UNITED STATES GLOBAL CHANGE RESEARCH PROGRAM STRATEGIC PLAN 2012–2021

TABLE OF CONTENTS

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EXECUTIVE SUMMARY

Earth's environment is changing rapidly. Increases in world population and industrialization are altering the atmosphere, ocean, land use, ecosystems and the distribution of species over the planet. Scientific research, including monitoring and modeling of the multifaceted Earth system, provides information for governments, businesses, and communities to understand these changes and to respond to potential risks brought about by global change, such as more severe heat waves, storms, floods, fires, crop failures, and water shortages.

Created by Congress in 1990, the United States Global Change Research Program (USGCRP) coordinates federal research aimed at understanding, assessing, and responding to global change. During the Program's first two decades, member agencies and partners in industry, academia, and state, local, and foreign governments have created and maintained a mix of atmospheric, oceanic, land, and space-based observing systems, gained new theoretical understanding of Earth system processes, developed predictive models, promoted advances in data management and sharing, and developed an expert scientific workforce.

This Strategic Plan for 2012–2021 builds on these accomplishments. In particular, USGCRP supports four strategic goals:

Goal 1. Advance Science: Advance scientific knowledge of the integrated natural and human components of the Earth system.

Goal 2. Inform Decisions: Provide the scientific basis to inform and enable timely decisions on adaptation and mitigation.

Goal 3. Sustained Assessments: Build sustained assessment capacity that improves the Nation's ability to understand, anticipate, and respond to global change impacts and vulnerabilities.

Goal 4. Communicate and Educate: Advance communications and education to broaden public understanding of global change and empower the workforce of the future.

These four goals and objectives (see **Box 1**) recognize that effective response to global change begins with scientific research of the highest quality.

Improving fundamental scientific knowledge is at the core of USGCRP activities. To build upon program successes and to address critical gaps in research, coordinated programs in observations, modeling, and research on fundamental processes will be directed at advances in understanding individual Earth system components and the integrated human and Earth system. The latter increasingly requires work spanning the science disciplines, including better integration of social sciences, and access to advanced computer technologies.

The goals acknowledge that global change research is not a purely academic endeavor. To be useful, scientists must understand the needs of decision makers at all levels in the public and private sectors and clearly and effectively make research results relevant to those decision makers. For example, farmers depend upon information to adjust and manage crops as planting seasons, growing zones, and pest and weed ranges change. Health care providers must prepare for more severe heat waves and outbreaks of diseases previously unknown in their regions. Insurers must account for shifting weather extremes in assessing future financial risk. Inhabitants of coastal cities need to understand the implications of sea level rise, while many regions of the country address changes in the availability of freshwater and increasing energy demands.

The goals recognize that global change is an international concern affecting many aspects of societies, livelihoods, and the environment. Across the Nation and around the world, people are making decisions to effectively minimize (mitigate) and prepare for (adapt to) global change. The global nature of today's economy, and the speed with which challenges faced in one part of the world can affect others, reinforces the need for a global response based upon the best available science. Vital resources, such as water and food supplies, cross regional and national boundaries, and the effects of global change can disrupt social, economic, and political systems. Understanding global change and our options to minimize and manage the risks of such change is important for U.S. national security and for maintaining regional and global stability, and for long-term economic vitality.

Providing decision makers with timely and relevant information requires assessing their needs. USGCRP, as part of its mandate to perform regular assessments, will implement a long-term, consistent, and ongoing process for evaluation of global change risks and opportunities, and for informing decision makers across diverse regions and sectors. USGCRP will work to establish a sustained assessment capacity focused on evaluating the current state of scientific knowledge relative to impacts and trends, and on informing the Nation's activities in adaptation and mitigation.

The final goal acknowledges that meaningful engagement with the public is essential. By integrating communication, education, and engagement into core activities over the next decade, USGCRP and its member agencies will serve as an important gateway to credible and authoritative global change information. USGCRP will build capacity to inform citizens of global change science and data through a user-friendly global change information system. USGCRP education efforts will also support the development of a workforce capable of using global change information and addressing global change issues. The Program will place particular emphasis on education that bridges physical, biological, social sciences, and engineering, and the support of educators' professional development in USGCRP-related STEM (science, technology, engineering and mathematics) areas.

