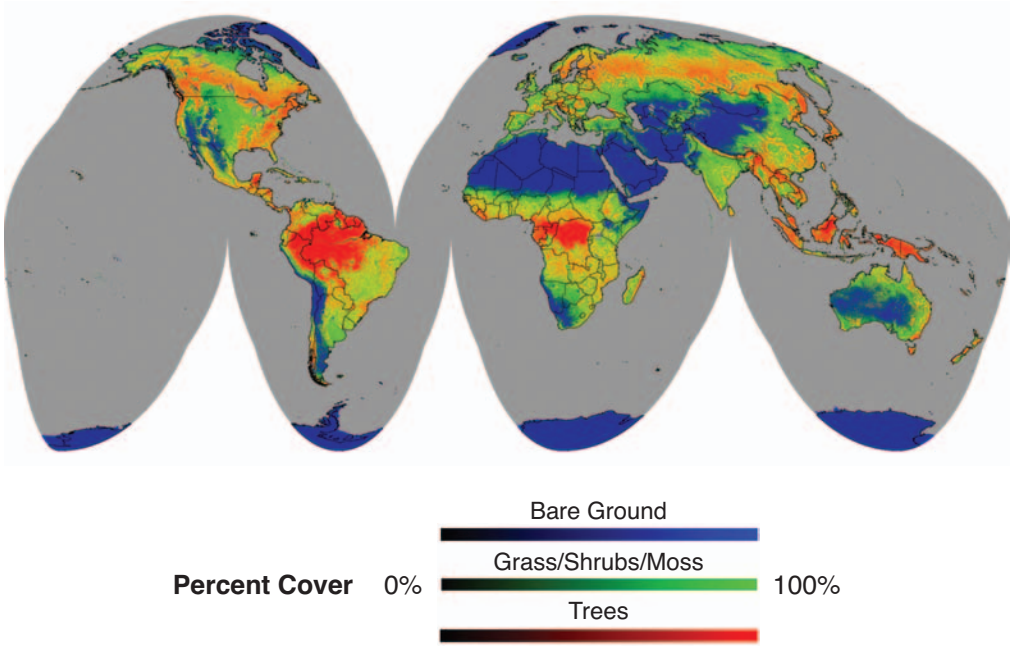


Figure 17: Global land-cover estimates of percentage tree cover, herbaceous cover, and bare ground within each 500-m by 500-m grid cell, derived from data acquired in 2001 by the Moderate-Resolution Imaging Spectroradiometer (MODIS) sensor onboard the Terra satellite platform. *Credit: R. DeFries, M. Hansen, and J. Townshend, University of Maryland-College Park.*

This is an improvement on previously produced assessments based on Landsat data. The freely available data set provides inputs to a range of terrestrial models and provides a baseline against which future changes in forest cover can be assessed (see Figure 17).

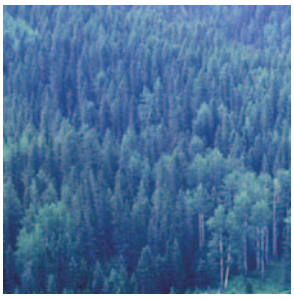
Highlights of Plans for FY 2004 and FY 2005

The CCSP 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 2004 and FY 2005 follow.

The extent of global agricultural land cover and land use. With the advent of remotely sensed data, researchers are now able to map global land cover consistently from space. However, remotely sensed data do not yet have the ability to distinguish between the various characteristics of agricultural land use. While they are able to distinguish croplands from other land cover, they are as yet unable to distinguish between different crops, identify irrigated land, or the amount of fertilizer applied. Such information is available only from ground-based sources, such as census data and land surveys. A combination of satellite-based land-cover data and ground-based agricultural census data will be used to derive global, spatially explicit data sets of agricultural land cover (croplands, pastures, and natural ecosystems) and land-use practices (cropping systems, irrigation, and fertilization). These data sets will be

critically important for the study of the ecosystem consequences of global agricultural land-cover change, including the trade-offs between various ecosystem goods and services.

These activities will address Question 6.1 (fourth and fifth of the milestones, products, and payoffs) of the CCSP Strategic Plan.



A new enhanced map of forest biomass for all Russian territory. Researchers will develop a map of the forest biomass of all Russia based on Landsat satellite and 500-m- and 250-m resolution Terra MODIS satellite products, through a combination of classification and modeling and use of Russian forest inventory data of both high and low spatial resolution. This map will be an improvement over existing products, as no current maps of the forest biomass of Russia exist. The only current data are based exclusively on Russian forest inventory data of unknown and unverifiable quality and with little spatial detail. After a reliable methodology is developed and tested, this product could be reproduced on a repeated basis allowing the assessment of changes of forest carbon stocks over time.

These activities will address Question 6.1 of the CCSP Strategic Plan.

A database of land-cover change in Alaska from 1950–2001. A database of land-cover change in Alaska from 1950 through 2001 will be developed. The database is tied to a circa-1991 satellite-based land-cover classification of vegetation in Alaska. Spatial resolution will be 1 km and temporal resolution will be annual. The database will describe forest stand-age at 1-km resolution, a measure that will be most reliable for areas that have burned since 1950. Successional changes in vegetation will be defined by: 1) the occurrence of fires from 1950 to 2001, 2) an empirical model that defines vegetation transitions, and 3) rules that resolve inconsistencies between the 1991 land cover and the successional trajectories of the model. This product can be used to define how successional vegetation changes affect water and energy exchange in regional climate models, how changes in stand-age and vegetation affect carbon dynamics, and for testing process-based ecosystem models of historical land-cover changes in response to fire in the Alaska region.

These activities will address Question 6.2 of the CCSP Strategic Plan.

Projecting land-use change and its effects on forest. Societal demands for land in residential, commercial, and industrial uses are expected to continue to increase with growing populations and rising incomes. Research will continue to develop and evaluate methods for analyzing associated implications for wildlife habitat, timber supplies, carbon sequestration for climate change mitigation, biodiversity, and other ecological and economic impacts. Spatial econometric studies will be conducted of forest-cover changes, with expanded use of ecological and economic theories to guide model development and enhance robustness of projected changes.

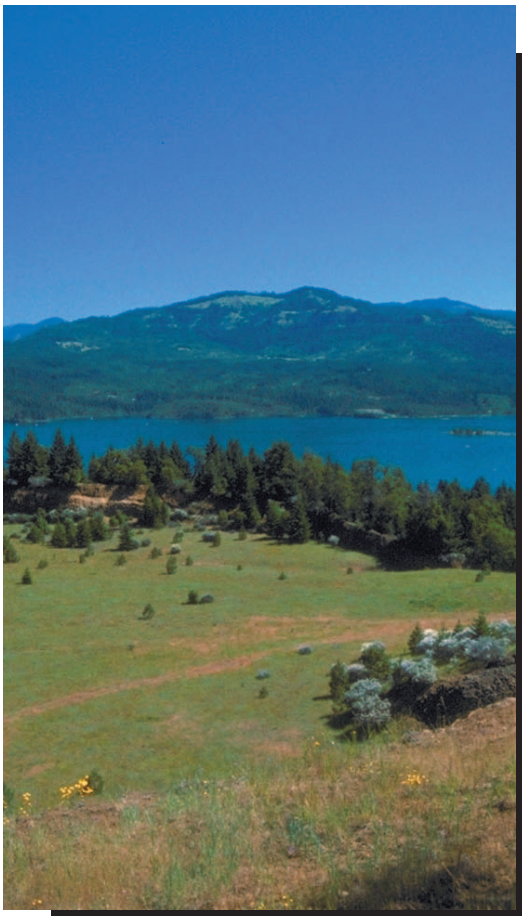
These activities will address Question 6.3 of the CCSP Strategic Plan.

Integrated regional climate study with a focus on land-use and land-cover change and associated changes in hydrological cycles in the southeastern United States. A study focused on the southeastern United States will examine the effects of changes in land use/cover, cloud-precipitation process, and terrestrial ecosystem processes on variability in surface latent heat flux (evaporation and transpiration), and hence the regional hydrological cycle. Both drought and non-drought conditions will be studied. The study will use a sophisticated atmosphere-ecological modeling system and remotely sensed satellite data and products. For regional climate simulations, a number of remotely sensed data sets will be utilized, with climate-related variables including soil moisture, cloudiness, and cloud-free optical depth. In addition, the study will explore the advantage of using derived surface latent heat (and surface CO_2) flux maps for an improved characterization of the regional land-atmosphere interactions, including the water cycle associated with land use/cover. After carrying out the analysis in the southeastern United States, this approach and product can be readily expanded for a global-tropical application.

These activities will address Question 6.4 (first, second, and third of the milestones, products, and payoffs) of the CCSP Strategic Plan.

Report on impacts of urbanization on ecological services in a semi-arid region of the United States. The Edwards Aquifer is the primary water supply for the city of San Antonio, Texas, one of the ten fastest growing U.S. metropolitan areas. Ongoing research has focused on determination of the impacts of past land-use and land-cover change on regional ecological services—including water resources, vegetation for carbon sequestration, and refugia for wildlife habitat—and evaluation of public policy instruments to enhance these services in the future. This research relies on a strong multidisciplinary approach, using satellite images, modeling, and geospatial analysis tools. In FY 2004, the ongoing analysis is being expanded over the entire aquifer recharge region. The outcome of this research will be a comprehensive understanding of the effects of urbanization on ecological services in a semi-arid region, a determination of the effectiveness of policies to enhance ecological services, and decision support for optimizing ecological services through policies that appropriately manage land-use and land-cover change.

These activities will address Question 6.5 of the CCSP Strategic Plan.



5 Global Carbon Cycle

Strategic Research Questions

7.1 What are the magnitudes and distributions of North American carbon sources and sinks on seasonal to centennial time scales, and what are the processes controlling their dynamics?

7.2 What are the magnitudes and distributions of ocean carbon sources and sinks on seasonal to centennial time scales, and what are the processes controlling their dynamics?

7.3 What are the effects on carbon sources and sinks of past, present, and future land-use change and resource management practices at local, regional, and global scales?

7.4 How do global terrestrial, oceanic, and atmospheric carbon sources and sinks change on seasonal to centennial time scales, and how can this knowledge be integrated to quantify and explain annual global carbon budgets?

7.5 What will be the future atmospheric concentrations of carbon dioxide, methane, and other carbon-containing greenhouse gases, and how will terrestrial and marine carbon sources and sinks change in the future?

7.6 How will the Earth system, and its different components, respond to various options for managing carbon in the environment, and what scientific information is needed for evaluating these options?

See Chapter 7 of the *Strategic Plan for the U.S. Climate Change Science Program* for detailed discussion of these research questions.

Carbon is important as the basis for the food and fiber that sustain and shelter human populations, as the primary energy source that fuels economies, and as a major contributor to the planetary greenhouse effect and potential climate change. Carbon dioxide (CO_2) is the largest single forcing agent of climate change, and methane (CH_4) is also a significant contributor.

Atmospheric concentrations of CO_2 and CH_4 have been increasing for about two centuries as a result of human activities and are now higher than they have been for over 400,000 years. Since 1750, CO_2 concentrations in the atmosphere have increased by 30% and CH_4 concentrations in the atmosphere have increased by 150%.

Approximately three-quarters of present-day anthropogenic CO_2 emissions are due to fossil fuel combustion (plus a small amount from cement production). Land-use change accounts for the rest. The strengths of CH_4 emission sources are uncertain due to the high variability in space and time of biospheric sources. Future atmospheric concentrations of these greenhouse gases will depend on trends and variability in natural and human-caused emissions and the capacity of terrestrial and marine sinks to absorb and retain carbon.

Decisionmakers searching for options to stabilize or mitigate concentrations of greenhouse gases in the atmosphere are faced with two broad approaches for controlling atmospheric carbon concentrations: 1) reduction of carbon emissions at their source—such as through reducing fossil fuel use and cement production or changing land use and management (e.g., reducing deforestation); and/or 2) enhanced sequestration of carbon—either through enhancement of biospheric carbon storage or through engineering solutions to capture carbon and store it in repositories such as the deep ocean or geologic formations.

Enhancing carbon sequestration is of current interest as a near-term policy option to slow the rise in atmospheric CO_2 and provide more time to develop a wider range of viable mitigation and adaptation options. However, uncertainties remain about how much additional carbon storage can be achieved, the efficacy and longevity of carbon sequestration approaches, whether they will lead to unintended environmental consequences, and just how vulnerable or resilient the global carbon cycle is to such manipulations.

Successful carbon management strategies will require solid scientific information about the basic processes of the carbon cycle and an understanding of its long-term interactions with other components of the Earth system, such as climate and the water and nitrogen cycles. Such strategies also will require an ability to account for all carbon stocks, fluxes, and changes and to distinguish the effects of human actions from those of natural system variability. Because CO_2 is an essential ingredient for plant growth, it will be essential to address the direct effects of increasing atmospheric concentrations of CO_2 on terrestrial and marine ecosystem productivity. Breakthrough advances in techniques to observe and model the atmospheric, terrestrial, and oceanic components of the carbon cycle have readied the scientific community for a concerted

research effort to identify, characterize, quantify, and project the major regional carbon sources and sinks—with North America as a near-term priority.

The agencies responsible for CCSP carbon cycle research (DOE, NASA, NIST, NOAA, NSF, USDA, and USGS) have planned a coordinated, interagency, and multidisciplinary research strategy to bring together the broad range of needed infrastructure, resources, and expertise essential for providing this information. A continuing dialogue with stakeholders—including resource managers, policymakers, and other decisionmakers—will be established and maintained to ensure that desired information is provided in a useful form.

Highlights of Recent Research

Highlights of recent research supported by CCSP participating agencies follow.

Recent trends in greenhouse gases quantified. Based on monitoring since the late 1970s, data from more than 50 global sites of the Global Cooperative Air Sampling Network show continuing increases in the atmospheric concentrations of CO_2, CH_4, nitrous oxide (N_2O), and other greenhouse gases. Percentage increases of CO_2 and N_2O are similar. The methane increase has slowed considerably, and the most

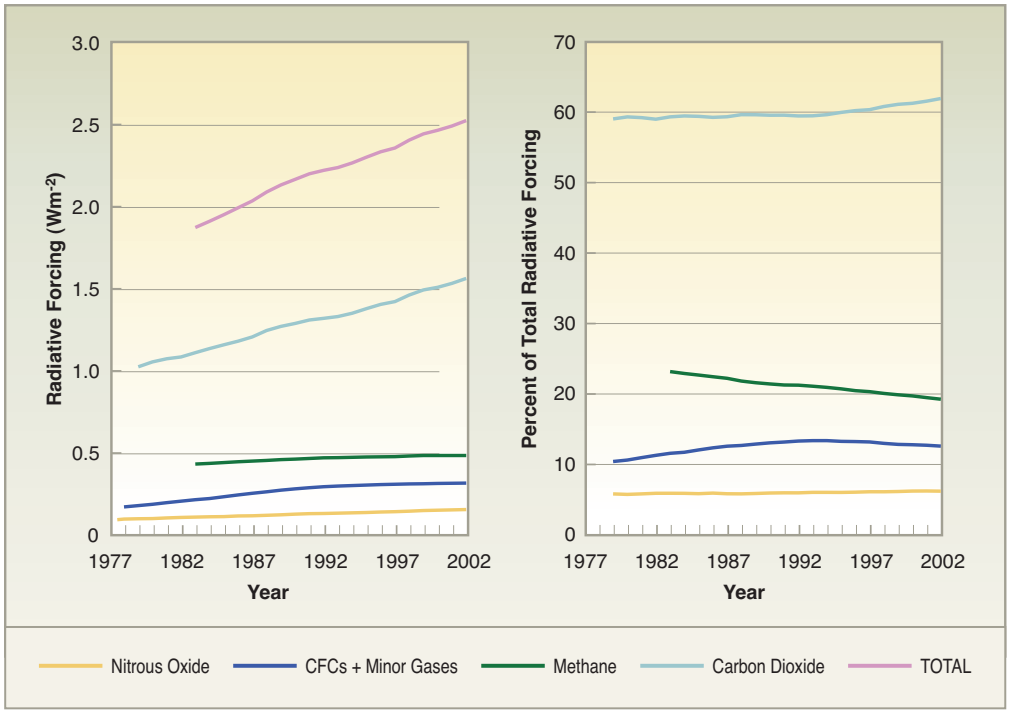


Figure 18: Radiative climate forcing by long-lived greenhouse gases. Direct radiative forcing (in Wm^{-2}) by four classes of major long-lived greenhouse gases (left panel), and percentage of the total direct forcing for each of the four (right panel). Annual averages are from NOAA's Global Cooperative Air Sampling Network. *Credit: NOAA Climate Monitoring and Diagnostics Laboratory.*

recent measurements indicate it has leveled off. CO_2 accounts for more than 60% of the calculated direct radiative forcing for these gases, and CH_4 is now less than 20% (see Figure 18). The time-averaged atmospheric CO_2 concentration increase has been approximately 1.5 ppm per year over the past several decades. While there is large year-to-year variation, and a very small annual rate of increase, 1.5 ppm per year would be most appropriate for use as the CO_2 forcing in current climate modeling applications.

AmeriFlux measures terrestrial carbon sinks. Measurements of the net exchange of CO_2 between terrestrial ecosystems and the atmosphere—referred to as net ecosystem exchange (NEE)—confirm that most terrestrial ecosystems in the United States are assimilating CO_2 and are important sinks for atmospheric CO_2. While NEE measures vary according to properties of ecosystems and their environments, over a 3- to 10-year period of observation annual net carbon uptake ranged from 2 to 4 tons per hectare for forests, and about 1 ton or less per hectare for agriculture and grassland. In addition to the unique NEE results, AmeriFlux sites are producing systematic biological and micro-meteorological data for understanding both terrestrial carbon cycling processes and the biophysical controls on them.

Climate-driven increases in terrestrial productivity. New analyses of 18 years of climatic data and satellite observations of vegetation indicate that changes in climate have eased several critical climatic constraints to plant growth around the world. Global terrestrial net primary productivity has increased 6% (3.4 PgC over 18 years), with 25% of the global land area showing significant increases and 7% showing significant decreases (see Figure 19). Ecosystems in all tropical regions and in the high latitudes of the Northern Hemisphere accounted for 80% of the increase in

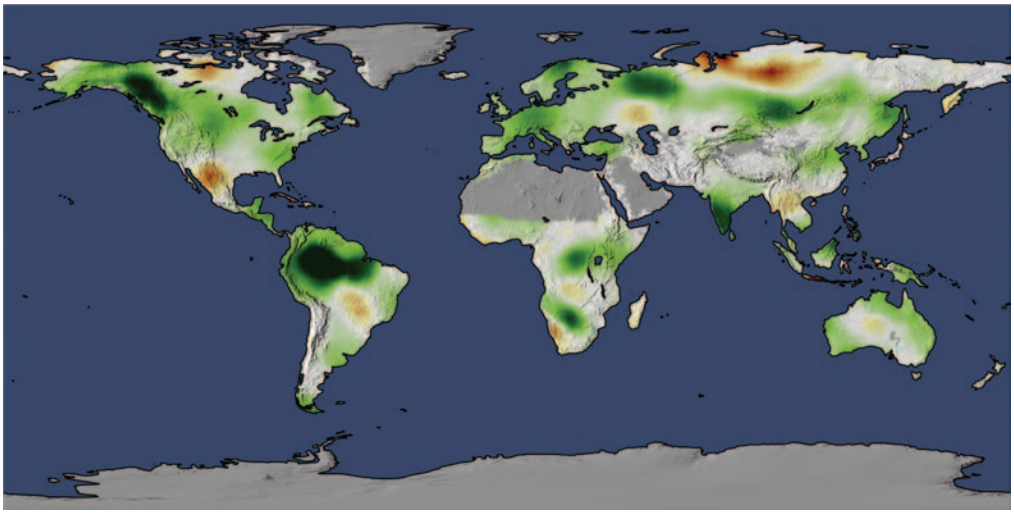


Figure 19:
Global change in terrestrial net primary productivity (NPP), 1982-1999. NPP was calculated using mean fraction of absorbed photosynthetically active radiation and leaf area index derived from two different Advanced Very High-Resolution Radiometer (AVHRR) data sets. Areas of increase in NPP are colored green and areas of decrease in brown.
*Credit: R. Nemani, NASA Ames Research Center [first presented in Science, **300**, 1560-1563 (6 June 2003)].*

productivity. Tropical increases were attributed to decreased cloud cover and the resulting increase in solar radiation. Increases in other regions were due to the combined effects of increasing temperature, changes in rainfall, and changes in solar radiation.

Conservation Reserve Program (CRP) lands removing greenhouse gases from the atmosphere. Results across a 13-state region of the United States show that CRP lands sequester about 910 kg of carbon per hectare in the top 20 cm of soil each year. This translates to 5.1 million metric tons of carbon removed from the atmosphere and sequestered into the soil each year in the 5.6 million hectares (about 13.8 million acres) of CRP land. The research demonstrates a clear role for farmers and ranchers in carbon sequestration and possibly climate change mitigation—in addition to the conventional CRP benefits of improving soil, water, and wildlife resource conservation.

Ocean Inventory of Anthropogenic Carbon. Estimates of the current oceanic anthropogenic CO_2 inventories and transports have been greatly improved using data from the global surveys of the World Ocean Circulation Experiment (WOCE), the Joint Global Ocean Flux Study (JGOFS), and the Ocean Atmosphere Carbon Exchange Study (OACES). Between 1991 and 1998, these programs produced a large number of high-quality measurements of important tracers for anthropogenic carbon, including nearly 100,000 dissolved inorganic carbon (DIC) samples as well as a large number of other high-quality measurements of important anthropogenic carbon tracers such as chlorofluorocarbons (CFCs), ^{13}C and ^{14}C of DIC, and other chemical species important in the study of biogeochemical cycling.

Analyses of these data indicate a total uptake of approximately 117 $\pm$ 19 PgC from anthropogenic sources and large regional differences in its horizontal and vertical distribution in the world's oceans. The reconstructed distribution of anthropogenic CO_2 in the oceans shows large differences between the North Atlantic, where anthropogenic CO_2 can be traced down to the bottom, and the tropical Pacific, where no anthropogenic CO_2 can be detected below 600 m. Despite the predominantly Northern Hemisphere source of fossil fuel CO_2, approximately 60% of the anthropogenic CO_2 is located in the Southern Hemisphere associated with the subtropical convergence zones (see Figure 20). This distribution is consistent with that expected based on current knowledge of large-scale ocean circulation.

Effect of climate variability on air-sea exchange of CO_2. Measurements from studies in the Equatorial Pacific Ocean show a large shift in the surface water partial pressure of CO_2 (pCO_2) levels and CO_2 fluxes to the atmosphere from the 1980s to the 1990s. The surface water pCO_2 levels increased much more slowly in the 1980s than in the 1990s, with the change in trend occurring around 1990. This timing

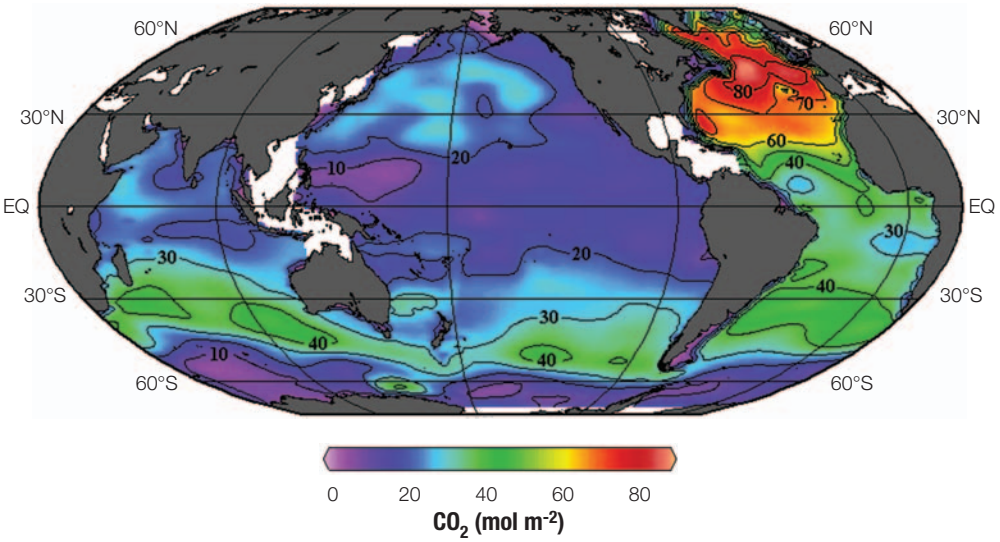


Figure 20:
Distribution of anthropogenic CO_2 in the global oceans through 1994. Between 1991 and 1998, global ocean CO_2 surveys produced a large number of high-quality measurements of important tracers for anthropogenic carbon. Estimates of the anthropogenic CO_2 uptake based on the observations indicate a total anthropogenic CO_2 inventory of approximately 117 ± 19 PgC in 1994. *Source: Sabine, C.L., et al., Chapter 2: Current status and past trends of the global carbon cycle. In Toward CO_2 Stabilization: Issues Strategies, and Consequences [C.B. Field and M.R. Raupach (eds.)], Island Press, Washington D.C. [in press].*

corresponds with a change in the Pacific Decadal Variability and is consistent with the hypothesis that natural climate variations have a major effect on air-sea CO_2 fluxes. This is the first documentation of an effect on the ocean carbon system by a time scale oscillation with a periodicity longer than that of the El Niño-Southern Oscillation (ENSO).

Ocean color calibration refinement improves carbon estimates. Observed ocean color variability, as measured by satellites, was modified based upon new radiometric characterizations of the *in situ* calibration sensors on the Marine Optical Buoy (MOBY), which is used for on-orbit calibration of satellite sensors such as SeaWiFS and MODIS. A new, portable, tunable-laser system was used to improve characterization of the MOBY sensors, and a new algorithm was developed to correct for stray light effects. These adjustments have improved SeaWiFS calibration, resulting in reductions in derived global mean chlorophyll concentrations of about 6%, which, in turn, reduced global ocean biomass and primary productivity estimates, yielding a more accurate understanding of the oceans' role in Earth's carbon budget.

Carbon On-Line Estimation (COLE). A new computer tool has been developed to provide forest carbon estimates for user-defined areas of the conterminous United States. The project is an effort to make forest inventory analysis data readily accessible. COLE should allow the user to harness these data and use them in a number of complex queries involving estimates of sequestered carbon. COLE gives the user an interactive, on-line database query capability, and has been implemented with a database for the eastern United States (see Figure 21).

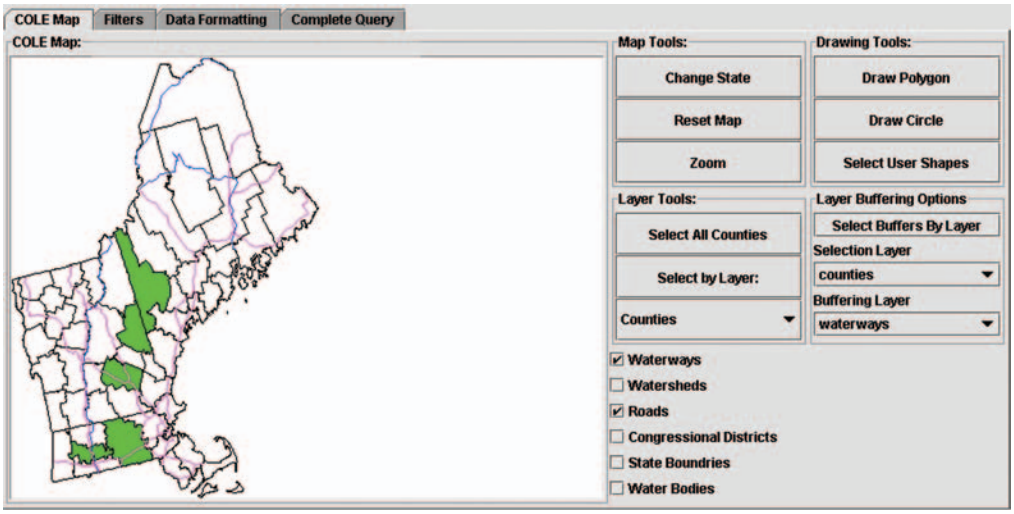


Figure 21: The USDA Forest Service's Carbon On-Line Estimation graphical analysis tool provides an interactive, on-line database query capability. A beta version of the program estimates carbon stocks based on the USDA Forest Service Eastwide Forest Inventory database. The program allows the user to designate an area of interest, and currently provides growing stock volume, areas, and carbon stocks for States east of the Great Plains in tabular, graphical, or map format. *Credit: USDA Forest Service.*

Disturbance and seasonal dryness reverse seasonality of carbon exchange in moist tropical forests. Recent results from eddy covariance flux and biometric measurements in two old-growth Amazonian forests indicate that the seasonality of carbon exchange is exactly the opposite of what conventional knowledge and models predict. Carbon was lost during the 7-month wet season and gained during the 5-month dry season. The short dry season strongly limits respiration due to desiccation of surface detrital materials, but only weakly affects photosynthesis because there is adequate moisture at depth. Decomposition of the large amounts of coarse woody debris in these forests, present due to past disturbances, predominates after the rains resume. These are also the first eddy covariance measurements that document a net carbon loss to the atmosphere from old-growth forests in the Amazon.

Highlights of FY 2004 and FY 2005 Plans

The U.S. carbon cycle science program 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 in order to reduce major uncertainties about the global carbon cycle. Special attention will be paid to carbon management and carbon cycle processes that can cause significant changes in the size and longevity of important carbon sources and sinks on land and in the ocean.

In the next 2 years, emphasis will be on implementing the North American Carbon Program (NACP) and the Ocean Carbon and Climate Change (OCCC) plans developed through the auspices of the Carbon Cycle Science Steering Group. Program coordination and data management infrastructure will be established and new

opportunities will be made available to conduct research in these areas. A strategy for conducting intensive research within the NACP will be communicated in 2004, and the first of these intensive field research programs and/or campaigns will be underway in 2005. Key research plans for FY 2004 and FY 2005 follow.

Systematic observations in the North American Carbon Program. In order to reduce the uncertainty in North American carbon sources and sinks, measurement networks are being installed and enhanced across the United States. The networks include AmeriFlux and AgriFlux sites, tall (500 m) towers, vertical atmospheric carbon profiling stations, and ocean platforms. In addition, a new tier of measurements at the landscape scale (landscape monitoring) will be initiated and evaluated. Systematic data from these networks will be merged with satellite observations to provide an integrated and consistent result and a framework for continental-scale synthesis and modeling of carbon sinks and sources. Specific activities include:

- Flux and atmospheric CO_2 concentration measurements will be upgraded at selected AmeriFlux and AgriFlux sites to support planned NACP intensive field research, regional atmospheric studies, and national inventories.
- Atmospheric profiling and flux measurements by aircraft and tall towers will be expanded to about 15 stations by the end of 2004 in preparation for NACP intensive research and to test integrated sampling protocols at regional and continental scales and methods for data assimilation and modeling.
- Air-sea CO_2 exchange measurements in the North Atlantic and North and Equatorial Pacific Oceans will be made to help define boundary conditions for improved modeling of North American carbon sources and sinks.
- Robust *in situ* sensors will be developed to better calibrate coastal ocean color data from satellites and improve coastal carbon source and sink quantification.
- New Earth Observing System satellite data products will be developed. The data products will be customized for analyzing primary productivity, land cover, and carbon dynamics in North America and adjacent oceans. The first of these data products will be made available in 2005; they will be used for spatial extrapolation and scaling and/or for driving carbon models. Regional studies to integrate remote-sensing data with forest inventory, water monitoring, and historical land-use change data to quantify carbon sources and sinks will be underway in 2004.
- A new measurement tier at the landscape scale will be initiated using an intermediate set of biometric measurements to link between the extensive monitoring of inventories and remote sensing and the intensive monitoring of flux towers, process studies, and manipulative experiments. This landscape-monitoring tier will include clusters of measurement sites that represent conditions over large landscapes. A study design has been developed and reviewed, and three pilot studies to evaluate the design will be implemented during 2004 and 2005.

These activities will address Question 7.1 (second of the milestones, products, and payoffs) and 7.4 (first of the milestones, products, and payoffs) of the CCSP Strategic Plan.

Intensive field research and campaigns in the NACP. In order to achieve the goals of the NACP, one or more intensive field research projects or campaigns will be needed to evaluate methodological approaches and test key hypotheses. These 'intensives' will be focused on specific, challenging issues that are critical to the success of the overall NACP, that require unusual concentrations of resources, and that are time-sensitive (i.e., lack of progress on this issue hinders major elements of the program). Each of these intensives will require especially close interagency cooperation and multidisciplinary research approaches. The first intensives to be conducted will be decided in 2004 and will be underway by 2005.

These activities will address Questions 7.1 and 7.2 of the CCSP Strategic Plan.

Carbon storage by crop and rangelands. Inventory and analytical studies will provide data on the extent to which commonly used soil management systems across the United States remove CO_2 from the atmosphere and store it in croplands and rangelands.

These activities will address Questions 7.1, 7.3, and 7.6 (first of the milestones, products, and payoffs) of the CCSP Strategic Plan.

Repeat hydrography CO_2/tracer measurement and new transport studies. CO_2 inventory and transport studies will be conducted in the North Atlantic and North Pacific Ocean to determine decadal changes in physical and biogeochemical process affecting the distribution of CO_2 in the oceans and to estimate anthropogenic carbon uptake in the basins. Additionally, new research will be initiated in 2004 on carbon transport and fate from drainage basins to ocean margins.

These studies will address Questions 7.1 and 7.2 of the CCSP Strategic Plan.

Underway pCO_2 measurements in the North Atlantic and North Pacific. Measurements of surface ocean pCO_2 will be implemented on research and volunteer observing ships as they are underway to quantify the seasonal and interannual variations of air-sea CO_2 fluxes in the ocean basins adjacent to North America.

These measurements will address Questions 7.1 and 7.2 of the CCSP Strategic Plan.

Relationships among climate, phytoplankton, carbon, and iron in the Antarctic Ocean. New studies will be conducted to assess the role of the Antarctic Ocean in absorbing atmospheric CO_2, as well as the role of iron in regulating ocean carbon cycle processes.

These studies will address Questions 7.2 and 7.5 of the CCSP Strategic Plan.

Seasonal and interannual ocean productivity patterns. Multiple overlapping and consecutive measurements of phytoplankton chlorophyll *a* and estimates of primary productivity from satellite sensors (OCTS, SeaWiFS, and MODIS) will be linked in an 8-year or longer time series, with new data to be added as it is collected. These consistent time series of data will become available in 2005. They will be used to

examine seasonal to interannual patterns of change, improve models, and reduce errors in estimates of carbon sources and sinks.

These studies will address Questions 7.1, 7.2, and 7.5 of the CCSP Strategic Plan.

Carbon cycle modeling. Advanced modeling research will be initiated in 2004 to improve regional- and continental-scale carbon models. Improved models of ocean margin productivity and coastal carbon cycling processes will be developed. New data assimilation approaches, employing both *in situ* and satellite observations, and improved land-atmosphere-ocean coupling, will be emphasized. Improved characterization of multiple, interacting process constraints also will be pursued.

These activities will address Questions 7.1 (fifth of the milestones, products, and payoffs), 7.2, and 7.5 (third and fourth of the milestones, products, and payoffs) of the CCSP Strategic Plan.

Greenhouse gas accounting rules and guidelines for forest systems and agricultural soils. In response to a Presidential directive, greenhouse gas accounting rules and guidelines for forest systems and agricultural soils will be developed for crediting forestry and agriculture sequestration projects, which is part of the Climate Change Research Initiative. Guidelines will provide for consistent reporting of carbon sequestration estimates by region and management intensity. Technical guidance and software will aid measurement and computation of carbon content of standing stocks as well as soils and wood products. The goal is to base greenhouse gas accounting guidelines on sound scientific information and to illustrate added value that carbon credits might bring to traditional forestry. Rules and guidelines will be available in 2005.

These activities will address Questions 7.1 (first of the milestones, products, and payoffs), 7.3, and 7.6 of the CCSP Strategic Plan.

Orbital Carbon Observatory (OCO). OCO will make space-based measurements of atmospheric CO_2 (total column) that will greatly improve the accuracy and resolution of the inverse atmospheric transport models used to characterize carbon sources and sinks. OCO was confirmed for mission formulation in 2003, and during 2004 and 2005 it will proceed through a series of important design and mission confirmation reviews. It is scheduled for a 2007 launch.

This activity will address Questions 7.4, 7.5, and 7.6 of the CCSP Strategic Plan.

Prototype State of the Carbon Cycle report. The first CCSP synthesis and assessment product related to carbon cycle science will be delivered in 2005. The topic is the North American carbon budget and implications for the global carbon cycle—providing an evaluation of our knowledge of carbon cycle dynamics relevant to the contributions of and impacts on the United States, and scientific information for U.S. decision support focused on key issues for carbon management and policy.

This activity will address Questions 7.1 (last of the milestones, products, and payoffs), 7.2, and 7.4 of the CCSP Strategic Plan.

6 Ecosystems

Strategic Research Questions

8.1 What are the most important feedbacks between ecological systems and global change (especially climate), and what are their quantitative relationships?

8.2 What are the potential consequences of global change for ecological systems?

8.3. What are the options for sustaining and improving ecological systems and related goods and services, given projected global changes?

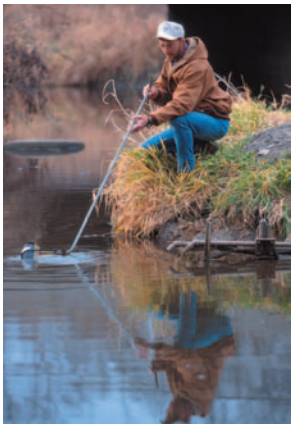
See Chapter 8 of the *Strategic Plan for the U.S. Climate Change Science Program* for detailed discussion of these research questions.

Ecosystems shape societies and nations by providing essential renewable resources and other benefits. They sustain human life by providing the goods and services on which life depends, including food, fiber, shelter, energy, biodiversity, clean air and water, recycling of elements, and cultural, spiritual, and aesthetic returns. Ecosystems also affect the climate system by exchanging large amounts of energy, momentum, and greenhouse gases with the atmosphere. The goal of the Ecosystems research element of the Climate Change Science Program is to understand and be able to project the potential effects of global change on ecosystems, the goods and services ecosystems provide, and ecosystem links to the climate system.

Climate variability and change can alter the structure and functioning of ecosystems. This, in turn, can affect the availability of ecological resources and benefits, can change the magnitude of some feedbacks between ecosystems and the climate system, and can

affect economic systems that depend on ecosystems. Research during the last decade focused on the vulnerability of ecosystems to global change and contributed to assessments of the potential effects of global change on ecological systems at multiple scales.