This Strategic Plan fulfills Congress's mandate in the Global Change Research Act to develop a program to "understand, assess, predict, and respond to" global change. It reflects recommendations from multiple reports of the National Academies, from dozens of listening sessions with stakeholders around the country, and from collaborative planning among the USGCRP member agencies. Altogether, the USGCRP envisioned through this Strategic Plan, by connecting fundamental human and Earth system research with the translation and dissemination

of credible and authoritative information, harnesses the work of Federal agencies into a coordinated effort for the future benefit of the Nation.

155

Box 1. USGCRP Strategic Goals and Objectives.

Goal 1. Advance Science: Advance scientific knowledge of the integrated natural and human components of the Earth system.

Objective 1.1. Earth System Understanding: Advance fundamental understanding of the physical, chemical, biological, and human components of the Earth system, and the interactions among and between them, to improve knowledge of the causes and consequences of global change.

Objective 1.2. Science for Adaptation and Mitigation: Advance understanding of the vulnerability and resilience of integrated human-natural systems and enhance the usability of scientific knowledge in supporting responses to global change.

Objective 1.3. Integrated Observations: Advance capabilities to observe the physical, chemical, biological, and human components of the Earth system over multiple spatial and temporal scales to gain fundamental scientific understanding and monitor important variations and trends.

Objective 1.4. Integrated Modeling: Improve and develop advanced models that integrate across the physical, chemical, biological, and human components of the Earth system, including the feedbacks among and between them, to represent more comprehensively and predict more realistically global change processes.

Objective 1.5. Information Management and Sharing: Advance the capability to collect, store, access, visualize, and share data and information about the integrated Earth system, the vulnerabilities of integrated human-natural systems to global change, and the responses to these vulnerabilities.

Goal 2. Inform Decisions: Provide the scientific basis to inform and enable timely decisions on adaptation and mitigation.

***Objective 2.1. Inform Adaptation Decisions*:** Improve the deployment and accessibility of science to inform adaptation decisions.

Objective 2.2. Inform Mitigation Decisions: Improve the deployment and accessibility of science to inform decisions on mitigation and the mitigation-adaptation interface.

Objective 2.3. Enhancing Climate Services: Develop the tools and scientific basis to support an integrated system of climate services, supported by sustained, relevant, and timely data and information to support decision making.

Objective 2.4. Enhancing International Partnerships: Provide leadership in international partnerships to enhance the scientific basis for decision making.

Goal 3. Sustained Assessments: Build sustained assessment capacity that improves the nation's ability to understand, anticipate, and respond to global change impacts and vulnerabilities.

Objective 3.1. Scientific Integration: Integrate emerging scientific understanding of the integrated Earth system into assessments and identify critical gaps and limitations in scientific understanding.

Objective 3.2. Ongoing Capacity: Strengthen and evolve ongoing capacity to conduct assessments with accessible, transparent, and consistent processes and broad participation of stakeholders across regions and sectors.

Objective 3.3. Inform Responses: Inform responses to global change with accurate, authoritative, and timely information that is accessible to multiple audiences in multiple formats.

Objective 3.4. Evaluate Progress: Ensure ongoing evaluation of assessment processes and products, and incorporate the findings into an adaptive response for systemic improvement.

Goal 4. Communicate and Educate: Advance communications and education to broaden public understanding of global change, and empower the workforce of the future.

Objective 4.1. Strengthen Communicate and Education Research: Strengthen global change communication and education research to enhance practices.

Objective 4.2. Reach Diverse Audiences: Enhance existing and employ emerging tools and resources to inform and educate effectively, providing for information flow in multiple directions.

Objective 4.3. Increase Engagement: Establish effective and sustained engagement to enable a responsive and wholly integrated Program.

Objective 4.4. Cultivate Workforce: Cultivate a capable, diverse workforce that is knowledgeable about global change.

I. INTRODUCTION

The United States Global Change Research Program (USGCRP) advances the collective efforts of 13 U.S. government agencies that collaboratively help the Nation better understand global change and its impacts.

Every day, governments, organizations, and individuals make long-term decisions worth billions of dollars that affect many lives. The outcomes of these decisions depend to a large degree on how well these people and groups understand the changes taking place in the Earth system, and how well they can use this knowledge to plan effectively to achieve societal benefits. For example, farmers need to adjust crop management as planting seasons, growing zones, and pest and weed ranges change. The defense and intelligence communities need to assess the implications of long-term climate change on national security and the threats that natural hazards pose to military bases. Health care providers must prepare for more severe heat waves and outbreaks of diseases previously unknown in their regions. Insurers must account for shifting weather extremes in assessing future financial risk. Inhabitants of coastal cities need to understand the implications of sea level rise. Many regions of the country need information about changing freshwater availability and energy demand.

Text Box 1. From the Global Change Research Act of 1990.

Global change means changes in the global environment (including alterations in climate, land productivity, oceans or other water resources, atmospheric chemistry, and ecological systems) that may alter the capacity of the Earth to sustain life … 'Global change research' means study, monitoring, assessment, prediction, and information management activities to describe and understand: A. the interactive physical, chemical, and biological processes that regulate the total Earth system; B. the unique environment that the Earth provides for life; C. changes that are occurring in the Earth system; and D. the manner in which such system, environment, and changes are influenced by human actions.

This 2012–2021 Strategic Plan describes a program that builds from core USGCRP capabilities in global climate observation, process understanding, and modeling to strengthen and expand our fundamental scientific understanding of climate change and its interactions with the other critical drivers of global change, such as land-use change, alteration of key biogeochemical cycles, and biodiversity loss.

The current rate of global change far exceeds anything we have observed and documented in human history. Society needs new scientific knowledge of how these unprecedented changes, including accelerating emissions of greenhouse gases, land-use and land cover change, disruption of natural biological and chemical cycles, and associated changes in climate, ocean chemistry, and the distribution of species over the planet, might put individuals and communities at risk. Failure to anticipate and manage these risks threatens our Nation's prosperity and security. On the other hand, effective and timely responses to global change can create new opportunities for economic growth while increasing society's resilience to change.

At the same time as these changes are occurring, there is an increasing demand for Earth's resources, including food, fiber, energy, and water. These needs mean greater pressure on the services that natural systems provide and upon which people depend, such as freshwater supply, natural waste recycling, flood control, pollination, and recreation, all of which are stressed today and will be further stressed in the future because of global change. Resource management needs science that can be used to devise environmentally sustainable solutions to these pressures that also promote economic growth and job creation.

The global nature of today's economy, and the speed with which challenges faced in one part of the world can affect others, reinforces the need for a coordinated response to global change. At the same time, not all countries, communities, and institutions will be equally affected, nor will all be equally ready or able to adapt. Nor will every consequence of global change be detrimental to everyone. To support the many different types of responses to global change needed nationally, regionally, and locally, society requires better understanding of differences in vulnerability among people and places, information about global change and its impacts that is relevant at regional and local scales, and accurate assessments of both risks and opportunities.

Created by Congress in 1990, and sustained through multiple administrations, the U.S. Global Change Research Program (USGCRP; **Figure 1**) has been shaped by more than two decades of Federal investment in global change science. During this time, the Federal government and its partners in industry, academia, and state, local, and foreign governments have created and maintained a mix of atmospheric, oceanic, land, and space-based observing systems, gained new theoretical understanding of Earth system processes, developed predictive models, promoted advances in data management and sharing, and developed an expert scientific workforce. These activities have played a critical role in improving scientific understanding of the richness of interconnections and feedbacks in the Earth system, the significant role that human activities play in global climate change, and the current and potential future rate, magnitude, and impacts of this change. Federal research coordinated through USGCRP is the cornerstone of our current understanding of these issues.[1]

Figure 1: USGCRP member agencies

- Department of Agriculture
- Department of Commerce
- Department of Defense
- Department of Energy
- Department of Health and Human Services
- Department of the Interior
- Department of State
- Department of Transportation
- Environmental Protection Agency
- National Aeronautics and Space Administration
- National Science Foundation
- Smithsonian Institution
- U.S. Agency for International Development

Now, however, society is placing increasing demands on the scientific community for timely information about global change that can be used directly in planning, management, and policymaking, even with a lack of complete certainty about the future long-term impacts of global change and the consequences of actions taken in response. Drawing on the foundation built over the last 20 years, USGCRP is in an unparalleled position to efficiently and authoritatively deliver the fundamental knowledge about the changing Earth system that decision makers need for the future.