We now know that the effects of environmental changes and variability may be manifested in complex, indirect, and conflicting ways. For example, warming may enhance tree growth by extending growing season length (in temperate and cool regions), but pathogens better able to survive the winter because of higher temperature may decrease forest productivity and increase vulnerability of forests to disturbances such as fire. Subtle changes in winds over the ocean can affect currents, which in turn may alter the ranges and population sizes of fish species and increase or decrease fish catches. Whether environmental changes result from human activities or are natural in origin, human societies face substantial challenges in ensuring that ecosystems sustain the goods and services on which we depend for our quality of life and survival itself.



Research should be focused on building the scientific foundation needed for an enhanced capability to forecast effects of multiple environmental changes (such as concurrent changes in climate, atmospheric composition, land use, pollution, invasive species, and resource management practices) on ecosystems, and for developing products for decision support in managing ecosystems. Near-term priorities will be placed on economically important ecosystems and special studies relevant to regions where abrupt environmental changes or threshold responses by ecosystems may occur. Investigations will emphasize changes in ecosystem structure and functioning and changes in the frequency and intensity of disturbance processes anticipated to have significant consequences for society during the next 50 years, including altered productivity, changes in biodiversity and species invasions (including pests and pathogens), and changes in carbon, nitrogen, and water cycles.

Ensuring the desired provision of ecosystem goods and services will require understanding of interactions among basic ecosystem processes and developing approaches to reduce the vulnerabilities to, or take advantage of opportunities that arise because of, global and climatic changes. Scientific research can contribute to this societal goal by addressing three questions that focus on linkages and feedbacks between ecosystems and drivers of global change, important consequences of global change for ecological systems, and societal options for sustaining and enhancing ecosystem goods and services as environmental conditions change. This research will produce critical knowledge and provide a forecasting capability that will continuously improve decisionmaking for resource management and policy development.

Highlights of Recent Research

Highlights of recent research supported by CCSP participating agencies follow.

Ocean primary production decreased since the early 1980s. Satellite and *in situ* chlorophyll records show that global ocean primary production has declined more than 6% since the early 1980s (see Figure 22). Almost 70% of this decline occurred in the high latitudes. The North Atlantic and North Pacific Oceans experienced increases in sea surface temperature of 0.7 and 0.4°C, respectively, over the time period of the study. However, decreases in primary production in the Antarctic basin were not associated with significant warming. Satellite data were blended with *in situ* data and used as inputs to a model that computed seasonal ocean primary productivity. The reduction in primary production may represent a reduced sink of carbon via the photosynthetic pathway in the high-latitude oceans. It is not clear whether the changes observed are part of a long-term trend or if they might be related to decadal-scale climate variations, such as the Pacific Decadal Variability or North Atlantic Oscillation/Northern Annular Mode.

Climate regime shifts in marine ecosystems. Climate regime shifts on multi-decadal time scales affect the productivity of marine and terrestrial systems, thus it is critical to be able to recognize and predict regime shifts to manage ecosystems. Research has produced a new understanding of the impact of regime shifts on ecosystem productivity and structure. In the North Pacific Ocean, the Pacific Decadal Variability changed from warm to cool phase in 1998, and was accompanied by immediate increases in plankton productivity and species composition, and significant increases in numbers of Pacific Northwest salmon and other commercially important fishes. In the North Atlantic Ocean, changes in quantities of zooplankton and fishes were observed, particularly in the Gulf of Maine, associated with a reversal in the North Atlantic Oscillation/Northern Annular Mode. Based on these new findings, indicators of ecological change are being developed for fisheries management and policymakers.

Observed impacts of climate change on plant and animal species. Analyses based on a large number of studies of plants and animals across a wide range of natural systems worldwide have found that many species have shifted their geographic ranges or changed temperature-sensitive behaviors—such as migration, flowering, or egg-laying—in ways consistent with reacting to global warming. However, causal attribution of recent biological trends to climate change is complicated because non-climatic influences dominate local, short-term biological changes. Any underlying signal from climate change is likely to be revealed by analyses that seek systematic trends, over

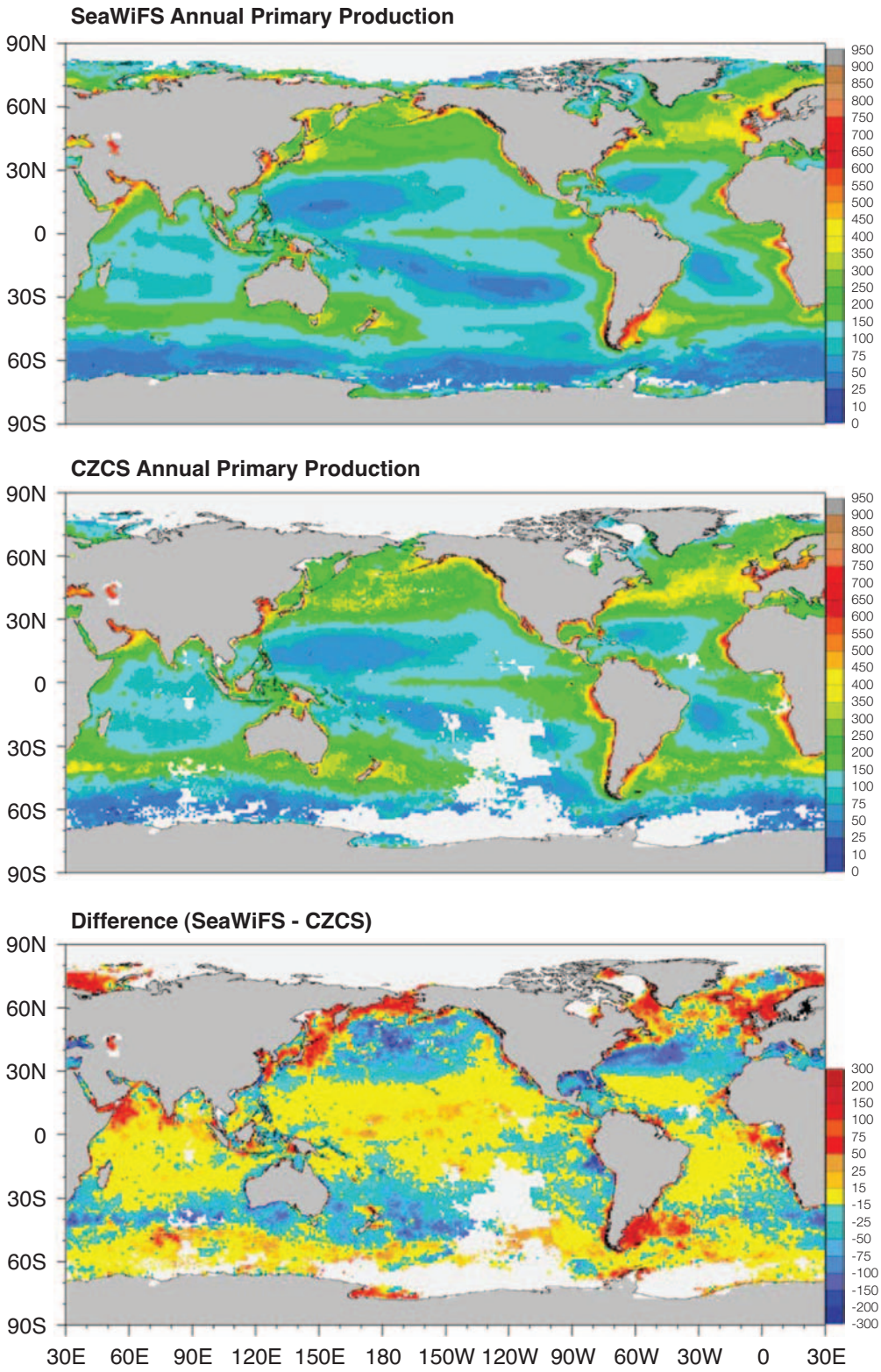


Figure 22:
Change in ocean primary production. Primary production distributions for the SeaWiFS era (1997 to mid-2002), the Coastal Zone Color Scanner era (1979 to mid-1986), and the difference. Units are gC m^{-2} yr^{-1}. White indicates missing data.
*Credit: Gregg, W.W., M.E. Conkright, P. Ginoux, J.E. O'Reilly, and N.W. Casey, 2003: Ocean primary production and climate: Global decadal changes. Geophys. Res. Lett., **30:15**, 1 August 2003.*

time and across many diverse species and geographic regions, that are consistent with what would be predicted by scientific understanding of the physiological tolerances of species to temperature. "Meta-analyses" provide a way to re-analyze and combine results from various studies to determine whether there are underlying consistent shifts.

One such re-analysis, based on observations made in studies of more than 1,700 species, documented significant range shifts averaging 6.1 km per decade towards the poles (or meters per decade upward in altitude) over time scales ranging from 16 to 132 years. The re-analysis found mean advancement of spring events by 2.3 days per decade, over time scales ranging from 17 to 1,000 years. A total of 279 species showed temporal and spatial responses that may be associated with 20th century climate trends. Another re-analysis based on observations made in 143 studies revealed a consistent temperature-related shift, or 'fingerprint,' in species ranging from molluscs to mammals and from grasses to trees. More than 80% of the species that showed changes were shifting in the direction expected on the basis of known physiological constraints of species. The balance of evidence from these studies suggests that impacts of global warming are discernible in animal and plant populations.

Natural resource management to offset greenhouse gas emissions. To help meet the need for identifying how terrestrial ecosystems can be managed to mitigate and adapt to climate change, optimize carbon sequestration, and reduce greenhouse gas emissions, a symposium was held to examine natural resource management opportunities for sequestering atmospheric CO_2 and reducing greenhouse gas emissions across multiple biomes. The scope of the symposium included forest, agriculture, range, boreal, desert, grassland, and wetland systems. Information presented included management options for increased storage of terrestrial carbon; monitoring information on current terrestrial carbon stocks; new and innovative technologies and methodologies for measuring and monitoring greenhouse gases in terrestrial ecosystems; economic projections for alternative carbon sequestration and emissions reduction practices in different terrestrial ecosystems; and policy implications of scientific carbon research findings. Some results presented indicate that nitrous oxide (N_2O) mitigation in cropping systems can be achieved with little or modest yield penalties by better adjusting nitrogen fertilizer additions to crop nitrogen needs. Other presentations described how, on fertile forest sites, or after fertilizer application, carbon sequestration in moderately long-lived carbon pools may be sustainably enhanced.

Effects of climate change on experimental forests. Precipitation amounts and atmospheric composition affected experimental forests in separate field experiments. Full analysis of the first 8 years of an experimental manipulation of precipitation on a deciduous forest ecosystem in Tennessee revealed that changes in precipitation amount affected nutrient cycling and mortality of young trees, but had little influence on large-tree wood or fine root growth, or on litter decomposition. In general, the forest

was resilient to altered precipitation amount, but long-term changes in forest species composition could result from changes in hydrology. In another field experiment (in Wisconsin), the postulated stimulation of trembling aspen growth by several years of elevated atmospheric CO_2 concentration (related to fossil fuel use) was approximately offset by a concomitant increase in tropospheric ozone (O_3) concentration (also related to fossil fuel use). These ongoing experiments and related activities are supplying policymakers with empirical data needed to evaluate the potential effects of global change on important ecosystems.

Farmers and ranchers can expect increased atmospheric carbon dioxide to be a mixed blessing. Increased growth and yield are well-known responses of crops to CO_2 enrichment. However, recent research shows that increased CO_2 also can have undesirable effects in agricultural systems. When plots of shortgrass prairie in northeastern Colorado were exposed to twice-ambient CO_2 levels in open-top chambers, the forage produced had less nitrogen and was less digestable than forage produced in ambient-level CO_2. In another experiment, increased CO_2 stimulated the growth of five of the most important species of invasive weeds, more than any other plant species yet studied. This suggests that some weeds could become bigger problems as CO_2 increases. In other studies, at twice the ambient CO_2 level, white clover leaf area consumed by an insect pest (the Western flower thrips) was approximately 90% greater than leaf area consumed in ambient CO_2. Although enriched atmospheric CO_2 could provide some benefits to plants, farmers and ranchers may face some surprises in managing agricultural systems to sustain both yield and quality as CO_2 levels continue to increase.

Interagency ecosystem model-data comparison. A multi-agency effort to evaluate 13 stand-level forest ecosystems models, which varied in spatial, mechanistic, and temporal complexity, was carried out with the use of independent field data. The field data were obtained from eastern Tennessee over an 8-year period using a wide range of methods. No single model consistently performed the best at all time steps or for all variables considered. Inter-model comparisons showed good agreement for water cycle fluxes but considerable disagreement among models for predicted carbon fluxes. The mean of all model outputs was nearly always the best fit to the observations. Models missing key forest components or processes, such as roots or modeled soil water content, were unable to provide accurate predictions of ecosystem responses to short-term drought. Models using hourly time steps, detailed mechanistic processes, and having a realistic spatial representation of the forest ecosystem provided better predictions of observed data. Predictive ability of all models deteriorated under drought conditions, indicating that further research is needed to evaluate and improve ecosystem model performance under unusual conditions, such as drought, that are a common focus of environmental change discussions.

Highlights of FY 2004 and FY 2005 Plans

The CCSP 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 and seizing opportunities to enhance resilience and sustain ecosystem goods and services. Key research plans for FY 2004 and FY 2005 follow.

Arctic Climate Impact Assessment. The goal of the Arctic Climate Impact Assessment (ACIA) is to evaluate and synthesize knowledge on climate variability, climate change, and increased ultraviolet radiation and their consequences. The aim is to provide useful and reliable scientific information to governments, organizations, and peoples of the Arctic and of areas influenced by the Arctic, to help them respond to climate variability and change. ACIA will examine possible future impacts on the environment and its living resources, on human health, and on buildings, roads, and other infrastructure. Such an assessment is expected to lead to the development of useful information for the nations of the Arctic region, their economy, resources, and peoples.

The assessment will be open and transparent, and the review of its conclusions is intended to be credible and rigorous. Also, the degree of uncertainty of the conclusions will be made clear. Two scientific volumes will be completed in 2004; the first will be a rigorous peer-reviewed scientific volume, and the second will be an overview document summarizing results in readily understandable language. There is broad participation of experts from many different disciplines, including indigenous cultures, and countries in preparing the assessment. NSF and NOAA have provided much of the funding for this effort.

These activities will address Question 8.1 (first milestone, product, and payoff) of the CCSP Strategic Plan.

Data from field experiments quantifying aboveground and belowground effects of elevated CO_2 concentration on the structure and functioning of agricultural ecosystems. By the end of FY 2005, experiments conducted in Free Air CO_2 Enrichment systems and open-top field chambers will be completed. These experiments will provide data on effects of carbon dioxide enrichment—alone and in combination with other environmental characteristics such as water availability, soil fertility, pest pressure, and tropospheric ozone—on crop growth and yield development, root development, carbon sequestration, nutrient cycling, and other processes. Results will be available for modelers to improve projections of crop production and carbon sequestration under different environmental scenarios projected for the 21st

century. Crop production estimates will be useful to investigations of the impact of global change on food security.

These activities will address Question 8.2 of the CCSP Strategic Plan.

Prediction of location and ecological impact of invasive weeds. By the end of FY 2004 an on-line system will be developed that combines remotely sensed data from Earth observing satellites with ground data provided by local users to generate projections of areas most likely to be changed through the incursion of certain non-native invasive plant species. The system will generate projections through analysis of geospatial and statistical data. These projections can help resource managers develop approaches for the control of invasive species.

These activities will address Question 8.3 of the CCSP Strategic Plan.

Fire forecasting, fuels management, and ecosystem carbon storage. Hazardous fuels in forests in the western United States have increased to catastrophic levels due to fire suppression policies and lack of active management. Recent research and observations, however, suggest that fuels have also increased due to a sudden ocean-climate 'regime shift' in the Pacific Decadal Variability in the mid-1970s. Mapped Atmosphere-Plant-Soil-System (MAPSS) researchers have constructed a simulation technology to forecast ecosystem and fire responses to climatic variations and change. Simulations using seven assumed future climate scenarios suggest that the U.S. Southeast will experience increased fire risk in the coming decades. From FY 2004 through FY 2005, the model will be tested against historical records, and is expected to produce national-scale, high-resolution forecasts of fire risks in the United States that incorporate climate-driven year-to-year changes in fuel loadings and moisture characteristics (see Figure 23). Additional efforts will focus on incorporating insect and disease interactions and management actions into the model, and forecasting risks and locations of future fires.

These activities will address Question 8.2 of the CCSP Strategic Plan.

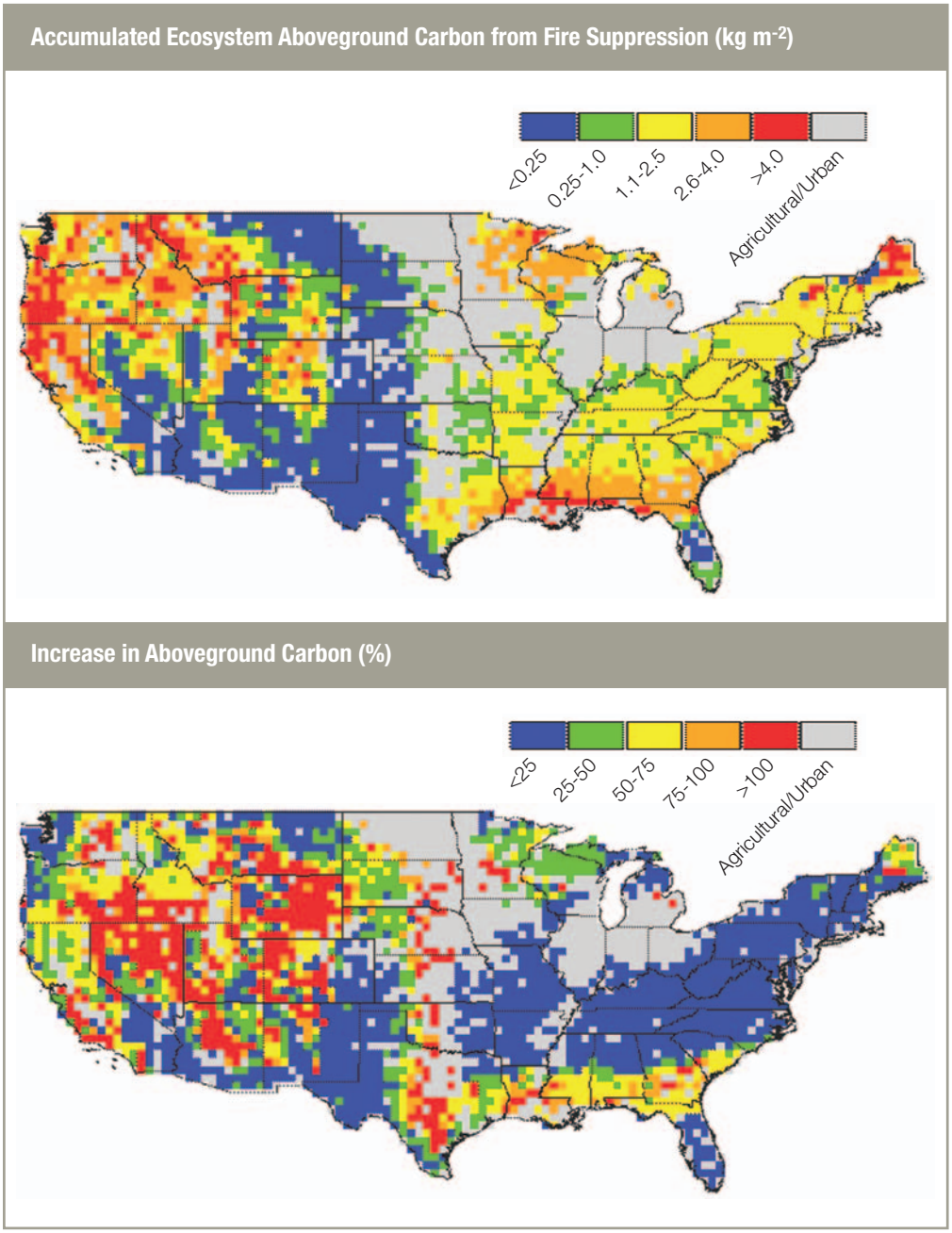


Figure 23: Simulated increase in total aboveground carbon (kg m^{-2}) due to fire suppression by the end of 2003. The map represents the first estimate of the amounts and locations of accumulated carbon in ecosystems as a direct result of over 50 years of fire suppression. The MC1 Dynamic General Vegetation Model is being used as a tool for forecasting wildfire over the course of the next 7 months, updated each month. Historical records show a dramatic drop in the area of wildfire over the United States, due to fire suppression, since the early 1950s. Although the map should be treated as an hypothesis to be tested, it does suggest areas that could be at risk of increased wildfire intensity due to fuels accumulation. However, historical simulations also underscore that interannual and interdecadal climatic variability are significant causes of recent increases in U.S. fire area. *Credit: James M. Lenihan, MAPSS Team, Pacific Northwest Research Station, USDA Forest Service.*

Quantifying effects of warming on boreal forests. Construction of a unique field facility will be completed to study effects of experimental warming on the structure and functioning of a boreal black spruce ecosystem. The facility, involving large open-top chambers combined with belowground temperature control, will be operational by early FY 2004. A long-term study of controlled manipulation of

temperature on ecosystem processes will be initiated during FY 2004. This facility and the experiments conducted in it will provide policymakers with unique data concerning possible effects of Northern Hemisphere warming on goods and services provided by boreal forests.