This 2012–2021 Strategic Plan describes a program that builds from core USGCRP capabilities in global climate observation, process understanding, and modeling to strengthen and expand our fundamental scientific understanding of climate change and its interactions with the other critical drivers of global change, such as land-use change, alteration of key biogeochemical cycles, and biodiversity loss. It describes a program that, while creating this new scientific knowledge simultaneously focuses on making this knowledge more readily usable in decision making. It describes a program that builds on member agencies' strengths in scientific measurement and modeling, while incorporating learning about decision making under uncertainty and improved methods for iterative, risk-based planning. This plan emphasizes greater coordination across the breadth of USGCRP activities, such as more effective

collaboration between researchers in the natural and social sciences, increased interagency cooperation to sustain ongoing assessments of global change impacts, and robust dialogues with diverse audiences to enhance communication of scientific knowledge beyond USGCRP.

The Federal government's role, not just in scientific research, but also in protecting lives, property, and livelihoods, is critical to the development of a program that creates the necessary links between researchers and decision makers to effectively manage global change risks. This new Strategic Plan emphasizes expanding the reach of USGCRP science over the next decade, both leveraging and supporting the full and varied capabilities and missions of its Federal agency members, including building partnerships with agencies, or parts of agencies, that have not been directly involved in USGCRP in the past.

In what follows, Chapter II provides an overview of the new vision and mission of the Program. Chapter III discusses in detail the goals and objectives that will guide the Program's activities over the next decade. Chapter IV discusses coordination with other nations and international organization. Chapter V outlines key aspects of a strategy for moving forward with implementation of the Plan.

II. VISION AND MISSION

USGCRP Vision and Mission

Vision: "A nation, globally engaged and guided by science, meeting the challenges of climate and global change."
Mission: "To build a knowledge base that informs human responses to climate and global change through coordinated and integrated federal programs of research, education, communication and decision support."

The Program's vision and mission reflect the challenges of global change and the strengths of the Program and its member agencies. To fulfill its mission and help the Nation achieve the vision, USGCRP is taking an "end-to-end" approach to global change (see **Text . Box 2**).

Much of the Program's traditional strengths and accomplishments are in monitoring and understanding global change and its likely future impacts, which will remain a priority. Knowledge from these areas is directly relevant to society's needs. USGCRP and its member agencies will use these investments and build on the Program's initial efforts in decision support to expand the reach of USGCRP science. The Program will improve its ability to assess, understand, and integrate stakeholder science needs into its planning, and to provide global change assessments and information in ways that are more useful for decision making. These directions reflect the Program's emphasis on developing information that is useable and useful. This approach requires enhanced coordination and integration among the agencies and will build on the strong partnerships already in place. The Program will also strengthen relationships beyond its current membership, to better understand and respond to the science needs of the agencies and their stakeholders, and to increase the use of USGCRP science in the country's response to global change.

Text Box 2: Understanding "End-to-End".

*Solving these problems requires research on the **end-to-end** climate change problem, from understanding causes and processes to supporting actions needed to cope with the impending societal problems of climate change…Addressing these issues requires the integration of disciplinary and multidisciplinary research, natural and social science, basic research and practical applications.*

- National Research Council (2009): *Restructuring Federal Climate Research to Meet the Challenges of Climate Change.*

USGCRP will continue to uphold principles of intellectual rigor, transparency, and traceability. In the goals and objectives of this Plan, the Program outlines some large challenges and difficult scientific questions. In addressing them, the Program will mobilize the best scientific skills of the country. It will use merit review in implementing its priorities and peer review to ensure the quality and accuracy of its products.