These activities will address Question 8.2 of the CCSP Strategic Plan.

Funding for three new marine Long Term Ecosystem Research (LTER) sites in coastal waters. In FY 2005, funding will be provided for three new marine LTER sites in coastal waters. Funding for the sites that are selected will be for up to 6 years with additional 5-year renewal possible. Such work will initiate collection of the long-term data sets in coastal waters that are needed for the study of possible impacts of climate variability and change on marine ecosystems and marine resources.

These activities will address Question 8.2 of the CCSP Strategic Plan.

Quantifying effects of altered temperature and precipitation on soil bacterial and microfaunal communities as mediated by biological soil crusts. About 30% of lands both globally and in the United States consist of semi-arid or arid landscapes. Soil surfaces in these landscapes are covered by biological soil crusts composed primarily of cyanobacteria, lichens, and mosses. Because these crusts cover almost the entire soil surface, most atmospheric inputs of water, nutrients, and solar radiation to soils are mediated by the soil crust community. Bacteria in lichen and cyanobacterial crusts are diazotrophic and photosynthetic, making crusts a dominant source of fixed nitrogen and an important source of fixed carbon in arid land soils. By the end of FY 2005, a series of manipulative and "natural" field experiments carried out across agencies will be used to test hypotheses that increased temperature and seasonal shifts in precipitation will:

1) Alter respiration, photosynthesis, and nitrogen-fixation rates in lichen- and/or cyanobacterially dominated crusts from cool (Colorado Plateau) and/or hot (Chihuahuan) deserts

2) Affect the composition of soil bacterial communities (cyanobacteria, N_2-fixing, and NH_3-oxidizing bacteria) within and beneath soil crusts
3) Change the abundance and composition of soil microfauna (nematodes, mites, collembolans, and protozoa) that serve as a nutritional link between crust inputs and vascular plants
4) Through changes in the soil food web and soil chemistry, indirectly alter growth and nutrient availability to vascular plants.

These activities will address Question 8.2 of the CCSP Strategic Plan.

Analyzing the potential effects of climate change and land-use change on selected watersheds. Water quality and quantity in rivers and streams can be affected by changes in temperature and in the timing, amount, and seasonality of precipitation. By the end of FY 2005, an analysis will be completed that examines the potential effects of climate change and land-use change on selected watersheds at varying scales. This analysis will address methodological approaches, stakeholder engagement, and methods employed for characterizing and communicating uncertainties.

These activities will address Question 8.2 of the CCSP Strategic Plan.

Quantifying impacts of livestock grazing management on carbon and nitrogen cycling. Measurements will be conducted during FY 2004 and FY 2005 on pastures that have been under different cattle grazing pressures for several years. Data will include year-round micrometeorological measurements of water and CO_2 fluxes, seasonal characteristics of the plant community and soil chemistry, and satellite imagery to relate fluxes and plant attributes.

These activities will address Question 8.3 of the CCSP Strategic Plan.

Linking a forest process model with a gap simulation model to refine estimates of forest growth under changing climate. Using known tree species attributes, climate scenarios, and other environmental factors as parameters, the PnET-II forest productivity model (developed at the University of New Hampshire) predicts net primary productivity (NPP) for a given set of conditions. NPP is then used as a parameter in the gap model, which interacts with SRTS, the economic model, on an annual time step. Currently, PnET-II is used with one species at a time, so multiple runs are performed to provide results for various species. The NPP estimates from each species run are then used in the gap model to predict forest stand dynamics. In FY 2004 and FY 2005, work will focus on fully integrating and linking these models.

These activities will address Question 8.3 of the CCSP Strategic Plan.

Quantifying climate change impacts on forest and rangeland vegetation, species shifts, and ecosystem productivity. Forest and rangeland vegetation, the geographic distribution of plant and animal species, and the productivity of these ecosystems is strongly influenced by the amount of rainfall and snow, the temperatures, the length of the growing season, and many other factors of the local climate. Identifying the vulnerabilities of ecosystems and economies to climate variability and change depends on an understanding of the sensitivity of those systems to climate. In FY 2004 and FY 2005, field and simulation studies will be employed to explore and evaluate the impact of changes in climate on forest and rangeland ecosystems in areas of the western United States.

These activities will address Question 8.3 of the CCSP Strategic Plan.

7 Human Contributions and Responses

Strategic Research Questions

9.1 What are the magnitudes, interrelationships, and significance of the primary human drivers of, and their potential impact on, global environmental change?

9.2 What are the current and potential future impacts of global environmental variability and change on human welfare, what factors influence the capacity of human societies to respond to change, and how can resilience be increased and vulnerability reduced?

9.3 How can the methods and capabilities for societal decisionmaking under conditions of complexity and uncertainty about global environmental variability and change be enhanced?

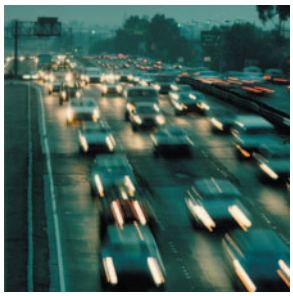
9.4 What are the potential human health effects of global environmental change, and what climate, socioeconomic, and environmental information is needed to assess the cumulative risk to health from these effects?

See Chapter 9 of the *Strategic Plan for the U.S. Climate Change Science Program* for detailed discussion of these research questions.

Human activities play an important part in virtually all natural systems and are forces for change in the environment at local, regional, and even global scales. Social, economic, and cultural systems are changing in a world that is more populated, urban, and interconnected than ever. Such large-scale changes increase the resilience of some groups while increasing the vulnerability of others. A better integrated understanding of the complex interactions between human societies and the Earth system is needed if we are to identify vulnerable systems and pursue options that take advantage of opportunities to enhance resilience.

Research on human contributions and responses includes studies of potential technological, social, economic, and cultural drivers of global change, and how these and other aspects of human systems may affect adaptation and the consequences of change for society. Human drivers of global environmental change include consumption

of energy and natural resources, technological and economic choices, culture, and institutions. The effects of these drivers are seen in population growth and movement, changes in consumption, de- or reforestation, land-use change, and toleration or regulation of pollution.



Global environmental variability and change must be analyzed in the context of other natural and social system stresses—such as land-use and land-cover change, population changes and migrations, and global economic restructuring. There has been significant progress in analyzing and modeling regional vulnerabilities and possibilities for adaptation, including in the context of multiple stresses. Progress has been made in understanding how society adapts to seasonal climate variability and, by extension, how it may adapt to potential longer term climate change.

It is well-established that human health is linked to environmental conditions, and that changes in the natural environment may have subtle, or dramatic, effects on health. Timely knowledge of these effects may support public health systems in devising and implementing strategies to compensate or respond to these effects. Federally supported research has thus far provided information on a broad range of health effects of global change, including the adverse effects of ozone, atmospheric particles and aeroallergens, ultraviolet radiation, vector- and water-borne diseases, and heat-related illnesses.

Decisionmaking is challenged by uncertainties including risks of irreversible and/or nonlinear changes that may be met with insufficient or excessive responses whose consequences may cascade across generations. The difficulties associated with uncertainty have become increasingly salient given the interest of policymakers in addressing global environmental change.

The NRC 2001 report, *Climate Change Science: An Analysis of Some Key Questions*, concluded that: "In order to address the consequences of climate change and better serve the Nation's decisionmakers, the research enterprise dealing with environmental change and environment-society interactions must be enhanced."

Highlights of Recent Research

Highlights of recent research supported by CCSP participating agencies follow.

Fire-climate assessment process. National priority issues such as drought, forest fires, energy supply, ecosystem restoration, and human health concerns such as West Nile and Encephalitis are being addressed locally and regionally through place-based,

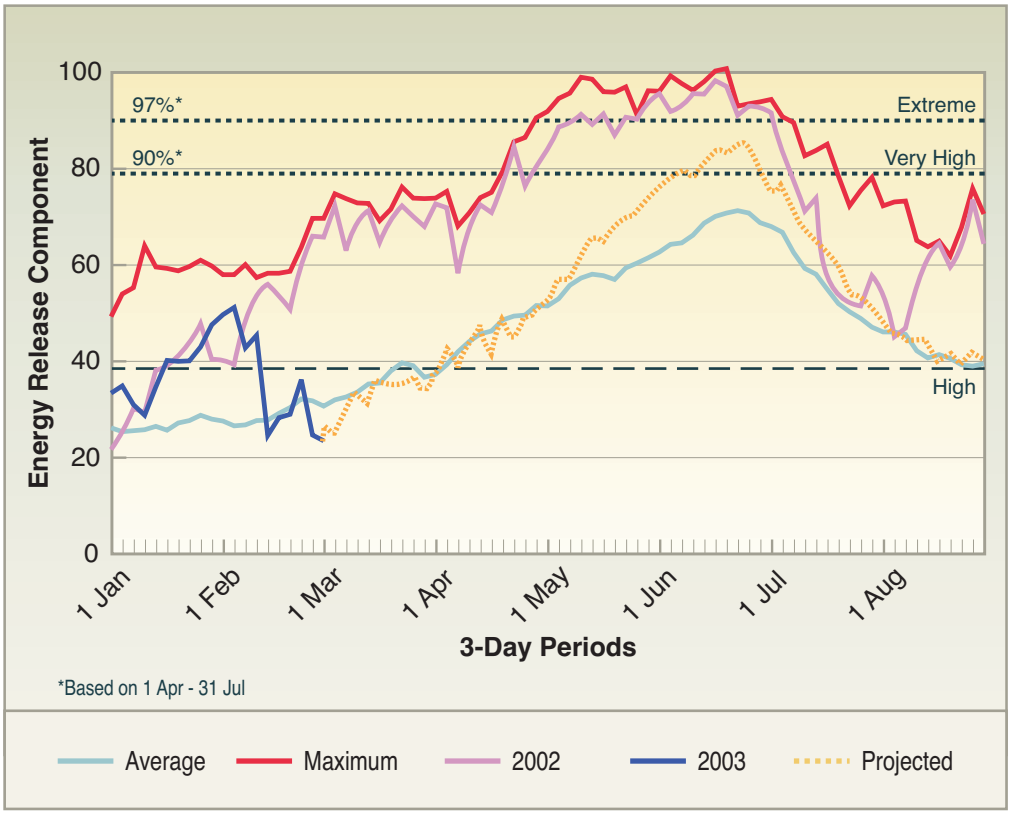


Figure 24: Southwest area GACC fire risk outlook for 2003. Southwest Area Energy Release Component (ERC) curve for 2003 with observed (January-February) and projected most likely scenario (March-August) of fire potential. ERC values are normally expected to peak between late May and early July, which correlates with the peak potential for large fire activity. The 2003 analysis correctly projected the timing of the very high fire danger period (mid-to-late June) encompassing the Aspen fire in Arizona's Coronado National Forest. The analysis also correctly projected that 2003 fire danger would be less severe for the southwestern United States than the 2002 fire danger. Through collaborative efforts of scientists and fire managers, pre-season forecasts can support improved management strategy and response and reduce the likelihood of future fires turning into major infernos. *Credit: Gregg M. Garfin, CLIMAS/Institute for the Study of Planet Earth, University of Arizona.*

stakeholder-driven climate research. Drawing on integrated research from the social, physical, and biological sciences, teams across the United States are developing decision support resources to expand decisionmakers' options in dealing with climate change and variability. One such example is the fire-climate assessment process (see Figure 24), which allows fire and fuels specialists in each of the National Interagency Fire Center's eleven Geographic Area Coordination Centers (GACCs) to work with NOAA climate scientists to develop GACC-level assessments of pre-season fire risk at seasonal and shorter time scales.

Comparing measures for measuring costs in cost-benefit analyses. In assessing potential climate change policies, as with any new economic or regulatory policies, there is a need to compare the costs and benefits of the new policies to existing policies and other alternatives to determine which policy is most cost-effective. Not all cost measures, however, arrive at the same ranking. An analysis of differences among a variety of measures showed that policies could rank differently depending on the choice of measure, and proposed a method for calculating costs that is theoretically superior to other measures.

Integrated assessment modeling of changes in terrestrial carbon stocks. The representation of the response of plant and soil carbon stocks to historical changes in land cover, land-use management, atmospheric CO_2 concentration, and climate has been analyzed and improved in integrated assessment models. This improvement helps understanding of how short- and long-term natural carbon fluxes, carbon sequestration, and human emissions contribute to the net global carbon emission trajectories. The results of this work will be available for the development of emission scenarios, both for the CCSP and for the IPCC.

Potential consequences of global climate change for the U.S. forest and agricultural sectors. Large-scale analyses are underway that examine the potential consequences of global climate change for the U.S. forest and agricultural sectors. A recently completed national assessment of several different climate scenarios and ecological responses concluded that, under several scenarios of global climatic change, economic welfare in the forest and agricultural sectors would be increased. Part of this improvement would be expected to result from an overall increase in U.S. forest productivity that boosts long-term timber inventory and allows more timber harvests. The projected impacts of global climate change on the two sectors vary over the 100-year projection period, with potential risks to producers' income. The forest sector was found to have adjustment mechanisms that mitigate climate change impacts, including interregional migration of production, substitution in consumption, and altered stand management. A more recent study of U.S. agriculture showed that, by the year 2060, the benefits of climate change to American croplands could be less than

CCRI PRIORITY - DECISIONMAKING UNDER UNCERTAINTY

The Climate Change Research Initiative will leverage existing U.S. Global Change Research Program efforts to provide structured information to inform national, regional, and local discussions about possible global change causes, impacts, and mitigation and adaptation strategies.

As part of the CCRI, NSF will provide continuing support for a set of competitively selected interdisciplinary centers focusing on decisionmaking under uncertainty associated with climate change and variability. These centers, which will be established in FY 2004 following a special competition, will conduct fundamental research on decisionmaking associated with climate change and variability. The centers are expected to advance basic understanding about decision processes dealing with issues such as inter-temporal choice, risk perception, hazards and disaster reduction, opportunities, tradeoffs, equity, framing, and probabilistic reasoning associated with uncertainty.

The centers will develop tools that people, organizations, and governments can use to better understand the risks and uncertainties associated with climate variability and change and the options they have to address them. In order to do this, they will develop and disseminate tangible products for researchers, decisionmakers, and other relevant stakeholders and make them readily accessible through a range of different media.

The centers will build on and complement work that has been and continues to be supported by NSF programs, such as the Decision, Risk, and Management Science Program, and by programs at other agencies.

previous work had indicated. A team of scientists found that finer scale simulations tend to reduce projected benefits and increase projected losses for a wide range of crops across most parts of the nation.

Youth and the future of the environment. The Center for the Integrated Study of the Human Dimensions of Global Change (CIS-HDGC) brings together more than 50 scientists and engineers. An important line of inquiry at CIS-HDGC has focused on the implications of environmental policy decisions across multiple generations. Current research into adolescent psychology suggests that young people in their mid-teens tend to harbor deep concerns about some aspects of their world, including the future of the environment. CIS-HDGC scientists are in the advanced stages of a project that has elicited young people's view of the natural world and their desires for it, in policy-relevant terms. Analyses reveal that, asked to explain changes or propose solutions, most teens do not think primarily in terms of institutions, such as governments or corporations. Instead, they consider responsibility to be widely diffused, using terms like "everybody," "just people," and "all of us." The most commonly proposed mitigation strategy was best classified as "increased public awareness." The results of this study are expected to offer guidance for parents, educators, and policymakers who are concerned with both the cognitive and the emotional bases for environmental values.

Health effects of exposure to ultraviolet radiation. Many measurements have demonstrated a relationship between stratospheric ozone depletion and increased levels of ultraviolet (UV) radiation at the surface. The internationally standardized UV Index scale presented to the public is defined in terms of the "skin-reddening" or "sunburning" UV irradiance.

- *Risk factors for malignant melanoma*. Sunlight exposure is known to be directly associated with risk for skin cancer. Although many of the risk factors for malignant melanoma—the deadliest form of skin cancer—are known, they are not well understood. Recent findings by National Cancer Institute researchers are providing new insights into the genetic and environmental factors that increase the risk for the disease. For example, a hospital-based case-control study published in 2003 is the first large epidemiological investigation to show that reduced DNA repair capability present in some individuals and not in others may play a role in causing sunlight-induced melanoma. This study may help explain why only a relatively small proportion of individuals exposed to sunlight develop the disease.
- *UV exposure and prevalence of cataract*. Epidemiological investigations have reported a higher prevalence of cataract in regions of the world that have unusually high levels of UV exposure. The National Eye Institute is supporting research that will examine various wavelengths of UV-A and UV-B to determine which are the most damaging to the lens and result in the formation of cataracts in human and animal tissue cultures.

Highlights of FY 2004 and FY 2005 Plans

The CCSP 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 2004 and FY 2005 follow.

Research centers for decisionmaking under uncertainty. During FY 2004, the process of establishing a set of centers focusing on decisionmaking under uncertainty (DMUU) associated with climate variability and change will be completed. The DMUU centers will function for 5 years (into 2008) and will conduct fundamental research on decisionmaking associated with climate change and variability. Center-supported research will be well-grounded in relevant theoretical frameworks based in the social, behavioral, and economic sciences as well as other appropriate science and engineering disciplines. Center research programs will advance basic understanding about decision processes dealing with issues such as inter-temporal choice, risk perception, hazards, disaster reduction, tradeoffs, equity, framing, and probabilistic reasoning associated with risky phenomena. The centers will develop tools that people, organizations, and governments can use to better understand the risks associated with climate variability and change and the options they have to address those risks. They also will develop and disseminate tangible products for researchers, decisionmakers, and other relevant stakeholders.

These activities will address a CCRI priority and Question 9.3 of the CCSP Strategic Plan.

Household composition and projections of energy demand. Projections of energy demand and associated greenhouse gas emissions will be improved by analyzing demographic variables. The research will use three case studies—the United States, China, and Indonesia—and focus on one subset of this problem (i.e., household composition) using survey data to estimate relationships with energy use. The objective is to improve projections of energy demand in integrated assessment models by taking into account variations in energy use across household types. Research results are expected at the end of FY 2004 with adoption by integrated assessment models in FY 2005.

These activities will address Question 9.1 of the CCSP Strategic Plan.

Societal use of seasonal forecasts. Researchers will identify lessons learned and tools developed in the area of how society prepares for and adjusts to seasonal and year-to-year climate variability. The focus will be on learning from experiences with and studies of societal use of seasonal forecasts, for the purpose of developing insights into potential longer term adaptation strategies in the face of climate variability and change. A workshop attended by a cross-section of researchers to discuss lessons

learned was convened in early FY 2004, and a report from the workshop is expected by late FY 2004.

These activities will address Question 9.2 of the CCSP Strategic Plan.

Enhancement of regional adaptive capacity. Development of research partnerships with stakeholders will continue to enhance regional adaptive capacity to climate change and variability in a variety of climate-sensitive sectors. Scoping meetings are planned for new regions of the United States where integrated climate research is expected to have the greatest capacity to meet the needs of decisionmakers. Two regional scoping meetings per year will take place in FY 2004 and FY 2005, with workshop reports following the meetings.

These activities will address Question 9.2 of the CCSP Strategic Plan.

State and local plans for sea-level rise. During FY 2004-2005, coastal elevation maps will be produced depicting areas vulnerable to sea-level rise. Planning maps will be created that synthesize current State and local baseline plans for sea-level rise along the U.S. Atlantic Coast. This work will improve understanding of the sensitivity and adaptability of coastal ecosystems and human systems and provide resources to support coastal zone environmental and infrastructure-related decisionmaking. The maps will synthesize current State and local coastal policies along the U.S. Atlantic and Gulf Coast, and divide coastal dry land into four categories: 1) conservation lands where current policies would allow the natural inland migration of wetlands and beaches; and lands where shore protection (and hence wetland elimination) is 2) almost certain, 3) likely, and 4) possible but-unlikely. Conservation officials will be able to use the maps to determine whether current policies ensure sufficient wetland migration, and identify areas where additional wetland migration is feasible. Local governments can focus infrastructure in areas where shores are certain to be protected. Ecologists assessing potential environmental consequences of climate change will have a better idea whether tidal habitat will shift inland or be replaced with seawalls.

These activities will address Question 9.2 (third of the milestones, products, and payoffs) of the CCSP Strategic Plan.

Assessment of global change consequences. Assessment activities will continue to advance understanding of relative risks in the context of multiple stressors, at multiple scales and multiple levels of biological and institutional organization. Assessments are conducted through public-private partnerships that actively engage researchers from the academic community, decisionmakers, resource managers, and other affected stakeholders in the assessment process. Assessment activities are ongoing with interim reports expected in FY 2004.

These activities will address Question 9.2 of the CCSP Strategic Plan.

Climate variability and human health. NOAA and NSF will continue to jointly award research grants to teams of investigators analyzing the connections between climate variability and human health. This research aims to provide the scientific foundation for improved public health early-warning systems for diseases such as dengue fever and malaria, and other climate-sensitive public health issues.

These activities will address Question 9.4 of the CCSP Strategic Plan.

Health effects of exposure to UV radiation.

- *Risk factors for malignant melanoma*. Melanoma is considered an epidemic cancer because its incidence and mortality are increasing rapidly. In the United States, the incidence has more than doubled and deaths have increased about 44% since 1973. Future research should help to further refine measures of exposure to solar radiation and clarify the relationship between sunlight exposure and melanoma risk. Researchers also hope to elucidate genetic and other susceptibility factors and their progression to melanoma and to identify appropriate interventions. To further this agenda, researchers are conducting a large international population-based study, covering a wide range of latitudes, that will determine the relative risk for developing melanoma due to various germline and gene mutations, polymorphisms, and variations that influence disease development in conjunction with UV radiation exposure. Results are expected to be published in 2004-2005.
- *UV exposure and photosensitivity*. Researchers have studied the photochemistry and photobiology of 7dehydrocholesterol (7-DHC), which accumulates in the plasma and tissues of patients with Smith-Lemli-Opitz syndrome (SLOS), a severe developmental disorder associated with multiple congenital and morphogenic anomalies, and enhanced photosensitivity to UV-A radiation. Findings showing that photosensitivity in SLOS patients may result from UV-A irradiation of skin containing high levels of 7-DHC will be submitted for publication in 2004.

These activities will address Question 9.4 of the CCSP Strategic Plan.

INTERNATIONAL RESEARCH AND COOPERATION

The United States is continuing and augmenting, through the CCSP, its international leadership in climate change science research and assessments, especially regarding planning for development of a new global Earth observing system. The United States involves and supports a variety of governmental, intergovernmental, and nongovernmental organizations, and academic activities in advancing climate and global change research. The United States has elevated international attention to Earth observing system issues by convening the first Earth Observation Summit (see Figure 25), and through establishment of the Group on Earth Observations (GEO).

Goals of International Climate Change Science and Its Support

It has long been recognized in the United States and other countries that it is essential to study climate change and variability on both global and regional scales. To do so effectively—in terms of both scientific and financial resources—requires international cooperation among scientists, among research institutions, among governmental agencies, and among governments themselves. The United States and its scientists, institutions, and agencies are at the forefront of such international cooperation, reflecting U.S. leadership in climate science.

The United States seeks to develop and maintain an intergovernmental framework within which climate change science, including research and observational programs, can be planned and implemented. The overarching goals of U.S. efforts to promote international cooperation in support of the CCSP are to:

- Actively promote and encourage cooperation between U.S. scientists and scientific institutions and agencies and their counterparts around the globe so that they can aggregate the scientific and financial resources necessary to undertake research on change at all relevant scales, including both the regional and global
- Expand observing systems in order to provide global observational coverage of change in the atmosphere, in the oceans, and on land, especially as needed to underpin the research effort

Figure 25:
Earth Observation Summit (EOS) participants, U.S. Department of State, 31 July 2003.
Credit: NASA.

- Assure that the data collected are of the highest quality possible and suitable for both research and forecasting, and that these data are exchanged and archived on a timely and effective basis among all interested scientists and end users
- Support development of scientific capabilities and the application of results in developing countries in order to promote the fullest possible participation by scientists and scientific institutions in these countries in research, observational, and data management efforts.

The International Framework

U.S. scientists and institutions work with their counterparts in other countries to identify climate change research issues of global and regional importance and to plan and implement cooperative programs and projects to address these issues. To assist in this process the United States supports a continually evolving framework through which the United States invites and encourages other countries to work to address climate change research and observations. The CCSP works with global-scale research programs and with both nongovernmental and intergovernmental international organizations in order to meet these global- and regional-scale needs.

As a leader in climate change science, the United States plays an important role in international assessments such as ozone, biodiversity, and ecosystems, as well as those concerned with regional climate. This includes financial and logistical support, support for U.S. scientists' participation in assessment activities, and the acquisition and exchange of data to support assessments. The CCSP intends to continue its support for and participation in activities of the Intergovernmental Panel on Climate Change (IPCC), international ozone assessments, the Millennium Ecosystem Assessment (MA), and the Arctic Climate Impact Assessment (ACIA).

EARTH OBSERVATION SUMMIT AND GROUP ON EARTH OBSERVATIONS

The Earth Observation Summit—held in Washington, DC, in July 2003, hosted by three U.S. Cabinet members (the Secretaries of State, Commerce, and Energy)—marked an extraordinary milestone in the development of a comprehensive, coordinated, and sustained Earth observation system. Thirty-three nations and the European Commission adopted a Declaration that signifies a political commitment to move toward development of a comprehensive system that will enable researchers and decisionmakers to monitor continuously the state of the Earth, increase understanding of dynamic Earth processes, enhance prediction of the Earth system, and further implement international environmental treaty obligations. Ministers from developed and developing countries seek through their agreement to increase timely, high-quality, long-term, global information, which can serve as a basis for sound decisionmaking for the benefit of society. More than 20 international organizations also participated in the initiative.

Other high-level U.S. officials participating in the Summit included Interior Secretary Norton; Science Advisor to the President Marburger; Council on Environmental Quality Chairman Connaughton; Under Secretary of Commerce for Oceans and Atmosphere and NOAA Administrator Lautenbacher; NASA Administrator O'Keefe; National Science Foundation Director Colwell; Under Secretary of State for Global Affairs Dobriansky; Under Secretary of Agriculture for Agricultural Research, Education and Economics Jen; Under Secretary of Transportation for Transportation Policy Shane; Undersecretary of Energy for Energy, Science, and Environment Card, and Acting Environmental Protection Agency Administrator Horinko.

The Earth Observation Summit also established the *ad hoc* Group on Earth Observations (GEO) to prepare a 10-year Implementation Plan for a comprehensive, coordinated, and sustained Earth observation system. NOAA Administrator Lautenbacher was named by the White House as the lead U.S. representative to the GEO and USGS Director Groat as his alternate. At the inaugural GEO meeting on 1-2 August 2003, the U.S. representative was elected co-chair along with representatives from the European Commission, Japan, and South Africa.

Historically, observation systems have been effective at providing critical data for a variety of regions and countries across the globe. But most of the global observational capabilities are not coordinated, and data collected are not of the same format or quality. Additionally, many countries in the developing world lack the resources to fund adequate observation systems and as a result do not benefit from these powerful tools. This lack of adequate observations in developing regions of the world also results in substantial observational gaps that impede the ability to understand climate and other systems.

An Earth observing system as described in the Declaration will produce a number of benefits, in both the near and long-term. In the near term, all of the countries participating in this system can expect that—through improved observations of weather, climate, the oceans, seismic activity, and fires, among others—loss of life and damage to property can be reduced. Additional benefits will include improved water management, health assessments, agricultural efficiencies, aviation safety, coastal management, and disaster management. In the long term, an Earth observing system will offer greater understanding of the Earth system that will underpin decisionmaking in many areas, including the reduction of disaster loss and supporting sustainable global development.

The Declaration supports the need for improved coordination of strategies and systems for observations and identification of measures to identify gaps; a coordinated effort to involve and assist developing countries in improving and sustaining their contributions to observing systems, as well as access to and utilization of observations; the exchange of observations recorded from *in situ*, aircraft, and satellite networks in a full and open manner, with minimum time delay and minimum cost; and the preparation of a 10-year Implementation Plan, building on existing systems and initiatives.

The inaugural meeting of the GEO established five subgroups: international cooperation; architecture; capacity building; data utilization; and user requirements and outreach. These groups, with the support of the GEO Secretariat, generated a draft Implementation Plan, the framework of which was accepted at the second Earth Observation Summit, held in Japan during the spring of 2004. The Implementation Plan is expected to be completed by late 2004, directly preceding the third Earth Observation Summit in Europe. International organizations will play a key role in the work of the subgroups, since those organizations have been instrumental in the development and maintenance of existing systems that will serve as the backbone for a future global network.

Supporting Climate Change Science and Technology by Improving the International Framework

Implementation of Presidential Initiatives

The President's climate change policy announcements on 11 June 2001, and 14 February 2002, highlighted the importance of international cooperation to develop an effective and efficient global response to the complex and long-term challenge of climate change. Under the leadership of the Department of State, the United States adopted a Bilateral Climate Change Strategy, focusing on countries or regional entities that are responsible for nearly 75% of the world's greenhouse gas emissions. Through this important network of bilateral and regional partnerships, the United States is advancing the science of climate change, enhancing the technology to monitor and reduce greenhouse gases, and assisting developing countries through capacity building and technology transfer.

Bilateral Cooperation in Climate Change Science and Technology

Working with a mix of developed and developing countries, the Department of State is leading a major effort to advance international cooperation in climate change science and technology, building on key elements of the CCSP and the CCTP: research, observations, data management and distribution, and capacity building.

Through this important network of bilateral and regional partnerships, the United States is advancing the science of climate change, enhancing the technology to monitor and reduce greenhouse gases, and assisting developing countries through capacity building and technology transfer. Significant progress is being made on many aspects of the President's international climate change agenda through establishment of results-oriented "action plans" with bilateral and regional partners. These partners presently include Australia, Brazil, Canada, the seven Central American countries (Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, and Panama), the European Union, India, Italy, Japan, Mexico, New Zealand, the People's Republic of China, the Republic of Korea, the Russian Federation, and South Africa. Italy and Japan are examples of two of the bilateral partnerships:

- *U.S.-Italy Cooperation in Climate Change Science and Technology*. The United States and Italy have developed a bilateral partnership encompassing a wide range of cooperative science and technology projects and activities, including climate change modeling, atmospheric processes, the carbon cycle, remote sensing, human and ecosystem health, and ocean observations and the ocean ecosystem. On the technology side,

the partnership is advancing cooperative efforts on the hydrogen infrastructure and energy technologies, including fuel cells, renewable energy, advanced power systems, and advanced energy technologies including carbon capture and sequestration. The two countries have announced their intention to promote the exchange of graduate students, young scientists, and senior scientists in the area of climate change science and technology.

- *U.S.-Japan Cooperation in Climate Change Science and Technology*. The two countries have established U.S.–Japan High Level Consultations (HLC) on climate change, through which they maintain active partnership in climate change science and technology. The HLC Working Group on Science and Technology has selected ten projects for priority implementation in seven areas: improvements of climate models; impacts and adaptation/mitigation policy assessment employing emission-climate impact integrated models; observation and international data exchange and quality control; research on greenhouse gas sinks including land-use, land-use change, and forestry; research on polar regions; and development of mitigation and prevention technologies. Experts are also collaborating on issues relating to developing countries and market-based approaches. The United States and Japan have also conducted a series of climate change science workshops on such important issues as "Water and Climate," "Health and the Environment," and "Carbon Cycle Management in Terrestrial Ecosystems."

U.S. Reentry to UNESCO

The United States rejoined UNESCO and participated in the UNESCO General Conference in the last quarter of 2003. At the General Conference, the United States was elected to the UNESCO Executive Board. U.S. participation in UNESCO is expected to afford a wide range of opportunities for international cooperation in climate change science and technology and international science in general. A particular focus of the UNESCO science agenda has to do with preservation of the world's freshwater resources. This focus is supported through a number of projects in the International Hydrology Program, including the Hydrology for the Environment Life and Policy (HELP) program, supported in part by the CCSP.

Inter-American Institute for Global Change Research (IAI)

U.S. scientists play an important role in the research programs carried out by the IAI, and in bringing together the over 200 research universities and government institutions in the Western Hemisphere that make up its research network. Research programs sponsored by the IAI have aided in development of new decision and management tools in diverse areas, ranging from the incorporation of long-range forecasts into dam

management for hydropower and irrigation, to the establishment of a tri-national sardine fishery forum that regularly brings together regulatory agencies, resource managers, fishermen, and researchers from Canada, Mexico, and the United States. In addition, IAI research enabled the first rigorous scientific ranking of drivers of global change, based on scenarios of changes in global biodiversity.

Engaging the International Climate Change Research Community

International cooperation plays an important role in focusing the world's scientific resources on the highest priority climate and global change research issues, in helping to reduce scientific redundancy in a world of limited financial resources, and in improving exchange of data and information internationally. By developing both conceptual and research frameworks, international research programs provide models that aid U.S. program managers in planning and coordinating their efforts. Much of the research conducted and sponsored through the CCSP benefits from and contributes to projects sponsored by the four major international research programs—the International Geosphere-Biosphere Programme (IGBP), the World Climate Research Programme (WCRP), the International Human Dimensions Programme (IHDP), and the Diversitas program—and the newly launched interdisciplinary collaboration between all of the programs, the Earth System Science Partnership (ESSP).

The IGBP is transitioning into its second phase with new emphases in biogeochemical sciences with relevance to issues of societal concern, interdisciplinarity, Earth system science, and regional-scale integrated research. Many of the IGBP phase-one projects are coming to a close or, as in the case of International Global Atmospheric Chemistry (IGAC), being reoriented. New projects such as Land-Atmosphere, Land, Land-Ocean, and Ocean are in the development stage or beginning work.

The WCRP is focusing its efforts on its major projects, including Climate and Cryosphere (CliC), Climate Variability and Predictability (CLIVAR), Global Energy and Water Cycle Experiment (GEWEX), Stratospheric Processes And their Role in Climate (SPARC), and the World Ocean Circulation Experiment (WOCE), which continues to provide satellite, *in situ* observations, and models. CLIVAR is hosting its 2004 international meeting in June 2004 in Baltimore, Maryland. Development of the first global integrated data set of the water cycle (GEWEX, CliC, CLIVAR), which is the first element of the Coordinated Enhanced Observing Period (CEOP), is currently underway.

IHDP is focusing on a number of core project efforts, including the Global Environmental Change and Human Security (GECHS) project, the Institutional Dimensions of Global Environmental Change (IDGEC) project, the Industrial Transformation (IT) project, and Land-Use Land-Cover Change (LUCC) project. In addition to the core projects, the IHDP is also addressing cross-cutting questions, such as thresholds/transitions, vulnerability/resilience, adaptation/learning, and governance in the face of global environmental change. Additional questions include study of human drivers of change, as well as its relevance for sustainable development. Through investigation of these issues, IHDP will develop perspectives on key questions in global environmental change research.

Diversitas, the newest of the international programs, is focusing on development of three core projects—bioDISCOVERY, ecoSERVICES, and bioSUSTAINABILITY—as well as cross-cutting networks and projects. The Biodiscovery project is focused on discovery and understanding of changes in global biodiversity. The Ecoservices project will assess the impacts of biodiversity changes, while the Biosustainability project will develop the science of conservation and sustainable use of biodiversity. The three core projects are completing their planning and beginning implementation.

The ESSP—a partnership for the integrated study of the Earth system, changes, and the implications of those changes—is currently developing its core projects: the Global Carbon Project (GCP), Global Environmental Change and Food Systems (GECAFS), the Global Water System Project (GWSP), and Global Environmental Change and Human Health (GECHH). These projects are designed to address issues critical to the understanding of global change and to build upon the existing core programs and, to the greatest extent possible, their existing infrastructure.

The SysTem for Analysis, Research, and Training (START)

START is the outreach arm of the WRCP, IGBP, and IHDP, and is hosted by the United States. START's primary purpose is to assist developing countries to better enable scientists and institutions in these countries to conduct research on global environmental change and the challenges these changes pose for human health, agriculture, water, and food security and to apply the results of such research in decisionmaking. START has ongoing activities in Africa, Asia, Central America, and South America and collaborates with a number of multilateral international organizations such as the IPCC, the IAI, and the Asia Pacific Network for Global Change Research.

International Research Institute for Climate Prediction (IRI)

IRI conducts strategic and applied research on climate information and prediction, decision systems, impacts, institutions and policy, with a focus on education and capacity building in developing countries. NOAA, under direction of the CCSP, has led in development of IRI in cooperation with Columbia University and the Central Weather Bureau of Taiwan. IRI works in partnership with experts and institutions in project regions to advance understanding of climate in the context of decision strategies in sectors including agriculture, health, and water resource management.