Figure 2: USGCRP Governance Structure.

USGCRP goals and priorities, developed here, reflect the Program's emphasis on working at the interface between global change and climate change. They also reflect the needs of the wider Federal government and help inform its directions in responding to global change. The Subcommittee on Global Change Research, which oversees USGCRP, is part of the National Science and Technology Council (**Figure 2**), and provides coordination with other parts of that structure.

USGCRP member agencies and their grantees will implement the mission. Their investments in activities such as observations and monitoring, information services, research and modeling, assessment, and communication and outreach totaled about $2B in FY 2010. Results from prior USGCRP programs and activities are highlighted throughout this Plan, in call-out boxes and text boxes. Outcomes from these activities are also summarized on a regular basis in the Program's annual report to Congress, *Our Changing Planet*, along with the investments made by member agencies. USGCRP priorities also nucleate cooperative efforts by state and local governments, the academic community, and industry.

Cooperative activities are coordinated through the Subcommittee on Global Change Research, a National Coordination Office, and interagency working groups. These Program functions bring agencies together to plan and co-develop coordinated activities, implement joint activities, and identify and fill gaps. They allow officials to communicate with each other on emerging directions within their agencies, on their stakeholder needs, and on best practices learned from agency activities. Together, these functions allow the agencies to work in a more effective manner. The Program will draw from and leverage agency strengths in achieving the collective USGCRP Strategic Plan goals and objectives.

USGCRP's stakeholders are critical to its success as a program. The Program and its member agencies interact with a wide variety of groups around the world—from international, national, state, tribal, and local governments, to businesses, nonprofit organizations, the scientific community, and the public. Each contributes to USGCRP's ability to carry out its mission. Through multidirectional dialogue with the agencies, stakeholders communicate their information needs to the Program, helping to shape Program directions and priorities and collectively advance the understanding of global change. In turn, USGCRP strengthens its ability to better communicate global change information to stakeholders to advance their ability to make informed decisions about the changes they face.

Framework for the New USGCRP

The USGCRP Strategic Plan identifies four main goals that frame the Program's vision and help carry out its mission:

Goal 1. Advance Science: Advance scientific knowledge of the integrated natural and human components of the Earth system. This goal identifies the research, including integrated observations and modeling, that is necessary to better understand the behavior and interaction of human and Earth systems and their response to global change. The Program will increasingly emphasize integrated physical, biological, and social science research, and developing reliable knowledge of the causes and consequences of global change at regional and global scales. USGCRP's strong research tradition provides the foundation for the entire Program.

Goal 2. Inform Decisions: Provide the scientific basis to inform and enable timely decisions on adaptation and mitigation. USGCRP member and cooperating agencies will emphasize translating research (from Goal 1) into formats and results that are policy relevant, useable, and accessible to decision makers. The Program and its member agencies are also expanding their ability to provide global change information, tools, and services the public and private sectors need to make decisions**.**

Goal 3. Sustained Assessments: Build sustained assessment capacity that improves the nation's ability to understand, anticipate, and respond to global change impacts and vulnerabilities. USGCRP will conduct and participate in national and international assessments to evaluate current and likely future scenarios of global change and their impacts, as well as how effectively science is being used to support the country's response to change. It will also build a standing capacity to conduct national assessments and support those at regional levels. Together, Goals 2 and 3 will evaluate progress in responding to change and identify science and stakeholder needs for further progress. The Program will use this regular assessment to inform its priorities.

Goal 4. Communicate and Educate: **Advance communications and education to broaden public understanding of global change, and empower the workforce of the future**. As a trusted provider of accurate information on global change, USGCRP will use its research results to communicate with and educate stakeholders in ways that are relevant to their lives and needs. The Program and its member agencies will adopt, develop, and share best practices in communication that enhance stakeholder engagement. Educational efforts will support development of a scientific and general workforce able to use global change knowledge in their lives and careers. They will also help build global change literacy among the general public.