In northeastern Brazil, IRI collaboration has resulted in the demonstration of decision opportunities to maximize water usage in a drought-prone region by introducing climate-informed strategies to minimize annual spill of reservoirs. In the Greater Horn of Africa, it has resulted in development of forecast tools for Rift Valley Fever in cattle, a disease that creates huge economic and trade impacts for the region. In South Asia, it has yielded a process by which agricultural systems analysis and climate information can be combined with direct linkages to smallholder farmers to positively influence agricultural decisions.

Many of the inhabitants of the vast, semi-arid region of the state of Ceará in Northeast Brazil live by small-scale, rain-fed agriculture and ranching. They face

Figure 26:
Irrigation of beans in Morada Nova, Ceará, Brazil. In northeastern Brazil, a collaboration between the state of Ceará and the International Research Institute for Climate Prediction is working to improve the state's water management systems in this vast, semi-arid region.
Photo credit: Kenneth Broad, IRI.

hunger, unemployment, and dislocation during recurrent water shortages in the region. Two million rural people were affected by the last severe drought in 1998, and received $360 million in aid from the United States. In April 2002, Ceará became an IRI member and committed to a collaboration to improve the state's water management systems. The IRI Ceará program concentrates on 1) seasonal and interannual water management and allocation, 2) drought relief and mitigation, and 3) long-term water management and development. Improvements in these areas will come from advances in forecasting and analyses of climate, water supply and demand, agriculture, and socioeconomics. Those advances will be incorporated into a new decisionmaking framework consisting of existing institutional channels, the people most affected by water and drought management, and a new procedure for them to use in comparing policies.

North Greenland Ice Core Project (NorthGRIP)

U.S. researchers from several universities and USGS are contributing to an international collaboration to retrieve the deepest ice core in Greenland. The Danish-led NorthGRIP project involves scientists from Denmark, Germany, Japan, Sweden, the United States, Switzerland, France, Belgium, and Iceland. Bedrock was finally reached at a depth of almost 3100 meters in mid-July 2003, after 7 years of effort. The NorthGRIP ice core is expected to provide important new information about the climate system during its transition from the last warm interglacial (the Eemian, 130-115 thousand years ago) into the Wisconsin Ice Age (10,000-60,000 years ago).

Global Terrestrial Network for Permafrost

U.S. scientists from various universities and Federal agencies are cooperating with their counterparts from 12 other nations to establish the Global Terrestrial Network for Permafrost (GTN-P), one of the new terrestrial sub-networks of the Global Climate Observing System (GCOS). Analysis of data from the GTN-P 16 network will be used to better define the current state of the Earth's cryosphere, for climate change detection (particularly in the Arctic), and to provide critical input to climate models used for impact assessments.

The Integrated Marine Biogeochemistry and Ecosystem Research (IMBER) Project

The primary goal of IMBER is to understand the sensitivity of the ocean to global change within the context of the broader Earth system, focusing on biogeochemical cycles, marine food webs, and their interactions. IMBER is directed at development of

a comprehensive understanding of the impacts of climate and anthropogenic forcing on food web dynamics and elemental cycling (including the impacts of underlying physical dynamics of the ocean) and how these linked systems respond to global change resulting from natural climate variability and anthropogenic perturbations, and their feedbacks to climate, ocean physics, and marine resources. A draft science and implementation strategy for IMBER has recently been prepared under the aegis of IGBP's Global Oceans Ecosystems Dynamics Program and the International Council for Science (ICSU) Scientific Committee on Oceanic Research (SCOR). U.S. scientists, with support from CCSP participating agencies, played a major role in preparation of this plan and the United States currently hosts the secretariat for this project. A Scientific Steering Committee for IMBER was formed in 2004.

Climate Information Access Program Project (CIP)

The Climate Information Access Program is in its fourth year of a cooperative effort to develop the Radio and Internet for the Communication of Hydro-Meteorological and Climate Information for Rural Development (RANET) project. The U.S. leads this effort with partners such as the World Meteorological Organisation and the African Center of Meteorological Applications for Development. Activities of RANET strengthen institutional capacities in developing country meteorological and related services, broaden the availability and application of forecasts and observations, and contribute to hazard preparedness and mitigation through provision of information. Currently RANET has developed throughout Africa, begun pilot activities in the Pacific, and is planning activities for much of Asia in FY 2004.

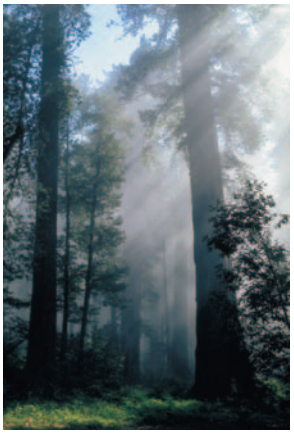
Famine Early Warning System Network (FEWS NET)

The United States supports FEWS NET to provide decisionmakers with information to respond effectively to drought and food insecurity in Africa. FEWS NET analyzes remote-sensing data and ground-based meteorological, crop, and rangeland observations to track progress of rainy seasons in semi-arid regions of Africa to identify early indications of potential famine. In addition to using data produced by host governments for its analyses, FEWS NET uses data from satellite imagery (NDVI or "greenness" images, and Meteosat rainfall estimation images) that it receives every 10 days throughout the year.

The Northern Eurasia Earth Science Partnership Initiative (NEESPI)

NEESPI is aimed at developing an enhanced understanding of interactions between the ecosystem, atmosphere, and human dynamics in northern Eurasia, especially to

understand how land ecosystems and continental water dynamics in that region of the world interact with and alter the climatic system, biosphere, atmosphere, and hydrosphere. NASA, the Russian Academy of Sciences, and possibly other partners in the United States, Europe, and Asia, are becoming involved in NEESPI activities. The NEESPI Science Plan will be published in 2004. Data capacity building workshops will be held in 2004 on boreal zone and on non-boreal zone of northern Eurasia to develop a comprehensive inventory of available space-borne and ground-based data sets for the region. This will facilitate preparation of a NEESPI Implementation Plan. NEESPI is organizing an interagency briefing in 2004, for major sponsors and stakeholders in the United States. The first NEESPI Open Science Conference will be held in 2004-2005.



Global Observations of Forest Cover and Land Cover Dynamics (GOFC-GOLD)

GOFC-GOLD is a coordinated international effort under the aegis of the Global Terrestrial Observing System to provide ongoing space-based and *in situ* observations of forests and other vegetation cover for sustainable management of terrestrial resources and to obtain an accurate, reliable, quantitative understanding of the terrestrial carbon budget. GOFC-GOLD is implemented through regional networks of data providers and users to address a combination of global change and natural resource management questions, and engages local scientists with local and regional expertise and knowledge. GOFC-GOLD seeks to develop methods and implement systems that provide both research and operational information on a regular sustained basis. Key activities in 2004 are expected to include two regional data capacity building workshops in northern Eurasia and meetings of the GOFC-GOLD Land Cover Implementation and Fire Implementation Teams.

The Climate and Societal Interactions Program

The Environment, Science, and Development (ESD) program of NOAA's Climate and Societal Interactions (CSI) effort seeks to catalyze and accelerate the use of climate science and technology in the resolution of key resource management challenges, such as adaptation, water management, and natural hazard mitigation. ESD fosters decision support-oriented research and applications activities that link science and technology to economic development, sustainable management needs, and policymaking processes. The program builds upon a 10-year global-scale pilot effort in climate research applications, and recent scholarship on research, assessment, and decision support systems for climate and global change. The program supports Regional Climate Outlook Forums, pilot applications projects, workshops, training sessions, capacity building, and technical assistance in Africa, Southeast Asia, Latin America and the

Caribbean, and the Pacific. This initiative is a collaborative effort that involves partners such as the World Bank, the World Meteorological Organisation, USAID, IRI, and regional institutions in Africa, Latin America and the Caribbean, Southeast Asia, and the South Pacific. In 2003, CSI convened a workshop on 'Insights and Tools for Adaptation: Learning from Climate Variability.' The report from this workshop, available in 2004, will offer recommendations for linking adaptation to today's climate to research and applications on longer time scales.

Large-Scale Biosphere-Atmosphere Experiment in Amazonia (LBA)

LBA is intended to improve understanding of the climatological, ecological, biogeochemical, and hydrological functioning of Amazonia; the impact of land-use change on these functions; and interactions between Amazonia and the Earth system. LBA is led by Brazil and involves substantial participation by U.S. scientists, institutions, and agencies. Recent results include the release of two LBA data sets for the study area (i.e., longitude 85° to 30°W, latitude 25°S to 10°N). The first data set consists of LBA regional historical climatology (precipitation, temperature, and pressure data) for the period 1832-1990, and is a subset of the Global Historical Climatology Network (GHCN) Version 1 database for sites in the LBA study area. The second data set on LBA Regional Derived Soil Properties includes measurements for several variables, including soil organic carbon density, soil carbonate carbon density, soil pH, and soil water capacity. Under the aegis of LBA, substantial progress has been made in training and educating students (73 PhD and 46 Masters degrees underway or completed). In addition, almost 300 students and 35 Amazonian institutions have been and are involved in U.S.-Brazil collaboration in LBA research.

APPENDIX
The Climate Change Science Program Participating Agencies

APPENDIX

THE CLIMATE CHANGE SCIENCE PROGRAM PARTICIPATING AGENCIES

The following pages present information about the contributions to the CCSP of each of the program's participating agencies:

- Department of Agriculture (USDA)
- Department of Commerce / National Oceanic and Atmospheric Administration (DOC/NOAA)
- Department of Defense (DOD)
- Department of Energy (DOE)
- Department of Health and Human Services (HHS)
- Department of the Interior / U.S. Geological Survey (DOI/USGS)
- Department of State (DOS)
- Department of Transportation (DOT)
- Agency for International Development (USAID)
- Environmental Protection Agency (EPA)
- National Aeronautics and Space Administration (NASA)
- National Science Foundation (NSF)
- Smithsonian Institution (SI).

Principal Areas of Focus, Program Highlights for FY 2004 and FY 2005, and Related Research are summarized for each agency.

U.S. DEPARTMENT OF AGRICULTURE

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

Principal Areas of Focus

Research conducted and sponsored by USDA supports 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 climate variability and change, atmospheric composition, and UV-B radiation) on food, fiber, and forestry production in agricultural, forest, and range ecosystems, and developing management systems to maintain and enhance agriculture and forest productivity and function in changing environments.

USDA's research program is strengthening efforts to determine the significance of terrestrial systems in the global carbon cycle, to identify agricultural and forestry activities that can contribute to a reduction in greenhouse gas concentrations, to quantify risks and benefits arising from environmental changes to agricultural lands and forests, and to develop management practices that can take advantage of beneficial effects of global change and mitigate or adapt to adverse effects. USDA's research agencies support the Department in responding to the President's directive to develop accounting rules and guidelines for carbon sequestration projects. Contributions from USDA's research programs include new tools for accurately measuring greenhouse gases, methods for measuring and estimating carbon in ecosystems at different scales, and effective ways to sustain productivity in a changing environment.

Program Highlights for FY 2004 and FY 2005

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 being implemented in FY 2004 and proposed for FY 2005 will: (1) serve to develop technologies, management practices, and decision support systems for storing carbon in natural soil and plants; (2) develop management strategies for natural resource decisionmakers to address the many diverse demands on U.S. rural water resources that may be caused by climate and other global changes; (3) develop environmentally compatible and economically feasible alternatives to the use of methyl bromide as a treatment to control pests; (4) continue to focus on developing information to assess possible impacts of climate and other global changes on agricultural ecosystems; and (5) improve the measurement of carbon fluxes from soils and vegetation in different land management systems at local, regional, and national scales.

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. CSREES will continue to support global change research through the National Research Initiative (NRI) Competitive Grants Program and formula-funded programs. The NRI initiative includes programs for carbon and water cycles, land-use and -cover change, and managed ecosystem research. CSREES will use the recently developed *CCSP Strategic Plan* in formulating priorities under the NRI program and in shaping specific grant announcements.

The Economic Research Service will contribute applied economics research on greenhouse gas mitigation options in the context of USDA conservation policies.

The Forest Service has identified the following key issues for future program emphasis: (1) Improve observations of forest carbon stocks and flows based on development and deployment of improved field measurement techniques and measurements integration, and initiate a forest carbon-monitoring program based on the FS experimental forest network as a component of the interagency research effort on the North American Carbon Program; (2) integrate observations with process-level studies to better understand, forecast, and manage the relationships between forest and rangeland systems and climate; (3) develop and deploy forest management technologies that increase carbon sequestration, provide fossil fuel offsets, enhance productivity, and maintain environmental quality; (4) provide integrated prediction models of forest carbon dynamics; and (5) provide and improve greenhouse gas accounting rules and guidelines for forest systems. In FY 2005, the Forest Service will invest an additional $1.5 million to provide improved estimation and projection systems for carbon stocks and fluxes from forested systems and develop science-based carbon management systems. The Forest Service will compile estimates of carbon fluxes from forest lands, 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.

Related Research

USDA maintains an active program directed at improving the measurement and accounting of greenhouse gases from agriculture and forestry systems and developing technologies and practices to improve the utilization of biomass energy and bio-based products. The Forest Service, NRCS, ARS, CSREES, and the Rural Development mission area support biofuels and biomass-related research and development. These research and development activities are reported under the Climate Change Technology Program.

DEPARTMENT OF COMMERCE / NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Principal Areas of Focus

NOAA's mission is: "To understand and predict changes in the Earth's environment and conserve and manage coastal and marine resources to meet the Nation's economic, social, and environmental needs." The long-term climate efforts of NOAA are designed to develop a predictive understanding of variability and change in 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, atmospheric composition, 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 time scales; 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; the relationship of climate to coastal and marine ecosystems; and archiving, managing, and disseminating data and information useful for global change research.

Program Highlights for FY 2004 and FY 2005

Climate Observations and Analysis

- Determine actual long-term changes in temperature and precipitation over the United States through deployment of the Climate Reference Network.
- Make the experimental monthly North America Drought Monitor product an operational product by the end of FY 2005. The North American Drought Monitor is a joint effort between drought experts from the United States, Canada, and Mexico. Within the United States, the major participants include NOAA's National Climatic Data Center, NOAA's Climate Prediction Center, the USDA, and the National Drought Mitigation Center.
- Expand deployment of the U.S. component of the Global Ocean Observing System, with emphasis on reduced uncertainty in sea level and sea surface temperature and deployment of the Argo global profiling float array.
- Establish indices for the intensity of the meridional overturning circulation, for decadal variability of the ocean gyres, and for oceanic heat flux in the Atlantic Ocean.
- Analyze long-term oceanographic and atmospheric records of upper ocean currents and temperatures and sea level pressure to interpret large-scale oceanographic and atmospheric interactions (e.g., the North Atlantic Oscillation, meridional overturning circulation, or hurricane formation and sea surface temperature).
- Analyze oceanic heat budgets and their effects on interannual to multidecadal climate fluctuations.

Climate Forcing

- Make airborne, shipboard, and ground-based observations of climate forcing species above the U.S. Northeast and western North Atlantic Ocean in the summer of 2004, helping to evaluate and improve model simulations that link pollutant emissions to radiative forcing.
- Complete 22 of the 36 stations in the U.S.carbon dioxide (CO_2) observing system, a key step in assessing and modeling carbon sources and sinks throughout the United States.
- Conduct CO_2 inventory and transport studies in the North Atlantic and North Pacific to determine decadal changes in physical and biogeochemical processes affecting the distribution of CO_2 in the oceans and to estimate anthropogenic carbon uptake in the basins. Additionally, new research will be initiated in 2004 on carbon transport and fate from drainage basins to ocean margins.
- Quantify the seasonal and interannual variations of air-sea CO_2 fluxes in the North Atlantic and North Pacific via measurements of surface ocean pCO_2 conducted by research and volunteer observing ships as they are underway.

Climate Predictions and Projections

- Assess the possible impacts of global warming on hurricane intensities, using scenarios from major modeling centers.
- Compare and evaluate possible 21st and 22nd century climate system impacts via scenarios used in the 2007 Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report and the latest model runs conducted by the Geophysical Fluid Dynamics Laboratory (GFDL) and National Center for Atmospheric Research (NCAR), both of which contribute to the IPCC process.
- Assess the uptake of greenhouse gases by natural systems in the 21st century for a baseline scenario utilized by CCSP and CCTP, utilizing the GFDL Earth System model.
- Assess possible changes in the El Niño-Southern Oscillation cycle from the 19th to the 21st centuries resulting from changes in radiative forcing, utilizing observations and GFDL climate simulations.
- Operationalize an end-of-the-month update for the 15-day lead temperature and rainfall monthly outlooks generated by the Climate Prediction Center.
- Operationalize a new coupled atmosphere-ocean system for seasonal forecasting [currently being tested at the National Centers for Environmental Prediction (NCEP) Environmental Modeling Center]. The components are the operational (July 2003) NCEP global atmospheric forecast model (200-km horizontal resolution and 64 levels) and the GFDL Modular Ocean Model (1° resolution and 40 levels). The two models are coupled directly without flux correction. Limited retrospective forecasts for this system show it to be very skillful, with an El Niño 3.4 sea surface temperature anomaly correlation averaging 0.80 out to 9 months for representative April initiation and 0.60 out to 9 months for January initiation. An operational implementation is anticipated in June-July 2004, once full calibration runs have been made and analyzed.
- Implement a calibrated forecast system to improve week-1 and week-2 extended range predictions issued routinely by the Climate Prediction Center. This system is a result of research efforts at the Climate Diagnostics Center, and its implementation at the NCEP Environmental Modeling Center will transition this product from research into operations.

Climate and Ecosystems

- Develop two new indices of ecosystem productivity based on anomalies in zooplankton species abundance from long-term observations of zooplankton in the northern California Current. The indices will demonstrate how changes in ocean productivity are linked to interannual and decadal scale climate variability and to marine fisheries. To date, zooplankton anomalies correlate with survival and growth of coho and chinook salmon, and with recruitment of black cod.

Regional Decision Support

- Develop a social science-based prototype information system for urban planning based on information about climate variability and change. The system will be completed in FY 2005 and will contribute to the CCSP deliverable of "best practice approaches for characterizing, communicating, and incorporating scientific uncertainty in decisionmaking."

Related Research

In addition to focused CCSP efforts, related activities include short-term weather forecasting and advance warning services; maintenance of operational polar-orbiting and geosynchronous satellites; 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.

DOC's National Institute of Standards and Technology (NIST) provides measurements and standards that support accurate and reliable climate observations. NIST also performs calibrations and special tests of a wide range of instruments and techniques for accurate measurements. NIST provides a wide array of data and modeling tools that provide key support to developers and users of complex climate prediction models.

DEPARTMENT OF DEFENSE

Principal Areas of Focus

The Department of Defense does not support dedicated global change research, but continues a history of participation in the CCSP through sponsored research that concurrently satisfies national security requirements and stated goals of the CCSP. All data and research results are routinely made available to the civil science community. DOD science and technology 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*.

Program Highlights for FY 2004 and FY 2005

Atmospheric Composition

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—is generated by the Navy Aerosol Analysis and Prediction System.

DOD areas of interest and science and technology investment for the continental boundary layer are transport and diffusion, and clouds and obscurations. For the marine boundary layer issues include 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.

Climate Variability and Change

Completed analysis of sea ice mass balance during the Surface Heat Budget of the Arctic (SHEBA) project has determined that there was a net loss of sea ice. Coordination and data management of the International Arctic Buoy Programme filled the "data void" of the Arctic Ocean with buoy data. These data have permitted quantification of the changes in circulation, temperature, and ice motion in the Arctic. The data suggest a 2°C per decade warming in surface air temperature over the eastern Arctic Ocean, as well as a lengthening of the melt season of the sea ice from 1979-1997. These variations in surface air temperature are related to the Arctic Oscillation, which accounts for more than 50% of the trends in surface air temperature over much of the Arctic region.

Recent Arctic research has included a decade-long set of time series measurements of flow through the Bering Strait and its variable water properties, and submarine-based acoustic doppler current profiler measurements of the upper Arctic Ocean. This provided significant advances in understanding the evolution of temperature change in the core of Atlantic water in the Arctic Ocean between 1991 and 2001, with implications concerning mechanisms for decadal changes in the Arctic Ocean. Further, analysis of the first acoustic thermometry time series record in the Arctic (from October 1998 to December 1999) indicates that the warming of the Atlantic intermediate water continues from the early 1990s and a wide frontal zone propagated into the Nansen Basin beginning in late 1999.

The Defense Modeling and Simulation Office sponsors the Master Environmental Library (MEL) to provide direct and timely access to natural environment information, data, and products wherever they may 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 and the Generalized Digital Environmental Model are in the public domain and are available through the National Oceanographic Data Center and NAVOCEANO, respectively.

The Ocean Acoustic Observatory Federation involves government and private research organizations to exploit data from active and retired Navy Sound Surveillance System stations for ocean acoustic tomography and thermometry measurements in the eastern Pacific Ocean. Another National Oceanographic Partnership Program (NOPP) research effort—working with academic and private sector economists in major U.S. coastal regions—is conducting a set of coordinated regional studies to assess the expected economic benefits of sustained, improved coastal ocean observing systems. The Multidisciplinary Ocean Sensors for Environmental Analyses and Networks (MOSEAN) project addresses the need for increased observations that are essential for solving a set of diverse interdisciplinary problems of societal importance. These include biogeochemical cycling, climate change effects, ocean pollution, harmful algal blooms, ocean ecology, and underwater visibility.

The DOD High-Performance Computing Challenge is sponsoring two relevant projects: a high-resolution coupled atmosphere-ocean-ice 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. Data and model output fields are available from the Global Ocean Data Assimilation Experiment (GODAE) server at the Fleet Numerical Meteorological and Oceanographic Center. Further information on research programs is also available at the Office of Naval Research, the U.S. Army Cold Regions Research and Engineering Lab, and the NOPP web sites.

Global Water Cycle

WindSat was launched 6 January 2003, on the Space Test Program 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 wind speed and direction 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 National Polar-Orbiting Operational Environmental Satellite System program office will use in the development of the Conical Microwave Imager Sounder (CMIS).

Ecosystems

DOD science and technology 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 is a public-private partnership and a new component of the Global Biodiversity Information Facility. Navy is directly investing in the development of new, in-water 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 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 CCSP.

DEPARTMENT OF ENERGY

Principal Areas of Focus

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. Research includes climate modeling, aerosol and cloud properties and processes affecting the Earth's radiation balance, and sources and sinks of energy-related greenhouse gases (primarily carbon dioxide). BER research also examines the consequences of climatic and atmospheric changes on ecological systems and resources, develops improved methods and models for conducting integrated economic and environmental assessments of climate change and options for mitigating climate change, and educates and trains the next generation of scientists for climate change research.

Program Highlights for FY 2004 and FY 2005

DOE's Office of Science supports climate change research at its National Laboratories and other public and private research institutions, including universities. In FY 2004 and FY 2005, DOE—along with the other CCSP 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 *CCSP Strategic Plan*, the Office of Science climate change program includes research activities in the following four areas to provide the data and predictive understanding that will enable objective, scientifically rigorous assessments of the potential for, and consequences of, human-induced climate change: climate and hydrology, atmospheric chemistry and carbon cycle, ecological processes, and human dimensions.

Climate and Hydrology

The Office of Science will develop, improve, evaluate, and apply the best, fully coupled atmosphere-ocean-sea ice-land surface general circulation models (GCMs) that simulate climatic variability and change over decadal to centennial time scales. Data collection at the Atmospheric Radiation Measurement (ARM) Cloud and Radiation Test Bed sites in the U.S. Southern Great Plains, the tropical western Pacific Ocean, and on the North Slope of Alaska will continue in FY 2004 and FY 2005 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 GCMs. ARM will conduct a campaign in FY 2004 to collect a focused set of observations needed to advance understanding of the dynamical processes in mixed-phase arctic clouds. Research on data assimilation methods will be increased both to improve the use of high-quality observational data streams provided by the ARM program and other climatic data programs, including satellite programs, and to evaluate GCM performance. Support will be provided in FY 2004 and FY 2005 to provide climate modelers access to the high-end computational resources needed to conduct climate model experiments and to complete ensembles of climate simulations using coupled GCMs. DOE will continue support of a multi-institutional climate modeling research consortia to further the development of comprehensive coupled GCMs for climate predictions that are of higher resolution and contain more accurate and verified representations of clouds and other important climatic processes.

As part of the Administration's Climate Change Research Initiative (CCRI), DOE will produce ensemble projections of multi-century climatic variability and change using the Community Climate

System Model (CCSM). In FY 2004 and FY 2005, climate model experiments will produce various climate scenarios, such as atmospheric carbon dioxide (CO_2) concentration stabilization scenarios and other climate forcing scenarios to be used as input to climate change assessments. The DOE component of the CCRI in FY 2004 will also include development, testing, and deployment of a mobile climate observatory, as part of the ARM program.

Atmospheric Chemistry and Carbon Cycle

DOE carbon cycle research in both terrestrial and marine environments will improve understanding of the global carbon cycle. Research supports the Climate Change Science Program, as described in Chapter 7 of the *CCSP Strategic Plan*. In support of the Administration's CCRI, eight new field investigations were initiated to strengthen the AmeriFlux Network, and to support the comprehensive North American Carbon Program (NACP). This research will continue in FY 2004 and FY 2005 to provide direct measurements of net CO_2 flux between the atmosphere and representative terrestrial ecosystems. The CCRI augmentation of the AmeriFlux network allows it to play an important role in the comprehensive NACP study, assuring the acquisition of important data on the magnitude of terrestrial carbon sequestration and the processes that control it. DOE carbon cycle research also supports model predictions of changes in atmospheric CO_2 concentration and terrestrial carbon storage in relation to projected increases of CO_2 emissions. Increased emphasis will be placed on linked carbon cycle and climate modeling research in FY 2004, with modeling and simulation studies of carbon cycle-climate feedbacks carried out in FY 2005. In FY 2005, research will be initiated to further focus the AmeriFlux network measurements on field "intensive" investigations of the NACP. This contribution will be coordinated with field research of NASA, NOAA, NSF, and other agencies that jointly support the NACP science implementation strategy.

In ocean carbon cycle research, DOE's Biotechnological Investigations-Ocean Margins Program (BI-OMP) is using the tools of modern molecular biology, including functional genomics, to investigate the linkages between carbon and nitrogen cycling in nearshore marine environments. In FY 2004, BI-OMP will take advantage of the availability of data on newly sequenced diatom and marine bacterial genomes to understand the molecular-level regulation of carbon and nitrogen transformations in the ocean. In FY 2005, BI-OMP researchers will begin to take ecogenomic approaches to investigating marine microbial communities and their responses to climate change.

DOE's Atmospheric Science Program (ASP) will be transitioning in FY 2004 and FY 2005 from research on the effects of energy-related emissions on urban air quality to research on aerosol radiative forcing of climate. In FY 2004, results of research from the April 2003 Mexico City Megacity Study supported by the ASP will be published. These results will address the export of aerosols and precursors from the Mexico City Basin into the regional atmosphere, the radiative effects of the aerosols (including potential reduction of photochemistry by aerosol absorption), and the resistance of black carbon to rainout. In FY 2005, the entire ASP will be focused on aerosol radiative forcing to reduce the uncertainties associated with the indirect effect of aerosols on clouds and the roles of black carbon and organic aerosols on climate. The new research to be funded by the ASP in FY 2005 will address many of the research needs related to aerosol forcing identified in Chapter 3 of the *CCSP Strategic Plan*.

Ecological Processes

DOE designs, implements, and maintains large-scale and long-term experimental field manipulations of environmental factors to study effects of energy production on important North American ecosystems. During FY 2004 and FY 2005, this will include field facilities that accomplish controlled manipulations of temperature, moisture, atmospheric CO_2 concentration, atmospheric ozone concentration, and/or

nitrogen deposition in a boreal forest, arid shrublands, temperate grasslands, and several temperate forests. These facilities and the experiments they support are needed to test the ability of ecological models to realistically predict effects of environmental changes on the structure and functioning of terrestrial ecosystems; such models form the basis of most assessments of the potential effects of projected future environmental change on ecosystems. A new research initiative is planned for initiation in late FY 2004 that will examine how quantitative information obtained at the level of macromolecules (e.g., genes, RNAs, and enzymes) can be used to understand and predict how processes in, and states of, whole ecosystems would be affected directly and indirectly by environmental changes associated with energy production.

Human Dimensions

The DOE human dimensions program supports 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 2004, research will continue on climate change technology innovation and diffusion, with particular emphasis on understanding forces that will assist the prediction of the penetration of new technologies to non-OECD countries such as China. Research initiated in FY 2002 and concluding in FY 2004 will improve projections of energy demand and associated greenhouse gas emissions by analyzing demographic variables. The research will use three case studies—the United States, China, and Indonesia—and focus on variations in energy use across household types. During FY 2004 and FY 2005, the representation of hydrogen production, transportation, and use will be improved in integrated assessment models. DOE's human dimensions research in FY 2004 will also include analysis and application of explicit models of methane and other non-CO_2 greenhouse gas emissions.

DOE will also continue support of its Global Change Education Program in FY 2004 and FY 2005, including support of undergraduate and graduate students. Support will also continue for the Carbon Dioxide Information and Analysis Center (CDIAC) in FY 2004 and FY 2005 to enable it to archive data on greenhouse gas emissions and concentrations and to respond to requests from users from all over the world for such information and data.

Related Research

DOE plays a major role in carbon sequestration research to reduce atmospheric concentrations of energy-related greenhouse gases, especially CO_2, and their net emissions to the atmosphere. DOE's carbon sequestration research is part of the Climate Change Technology Program. The research builds on, but is not part of, the CCSP. It focuses on both developing the scientific information needed to enhance the natural sequestration of excess atmospheric CO_2 in terrestrial and ocean systems and assessing the potential environmental consequences and ancillary benefits of that enhanced sequestration. It also includes research to develop biotechnological approaches for sequestering carbon either before or after it is emitted to the atmosphere.

DEPARTMENT OF HEALTH AND HUMAN SERVICES

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

Principal Areas of Focus

Four National Institutes of Health (NIH) institutes support research on the health effects of ultraviolet (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 chlorofluorocarbon replacement chemicals, including studies on the metabolism and toxicity of hydrofluorocarbons and halogenated hydrocarbons. HHS [NIH and the Centers for Disease Control and Prevention (CDC)] also conducts research related to other impacts of global change on human health, including renewed concern about infectious diseases whose incidence could be affected by environmental change. In addition, NIH sponsors a program to assess the impact of population change on the physical environment and to account for effects of the physical environment on population change.

Program Highlights for FY 2004 and FY 2005

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% 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.

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 UV-B 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 UV-B radiation. The goal of this effort is to identify drugs that might have therapeutic or preventative applications.

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 UV-B induced skin cancer in people with Basal Cell Nevus Syndrome.

NIAMS supports basic and clinical research on the effect of UV-A and UV-B radiation on skin.

Related Research

In addition to research areas designated as part of the CCSP budget, HHS agencies conduct other research relevant to the overall CCSP program.

Climatic models have indicated that a possible result of global climate change would be an increase in the number and intensity of heat waves impacting the U.S. population. The CDC Division of Environmental Hazards and Health Effects conducts intramural research to investigate morbidity and mortality associated with exposure to excess heat. Key program components include conducting epidemiologic investigations on heat-related mortality and morbidity, providing technical assistance to municipal agencies in the development of Heat Emergency Response Plans aimed at reducing the public health impact of heat waves, and publishing an annual summary of heat-related mortality in the United States. CDC's scientists provided technical advice and support to the French Ministry of Health in responding to the massive heat wave that struck Europe in August 2003 and have identified critical components for effective response plans that will be published in FY 2004.

Renewed concern about emerging and re-emerging infectious diseases has prompted increased attention to a variety of diseases whose incidence would be affected by environmental change. 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 habitat, reduce the levels of sanitation, and overwhelm the ability of public health systems to respond.

DEPARTMENT OF THE INTERIOR / U.S. GEOLOGICAL SURVEY

Principal Areas of Focus

Research at USGS contributes directly to CCSP strategic goals, principally through studies designed to understand the interactions between climate, Earth surface processes, and ecosystems on time scales ranging from years to millennia. The goal of global change research at USGS is to improve knowledge and understanding of the Earth's past and present climate and environment, the forces bringing about changes in the Earth's climate, and the sensitivity and adaptability of natural and managed ecosystems to climate changes. This information may be used to assess the impacts of climate change and variability at a landscape scale and to allow policymakers and land and resource managers to gauge the relative sensitivity of particular ecosystems, resources, and regions to climatic change and variability.

USGS supports multidisciplinary studies of past environmental and climatic changes (climate history); process studies that explore the sensitivity of the Earth's surface, the hydrologic cycle, and ecosystems to climate variability; and forecasting of potential future changes and their effects on landscapes and ecosystems (particularly on public lands). The combination of these studies provides integrated long-term perspectives on the effects of climatic change and variability and on the interactions through time among climatic, geologic, and biologic systems on regional and landscape scales.

Program Highlights for FY 2004 and FY 2005

Geographic Analysis and Monitoring (GAM)

Research is directed to understand the rates, causes, and consequences of landscape change over time. This knowledge is used to model processes of landscape change and to forecast future conditions. Studies are designed to document and understand the nature and causes of changes occurring on the land surface; to analyze the impacts of land surface changes (including urbanization) on ecosystems, climate variability, biogeochemical cycles, hydrology, and human health; and to develop the best methods to incorporate GAM science findings in the decisionmaking process.

Hydroclimatology

Research on effects of climate change and variability on the hydrologic cycle focuses on characterizing—and developing predictive methods related to—the hydroclimatology of North America. This includes identification of seasonal variations in regional streamflow in relation to atmospheric circulation for regional streamflow prediction and flood/drought hazard assessment; the linkage between atmospheric circulation and snowpack accumulation (for forecasting spring and summer water supply in the western United States and for flood forecasting) as well as glacier mass balance; and the physical and chemical variability in riverine and estuarine environments in relation to large-scale atmospheric and oceanic conditions (to discriminate natural from human-induced effects on such systems). It also includes documenting the long-term behavior of hydrologic systems in response to past climatic variations and changes (from decades to hundreds of thousands of years) as well as more recent (decadal) hydrologic trends. The program maintains an active effort to develop improved representations of terrestrial hydrologic processes in general circulation and regional climate models. In broad terms, these activities are aimed at improving statistical and deterministic methods for predicting hydrologic hazards and related environmental conditions on monthly to interannual time scales.

Carbon Cycle

USGS conducts a broad range of carbon cycle research focused on North America, which includes the following activities:

- *Assessment of Carbon Stocks and Soil Attributes*—Determine the spatial distribution of carbon in the terrestrial environment in relation to historical natural and human processes, as a basis for initializing dynamic models of soil carbon.
- *Carbon Sequestration in Sediments*—Study the redeposition of eroded soils and sediments (and their associated organic carbon) which sequesters large quantities of carbon, buried at the base of slopes and in wetlands, riparian areas, and reservoirs.
- *Landscape Dynamics and Vegetation Change*—Examine the long-term dynamics of vegetation change in relation to climate change and variability. A detailed history of vegetation change in the western United States is being constructed. Past changes are used to model vegetation response to climatic variables. This knowledge is applied to forecasting the effects of future climate change on the distribution of vegetation in the western United States.
- *Fate of Carbon in Alaskan Landscapes*—Expand process studies and modeling to better understand the historic and modern interactions among climate, surface temperature and moisture, fire, and terrestrial carbon sequestration. Cold region forests (boreal ecosystems) contain large carbon reserves that are highly susceptible to changes in climate.
- *Exchanges of Greenhouse Gases, Water Vapor, and Heat at the Earth's Surface*—Employ field measurements, remote sensing, and modeling of carbon fluxes to develop estimates of gross primary productivity, respiration, and net ecosystem exchange at flux tower sites, and use remotely sensed data to extrapolate these carbon fluxes to ecoregions.

Cryosphere Dynamics

The Arctic is particularly vulnerable to climate change because of the large temperature changes that occur there and the disruption caused by melting/freezing of ice and permafrost. In addition, the polar regions have the greatest potential for causing abrupt global-scale climate changes through instabilities and feedbacks involving the cryosphere and ocean circulation. USGS research focuses on documenting change in the cryosphere via studies of the thermal state of the permafrost in northern Alaska; mass balance studies of benchmark glaciers in the Pacific Northwest and Alaska; a global assessment of changes in glacier extent; and mapping of changes in ice extent along the coast of Antarctica.

Changes in Ecosystems

USGS ecosystems research focuses on impacts on terrestrial and coastal ecosystems 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. Research provides the scientific knowledge and technologies for conservation, rehabilitation, and management of ecosystems needed by public land management agencies.

Satellite Data Management and Dissemination

USGS operates and continually enhances the capabilities of the Earth Resources Observation System (EROS) Data Center to serve as the National Satellite Land Remote-Sensing Data Archive, by maintaining existing data sets, 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.

DEPARTMENT OF STATE

Principal Areas of Focus

Through DOS annual funding, the United States is the world's leading financial contributor to the United Nations Framework Convention on Climate Change (UNFCCC) and to the Intergovernmental Panel on Climate Change (IPCC), a major organization for the assessment of scientific, technical, and socioeconomic information relevant to the understanding of climate change, its potential impacts, and options for adaptation and mitigation. Recent DOS contributions to the IPCC provide substantial support for the Global Climate Observing System, among other activities.

Program Highlights for FY 2004 and FY 2005

During FY 2004 and FY 2005, DOS will support development of the IPCC Fourth Assessment Report, which will serve as a decision support resource for policymaking related to climate change.

DEPARTMENT OF TRANSPORTATION

Principal Areas of Focus

DOT utilizes existing science to improve decisionmaking tools in three primary areas: (1) impact of climate variability and change on transportation (research to examine the effects that climate change and variability may have on transportation infrastructure and services, and to identify potential adaptation strategies for use by transportation decisionmakers, operators, state and local planners, and infrastructure builders); (2) increasing energy efficiency and reducing greenhouse gases (research on reducing energy use to mitigate transportation's environmental impacts both through conservation and through the application of new technology); and (3) modeling (research to develop and improve analytical tools for transportation energy use to support decisionmaking throughout government and in the private sector).

Program Highlights for FY 2004 and FY 2005

The U.S. Department of Transportation's virtual Center for Climate Change and Environmental Forecasting plans to complete research in four areas in FY 2004-2005, including 'Measuring the Greenhouse Gas Intensity of the Transportation Sector;' 'Stock Modeling for Selected Transportation Equipment;' 'Characterization of Power Plant Emissions and Fuel Quality;' and 'Consumption Rates of the U.S. Waterborne Fleet.' DOT also will complete an evaluation of the New York State Energy Plan.