Unifying Ideas

The four USGCRP goals and objectives provide a framework for an integrated program. For example, the need to understand Earth and human systems and their connections underlies all four goals. Other ideas that connect the plan's goals and objectives include:

Nesting Global and Regional Scales. A unifying idea of this Strategic Plan is to acquire and use scientific knowledge about global change to make planning, management, and policy decisions at national, regional, and local scales. Improvements in global models, and in robust downscaling

from global to regional scale models, are necessary for this step. The Program will coordinate research in regions where the effects of global change will be most acutely felt, for example, agricultural, urban, and coastal areas. Furthermore, the Program will develop additional capacity for modeling Earth's climate system on seasonal, annual, and decadal scales relevant for regional planning. Models will address extremes, thresholds, and tipping points, in addition to gradual changes in the mean.

Developing Science for Adaptation and Mitigation. USGCRP conducts research and related activities that help manage risks and inform decisions on adaptation to, and mitigation of, global change. USGCRP will address critical science gaps in support of adaptation, improve the accessibility of existing science for decision makers, and advance understanding of the process of adaptation itself. In cooperation with other parts of the Federal government, USGCRP contributes to the country's larger sustainability framework.

Incorporating Social and Behavioral Sciences. This Plan highlights the importance of integrating the natural, social, and behavioral sciences, which is critical to understanding how humans drive and respond to global change. For example, contributions from social and behavioral sciences are essential to managing risks, understanding decisions, and formulating policy options in the face of imperfect information. Harnessing the benefit of such integration will require attention to the observational and information management needs in the environmental social sciences. Such attention would focus on opportunities where USGCRP can add value to existing capabilities and, looking longer term, to where new social and behavioral data would need to be collected. This Plan also notes the workforce challenges and opportunities in better incorporating social scientists into the Program.

Supporting Responses to Global Change via Iterative Risk Management. USGCRP has an important role to play in iterative risk management, which refers to an adaptive process of identifying risks and response options to global change, advancing a portfolio of actions that emphasize risk reduction across a range of likely future conditions, and revising responses to reflect new knowledge. In particular, USGCRP will support research and development to provide the knowledge needed to improve response options. As options are selected and implemented, the Program will assess progress being made through the country's response efforts and the science needed to support further progress. Global change reflects the complex interactions of multiple stresses on the Earth system, including climate change; the scientific expertise mobilized by USGRCP will develop the knowledge necessary to prepare and evaluate responses to change, and to evaluate their consequences, both intended and unintended.

Cross-Linking Activities

In addition to ideas that link the goals and objectives of this Plan, there are activities that simultaneously benefit multiple goals. The topics below are discussed under specific objectives in Chapter III, but here we briefly highlight their connectivity across goals.

Enhance Information Management and Sharing. Creating and sharing knowledge, data, and projections of likely future conditions is essential to researchers, resource managers, decision makers, educators, and the general public. The Program will leverage information tools, services, and portals from its member agencies to develop a global change information system, a "one-stop shop" for accessing global change data and information (see **Text Box 8**). Through its

members, the Program will also develop a virtual environment for collaboration between researchers and educators providing enhanced capabilities in areas such as data assimilation, community models, and visualization.

Enable a High Capability for Integrated Observations and Modeling. Integrative modeling and observations are essential approaches for USGCRP. Observations test and improve the ability of models to represent reality. Models integrate knowledge and identify gaps in observations and insight. Together, they provide the scaffolding needed to develop scenarios of likely future conditions and characterize their uncertainties, understand changes over time, and investigate the likely consequences of action (and inaction) in responding to global change. Over the next decade, USGCRP member agencies will work to sustain essential observations, fill critical observational gaps in key regions and disciplines (including biological and societal) and improve data quality where necessary to improve model predictability and reduce uncertainties. USGCRP will also improve the capacity to rigorously model global change on regional scales, reduce model uncertainties, and integrate the social, ecological, and physical aspects of global change.

Box 2. Department of Defense and the Use of Climate Change Science.

USGCRP-produced material was cited in the 2010 Quadrennial Defense Review as a primary source of information on expected climate change that would affect the Department of Defense by shaping its operating environment, roles, and missions and requiring it to consider taking early action to prepare effective responses to these challenges in the near term and in the future. In addition, assessments conducted by the intelligence community indicate that climate change could have significant geopolitical impacts around the world by contributing to poverty, environmental degradation, and the further weakening of fragile governments. Although climate change alone does not cause conflict, it may act as an accelerant of instability or conflict and place a burden to respond on civilian institutions and militaries around the world. The intelligence community also judged that more than 30 U.S. military installations were already facing elevated levels of risk from rising sea levels. Finally, extreme weather events may lead to increased demands for defense support to civil authorities for humanitarian assistance or disaster response both within the United States and overseas.

Figure B2-1. To increase coordination for a more coherent and coordinated picture of the Arctic, the Navy and USCG participate in Arctic Domain Awareness flights that take place every two weeks from mid-spring to mid-fall. The flights collect scientific information on CO2 and methane in the atmosphere, as well as monitor maritime traffic in the U.S. Arctic maritime environment. (Photo taken 23 Sept, 2010 from loading ramp of a USCG C-130 over the Beaufort Sea. Credit CDR B. McBride)

Increase Proactive Engagement and Partnerships. To maximize the benefit of USGCRP, the Program will strengthen its partnerships across multiple levels of government, including engaging a broader cross section within USGCRP agencies and with agencies currently outside of USGCRP where division and agency missions directly depend on Program activities. USGCRP will also build appropriate relationships with private foundations, nongovernmental organizations, and business sectors to inform USGCRP planning, and extend the reach and utility

of its research and services. The Program will establish a framework that successfully engenders effective multi-way dialogue with policy- and decision makers in both public and private sectors.

Leverage International Leadership. In the Global Change Research Act, Congress recognized the importance of international cooperation to global change research and mandated a role for USGCRP. The Program engages in international cooperation because it enhances and complements the strengths, interests, and needs of USGCRP and its partner agencies. The challenges and opportunities that USGCRP faces are global in scope and are larger than what the United States can achieve on its own. International engagement is important in all fields of science, but it is indispensable for the science of USGCRP. Global observing systems are essential to global change research and require international partnerships. Field-based campaigns often require international partnership. USGCRP works with sister interagency entities such as the U.S. Group on Earth Observations and the Interagency Working Group on Digital Data which help set the standards and coordination of earth observation data in a long-term, durable, and usable fashion. U.S. and international efforts together provide the information and capabilities needed by scientists and institutions in developing countries as they respond to global change. More detailed information about coordinating USGCRP global change research activities with other nations and international organizations is provided at the end of Chapter IV.

Support the Workforce for the Future. The military, various business sectors, and all levels of government are increasingly making decisions that take global change into account. In addition, the Nation is developing new strategies for adapting to change or limiting its magnitude and effects. These directions create opportunities for developing new skilled jobs in America, for enhancing workforce diversity, and for increasing literacy about global change. Research to support adaptation strategies, its translation for decision makers, and assessment of its effectiveness are all areas requiring specialized skills and a trained workforce. USGCRP agencies will use their relationships with academia to help promote the interdisciplinary education at undergraduate and graduate levels needed for a professional and technical workforce in areas directly related to global change, and for a general workforce that needs to use such knowledge in areas such as insurance, agriculture, health care, and water management.

The next chapter provides a detailed look at the four goals and their objectives. It outlines key areas of research and new capabilities for over the next decade to support the country's response to global change. Chapter IV discusses USGCRP coordination with other nations and international organizations. Chapter V outlines guidelines the Program will use in implementing these priorities over the next ten years.

III. GOALS AND OBJECTIVES

Goal 1: Advance Science

Advance scientific knowledge of the integrated natural and human components of the Earth system.

Scientific knowledge of the integrated Earth system is the foundation for responding effectively to global change. In the next decade, USGCRP and its member agencies will advance fundamental, use-inspired research (see **Text Box 3**) that contributes to improved understanding and effective decision making. To serve society in meeting present and future challenges, this research program will be built on two principles: improving fundamental scientific understanding of the integrated natural and human components of the Earth system, and focusing on the essential science needs for increasing ecological and societal resilience to global change and reducing vulnerability through well-informed responses.