As a synthesis and assessment project under the President's Climate Change Research Initiative, the Department will continue research on 'The Potential Impacts of Climate Change on Transportation Systems' through a case study of transportation infrastructure in the Gulf Coast. Phase I of the project will formally begin in FY 2004 through joint research with the U.S. Geological Survey. The first phase will provide an integrated overview of climate and weather trends and projections in the Gulf Coast region with other relevant environmental, economic, and demographic data; assess the potential implications of these changes for transportation infrastructure and facilities; and conduct an initial assessment of relative infrastructure sensitivities in the region.

The Center has already completed research on five topics in FY 2003-2004 that address the links between transportation and climate change, including the potential impacts of climate change on transportation. Copies of the reports are available on-line at <http://www.dot.gov/climate>.

- *Fuel Options for Reducing Greenhouse Gas Emissions from Motor Vehicles*—Assesses the potential of gasoline substitutes to reduce emissions of carbon dioxide and other greenhouse gases by automobiles and light-duty trucks.
- *Modeling of Advanced Technology Vehicles*—Reviews some methods for representing advanced technology vehicles in engineering and market simulation models.
- *Passenger Ferries, Air Quality, and Greenhouse Gases: Can System Expansion Result in Fewer Emissions in the San Francisco Bay Area?*—Evaluates the potential greenhouse gas benefits achievable through better integration of passenger ferries under several ferry technology and fueling options.
- *The Potential Impacts of Climate Change on Transportation: Workshop Summary and Proceedings*—Summarizes and provides 18 discussion papers from DOT's Center for Climate Change and Environmental Forecasting October 2002 workshop exploring the potential impacts of climate change on transportation systems and services.
- *Greenhouse Gas Reduction through State and Local Transportation Planning*—Evaluates how and why states, metropolitan planning organizations, cities, and transportation providers are pursuing greenhouse gas emission reductions, with a focus on transportation planning.

AGENCY FOR INTERNATIONAL DEVELOPMENT

Principal Areas of Focus

Through its Famine Early Warning System Network (FEWS NET), USAID provides decisionmakers—both in the United States and in other parts of the world—with information designed to inform decisions and more effectively respond to drought and food insecurity. In the past, FEWS NET focused activities in 18 drought-prone countries across sub-Saharan Africa. As of 2003, FEWS NET began expanding coverage to selected countries of Asia and Latin America and the Caribbean. In addition to monitoring a wide variety of socioeconomic indicators to identify levels of food insecurity, FEWS NET monitors and analyzes remotely sensed data and ground-based meteorological, crop, and rangeland observations to track the progress of rainy seasons and crop production in semi-arid regions, in order to identify early indications of reduced food availability and access.

Program Highlights for FY 2004 and FY 2005

In FY 2004, FEWS NET begins providing a broad range of monitoring and analysis of food insecurity conditions in 20 countries in Africa, three countries of Central America, as well as in Haiti and Afghanistan. In addition to its assessment activities in each country, FEWS NET is committed to building the capacity of local institutions that will take over those functions in the future. In FY 2004, FEWS NET will likely complete the indigenization of its field staff in Africa, and will begin moving experienced Africa early warning staff into programs on other continents.

ENVIRONMENTAL PROTECTION AGENCY

Principal Areas of Focus

EPA's Global Change Research Program has its primary emphasis on evaluating the potential consequences of climate variability and change on air quality, water quality, ecosystems, and human health in the United States. This entails: (1) improving the scientific basis for evaluating effects of global change in the context of other stressors; (2) conducting evaluations of the risks and opportunities presented by global change; and (3) investigating 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. This work is consistent with and closely coordinated with the *CCSP Strategic Plan*.

The planning and implementation of EPA's program is integrated by the CCSP with other participating Federal departments and agencies to reduce overlaps, identify and fill programmatic gaps, and add integrative value to products and deliverables generated under the CCSP's auspices. EPA coordinates with other CCSP agencies to develop and provide useful and scientifically sound information to decisionmakers in a timely manner. This includes the development of decision support tools for resource managers and decisionmakers. Also, as called for by the National Research Council, EPA supports and fosters projects 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 scientific credibility. EPA's program has four areas of emphasis: air quality, water quality, ecosystems, and human health.

Air Quality

Few studies have investigated the effect of global change on air quality. Studies are planned that will examine the potential consequences of global change on air quality in urban areas in the United States. The long-term goal of this focus area is to provide the approaches, methods, and models to quantitatively assess the effects of global change (climate change, land-use change, and UV radiation changes) on urban air quality, and to identify technology advancements and adaptive responses and quantify their effect on air quality.

Water Quality

Water quality can be affected by changes in runoff following changes in precipitation and evapotranspiration and/or changes in land use. The program is investigating the possible impacts of global change (climate and land-use change) on water quality using a watershed approach. The water quality studies will both contribute to and benefit from human health and ecosystems studies.

Ecosystems

EPA's mission is not only to protect human health but also to safeguard the natural environment. EPA promotes 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 activities that investigate the effects of global change on aquatic ecosystems (which may

include lakes, rivers, and streams; wetlands; and estuaries and coastal ecosystems); invasive non-indigenous species; and ecosystem services.

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

Human Health

Since health is affected by a variety of social, economic, political, environmental, and technological factors, investigating the health impacts of global change is a complex challenge. As a result, health studies in EPA's Global Program go beyond basic epidemiological research to development of integrated health evaluation frameworks that consider the effects of multiple stresses, their interactions, and human adaptive responses. Along with health sector studies conducted in conjunction with other CCSP agencies, there are research activities focused on the possible 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.

Intramural and extramural research contributes to all of EPA's investigations. In an attempt to capitalize on expertise in the academic community, a significant portion of the program's resources is dedicated to extramural research grants administered through the Science to Achieve Results (STAR) program. The STAR program focuses on science to support investigations of consequences of global change for air quality and ecosystems in the United States. EPA will continue to coordinate closely with other CCSP agencies to identify the specific topics that should be emphasized within the STAR program.

Program Highlights for FY 2004 and FY 2005

EPA will continue to make significant contributions to the ongoing assessment activities of the CCSP. EPA strives to understand relative risks in the context of multiple stressors, at multiple scales and multiple levels of biological and institutional organization. The EPA-sponsored investigations will continue to be conducted through public-private partnerships that actively engage researchers from the academic community, decisionmakers, resource managers, and other affected stakeholders. Highlights of specific activities that will be undertaken by EPA in FY 2004 and FY 2005 include:

- Support the CCSP commitment to generate 21 synthesis and assessment products by leading or co-leading three analyses and supporting seven others.
- Investigate the potential consequences of climate change for human health.
- Develop best-available scientific information about the potential consequences of climate variability and change for the Gulf Coast, Great Lakes, and Mid-Atlantic regions.
- Evaluate the feasibility of adaptation strategies that might be employed to respond to the direct and indirect impacts of global change on human health in the United States.
- Investigate the potential effects of global change on waterborne diseases in the United States.
- Evaluate the potential global change impacts on water quality (pollutants and pathogens).
- Develop socioeconomic scenarios for use in EPA's global air quality studies and in related CCSP studies.

Related Research

In addition to the focused CCSP activities, EPA conducts research that contributes to the characterization and understanding of risks to ecosystems and to human health. The ecosystems-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.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Principal Areas of Focus

The mission of NASA's Earth Science Enterprise is to understand and protect our home planet by using our view from space to study the Earth system and improve prediction of Earth system change. NASA programs are aimed at understanding the Earth system and applying Earth system science to improve prediction of climate, weather, and natural hazards in partnership with other Federal agencies and international space and research programs. NASA's Research Strategy orchestrates observing and modeling programs to address these essential 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 change?
- What are the consequences of change in the Earth system for human civilization?
- How well can we predict future changes in the Earth system?

NASA's portfolio includes observations, research, analysis, modeling, and advanced technology development, in order to answer selected science questions, and benchmarking decision support resources to ensure society receives the benefits of this research.

NASA pioneered the interdisciplinary field of Earth system science which explores the interaction among land, oceans, atmosphere, ice, and life. To study these interactions, NASA has developed and deployed the Earth Observing System (EOS) and related satellites, and suborbital and surface-based sensors— collecting, processing, archiving, and distributing these data through the EOS Data and Information System (EOSDIS). Distributing more than 25 million data products in response to more than 2.3 million users each year, EOSDIS is the largest "e-science" system in the world. Following the Earth system science construct, NASA has organized its research into six science focus areas. The table below identifies these six focus areas and how they align with the CCSP research areas.

CCSP RESEARCH ELEMENTS	EARTH SCIENCE ENTERPRISE SCIENCE FOCUS AREAS
Atmospheric Composition	Atmospheric Composition
Climate Variability and Change	Climate Variability and Change
Global Water Cycle	Global Water and Energy Cycle
Land-Use/Land-Cover Change Global Carbon Cycle Ecosystems	Carbon Cycle and Ecosystems
Human Contributions and Responses	
	Weather
	Earth Surface and Interior

Recent Accomplishments

- Produced the most accurate map yet of the Earth's gravity field from the twin Gravity Recovery And Climate Experiment (GRACE) satellites, improving from 10 to 100 times the accuracy of previously existing assessments. Ultimately, GRACE will help determine the distribution of mass under the Earth's surface, including the change in volume of large aquifers.
- Instruments on the Aqua satellite are generating the most accurate, highest resolution measurements ever taken from space of the infrared brightness of Earth's atmosphere, yielding a global, three-dimensional map of atmospheric temperature and humidity.
- The Eurasian and South American continents are the latest for which detailed topographic data have been processed and released from the Shuttle Radar Topography Mission, for use in a wide variety of scientific investigations and practical applications.
- NASA satellite observations have provided the first evidence that the rate of ozone depletion in the Earth's upper atmosphere is decreasing. This decrease is consistent with the decline in abundance of human-made chlorine and bromine-containing chemicals previously documented by satellite, airborne, and ground-based sensors.
- The USDA Forest Service is using data from NASA satellites to understand how fires behave before, during, and after their damage has been done. After a fire is contained, imagery from space helps classify the burn area into levels of severity for prioritization of rehabilitation work. These satellites also keep daily track of the carbon monoxide plumes from fire and the scope of pollution produced regionally and globally.
- Recent research has found perennial, or year-round, sea ice in the Arctic is declining at a rate of 9% per decade and that in 2002 summer sea ice was at record low levels. Early results indicate this persisted in 2003. The Arctic warming study—appearing in the 1 November issue of the American Meteorological Society's *Journal of Climate*—shows that, compared to the 1980s, most of the Arctic warmed significantly over the last decade, with the biggest temperature increases occurring over North America.

Program Highlights for FY 2004 and FY 2005

FY 2004

- Complete deployment of the first phase of EOS with the launch of the Aura satellite. Aura will make a variety of measurements of atmospheric composition, including the first measurements of global tropospheric ozone and precursors.
- Use satellite observations to provide daily and seasonal global atmospheric water vapor, rainfall, snowfall, sea ice, and ice sheet maps, and use these observations to improve the scientific understanding and models of the global cycling of water through the Earth system.
- Use satellite-derived localized temperature and moisture profiles of unprecedented accuracy and global coverage to improve predictive capabilities of regional weather models.
- Assimilate satellite and *in situ* observations into a variety of ocean, atmosphere, and ice models for the purpose of estimating Earth's seasonal and decadal climate.
- Demonstrate the benefits of formation-flying multiple satellites in a constellation for the first time (i.e., creating a supersatellite) to enable generation of integrated science information products (e.g., aerosol distribution, optical thickness, and properties to assess their total effect on climate).

FY 2005

- Launch the Cloudsat and Calipso satellites to obtain the first global three-dimensional measurements of cloud structure and aerosol distribution, to reduce key uncertainties in climate forcing.
- Continue development of missions to measure ocean topography, ocean surface winds, global precipitation, sea surface salinity, atmospheric carbon dioxide, and aerosol properties, as well as development of the preparatory mission for the next generation converged polar-orbiting operational environmental satellite system.
- Select new missions under the fourth Earth System Science Pathfinder Announcement of Opportunity.
- Integrate satellite, suborbital, and ground-based observations to assess the potential for future ozone depletion in the Arctic.
- Improve predictive capabilities of regional models for hurricane tracks and landfall using satellite-derived localized temperature and moisture profiles and ensemble modeling.
- Assimilate satellite and *in situ* observations into a variety of ocean, atmosphere, and ice models for improved state estimation and experimental prediction on a variety of climatological time scales, and determine plausibility of predictions through validation strategies.

Related Research

Outside the scope of the CCSP, NASA's Earth Science Enterprise also conducts research and observing missions to study the solid Earth and related natural hazards. The Earth Science Enterprise also manages an Earth Science Applications 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 twelve applications of national priority:

National Application	Partner Agencies
Renewable Energy	DOE, EPA
Agricultural Efficiency	USDA, EPA
Carbon Management	USDA, EPA, DOE, USGS, USAID
Aviation	DOT/Federal Aviation Administration
Homeland Security	Department of Homeland Security, National Governors Association, USDA, USGS, NOAA, DOD
Ecological Forecasting	USGS, USDA, USAID
Disaster Preparedness	Federal Emergency Management Agency, USGS, NOAA, USDA
Public Health	CDC, DOD, NIH, EPA, USGS , NOAA
Coastal Management	NOAA, EPA
Invasive Species	USGS, USDA
Water Management	Bureau of Reclamation, USGS, EPA, USDA
Air Quality	EPA, NOAA, USDA, FAA

NATIONAL SCIENCE FOUNDATION

Principal Areas of Focus

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. The programs promote the development of advanced analytic methods and the creation of digital models designed to improve understanding of Earth system processes and interactions. 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. Through its investment, NSF will contribute to CCSP by providing a comprehensive scientific foundation for many of the synthesis and analysis products identified in the *CCSP Strategic Plan*.

Program Highlights for FY 2004 and FY 2005

During FY 2004 and FY 2005, NSF will support research and related activities addressing all of the CCSP program elements and the interdisciplinary science aspects that link them. NSF will also support several key Climate Change Research Initiative topics. NSF will continue to invest in collaborative international programs such as the World Climate Research Programme, the International Geosphere-Biosphere Programme, the International Human Dimensions Programme, and Diversitas.

Atmospheric Composition

A major focus on atmospheric composition and atmospheric chemistry will continue through programs in tropospheric and stratospheric chemistry. Studies of atmospheric transport of constituents and aerosols will continue to provide insights about how they affect the radiative and cloud nucleating properties of the atmosphere and ultimately the climate. Studies to reduce uncertainty in global distributions of greenhouse gases should provide input for future scenarios of radiative forcing.

Climate Variability and Change

NSF will continue its emphasis on climate variability and change as a major component of its investments. This element will support observational campaigns and numerous analytical and modeling activities. A number of ocean and atmospheric science projects will address topics identified in the CLIVAR implementation plans. Ocean science efforts will focus on changes in ocean structure, circulation, and interactions with the atmosphere to improve our current understanding of the processes and models that address future changes, particularly those that may happen abruptly. Major support will continue to permit the Community Climate System Model to develop more comprehensive models through the incorporation of improved parameterizations. Paleoclimate studies will continue to be supported as a means to provide baseline data on natural climate variability from key climatic regions (e.g., the high latitudes) to improve understanding of natural variability. These data will be used to reconstruct and evaluate past environmental change due to climate and as an input for model validations.

The Global Water Cycle

NSF supports a broad-based effort to understand all aspects of the global water cycle. For FY 2004 and FY 2005, the program will continue to address the wide range of hydrological data types—continuous and discrete time and space information from a variety of platforms—that are major obstacles facing water cycle researchers. Information from process studies will be used to refine models through scaling and parameterizations of sub-grid processes. For example, a high-resolution cloud model is run "inside" a lower resolution global model to create a "multi-scale modeling framework." Results show major improvements in the simulation of weather, climate systems, and hydrological variables.

Land-Use and Land-Cover Change

Several NSF programs address key aspects of land-use and land-cover change. Support continues for studies in ecological rates of change and related species diversity, Arctic systems, temporal variability, water and energy influences on vegetative systems, and diverse human influences on land utilization. These activities support numerous research needs in the *CCSP Strategic Plan*.

Global Carbon Cycle

NSF will continue to support a wide variety of carbon cycle research activities. For FY 2004 and FY 2005, one specific program—Integrated Carbon Cycle Research—will focus on the transport of materials from their origin in various river basins to their deposition along ocean margins. The transport process, including modification en route, and the ultimate fate of carbon species will be addressed and used as key input for the North American Carbon Program. Integration of observational data into models will continue to provide insights for the global carbon cycle.

Ecosystems

Several NSF programs address terrestrial and marine ecosystems through observational and laboratory studies. NSF will continue to support the collection of ecosystem data through its Long-Term Ecological Research programs. For FY 2004 and FY 2005, the Global Ocean Ecosystem Dynamics program will evaluate the impact of global ocean changes on marine ecosystems.

Human Contributions and Responses

NSF will support basic research on the processes through which people (individually, in groups, or through organizations) interact with natural environmental systems. For FY 2004 and FY 2005, NSF programs will support a set of centers that focus on decisionmaking under uncertainty associated with climate change. The work of these centers will contribute to decisionmaking in the following years.

Related Research

NSF will continue to support "contributing" research on broader topics that are closely related to global change and climate change. These include, *inter alia*, studies of the atmosphere, ocean, land surface, ecosystems, paleoclimatology, and human dimensions that add substantively to the specific programs supporting CCSP objectives, and cyberinfrastructure which will enable more effective utilization of the research information. In addition, projects that integrate research with education on global and climate change are 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 global and climate change debates.

SMITHSONIAN INSTITUTION

National Museum of Natural History (NMNH)
National Zoological Park (NZP)
Smithsonian Tropical Research Institute (STRI)
Smithsonian Environmental Research Center (SERC)

Principal Areas of Focus

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, the National Museum of Natural History, the Smithsonian Tropical Research Institute, and the 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 the lay public. The unique contribution of the Smithsonian Institution is a long-term perspective—for example, undertaking investigations that may require extended study before producing useful results and conducting observations on sufficiently long (e.g., decadal) time scales to resolve human-caused modification of natural variability.

Program Highlights for FY 2004 and FY 2005

Climate Variability and Change
Research at the National Air and Space Museum will emphasize 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 will 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 United States. These data will be electronically disseminated to meet the needs for assessing the biological and chemical impact of varying UV exposure. During FY 2004 and FY 2005, results will be used to update trends in surface UV radiation and will be reported in national meetings and peer-reviewed publications (Question 3.4 of *CCSP Strategic Plan*).

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 carbon dioxide (also a contribution to the Global Carbon Cycle program), invasive species, and solar UV-B. 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. During FY 2004 and FY 2005, results will be reported from a study on long-term changes in Amazonian tree communities, which are evidently related to climatic or atmospheric drivers (Question 8.2 of *CCSP Strategic Plan*).

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. During FY 2004 and FY 2005, exhibits will be displayed at NMNH in the "Forces of Change: Global Links" series concerning El Niño events, the atmosphere, and the Arctic, with accompanying educational programs and other ancillary information accessible through the internet (see Chapter 14 of the *CCSP Strategic Plan*).

Related Research

Much of the global change research performed at the Smithsonian is not supported by funds appropriated directly to the Smithsonian, and instead is supported by other public and private sources (including other CCSP participating agencies). These projects are nonetheless organized around the CCSP research elements and thus amplify the scope and impact of research supported directly by the CCSP. These include programs at the Smithsonian Astrophysical Observatory 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 carbon dioxide, 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 human-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 Smithsonian 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.

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To obtain a copy of this document, place an order at the Global Change Research Information Office (GCRIO) web site: http://www.gcrio.org/orders.

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