Text Box 3: Fundamental, Use-Inspired Research.

Climate change research should focus on fundamental, use-inspired research. This report recognizes the need for scientific research to both improve understanding of climate changes and assist in decision making related to climate change. In categorizing these types of scientific research, we found that terms such as "pure," "basic," "applied," and "curiosity driven" have different definitions across communities, are as likely to cause confusion as to advance consensus, and are of limited value in discussing climate change. More compelling, however, is the categorization offered by Stokes (1997), who argues that two questions should be asked of a research topic: Does it contribute to fundamental understanding? Can it be expected to be useful? Research that can answer yes to both of these questions, or "fundamental, use-inspired research," warrants special priority in the realm of climate change research.

National Research Council (2010): *America's Climate Choices: Advancing the Science of Climate Change*

Integration is the key to achieving this goal. This chapter defines a research program for USGCRP that acknowledges the complexity and "end-to-end" nature of the global change challenge (see **Text Box 2**). It will thus be integrative in multiple senses: across the components of the Earth system (including people), across observations and modeling, across space and time, across scientific disciplines, across domestic and international partnerships, and across the capabilities of science and the needs of stakeholders.

USGCRP will accomplish Goal 1 through pursuit of five objectives:

Objective 1.1 (Earth System Understanding): Advance fundamental understanding of the physical, chemical, biological, and human components of the Earth system, and the interactions among and between them, to improve knowledge of the causes and consequences of global change.

Objective 1.2 (Science for Adaptation and Mitigation): Advance understanding of the vulnerability and resilience of integrated human-natural systems and enhance the usability of scientific knowledge in supporting responses to global change.

Objective 1.3 (Integrated Observations): Advance capabilities to observe the physical, chemical, biological, and human components of the Earth system over multiple spatial and temporal scales to gain fundamental scientific understanding and monitor important variations and trends.

Objective 1.4 (Integrated Modeling): Improve and develop advanced models that integrate across the physical, chemical, biological, and human components of the Earth system, including the feedbacks among and between them, to represent more comprehensively and predict more realistically global change processes.

Objective 1.5 (Information Management and Sharing): Advance the capability to collect, store, access, visualize, and share data and information about the integrated Earth system, the vulnerabilities of integrated human-natural systems to global change, and the responses to these vulnerabilities.

Although each of these five objectives are defined distinctly and discussed separately in this chapter, they describe one integrated body of knowledge and practice. The deeper understanding that is the aim of Objectives 1.1 and 1.2 will only be achieved by integrating observations of all essential Earth system components and processes (Objective 1.3). Such integration is essential for developing theories and explanations of the causes and consequences of global change, for monitoring the effectiveness of responses, and then capturing and testing these theoretical advances in integrated modeling systems (Objective 1.4). Success in these first four objectives will build on future advances in information management and data sharing (Objective 1.5).

Objective 1.1: Earth System Understanding

Advance fundamental understanding of the physical, chemical, biological, and human components of the Earth system, and the interactions among and between them, to improve knowledge of the causes and consequences of global change

USGCRP research has been foundational for our understanding of key of aspects global change. Over the past two decades, advances in knowledge of individual components of the Earth system and their interactions and feedbacks have led to a growing appreciation for the complexity and interconnectedness of these components, the significant role that human activities play in global climate change, the importance of land-use and land cover change as both a driver of and co-stressor with climate change, and the current and potential future rate, magnitude, and impacts of further change. Building on this history of success, the Program faces the challenge of developing the knowledge base required to help society respond to global change.

The cornerstone of this knowledge base is the research that will be conducted under the auspices of USGCRP to continue deepening our understanding of individual natural and human Earth system components and processes, and address the many critical research gaps that remain there, while simultaneously promoting greater scientific progress in the following areas:

- The interactions and degree of interconnectedness among and between these natural and human Earth system components and processes and the interplay between climate change and other dimensions of global change;
- The coupling of different spatial and temporal scales;
- The complex behaviors that emerge from these component and scale interactions.

There is a workforce dimension to the exploration of these integrated research questions that will be an important part of the Program's effort over the next decade. As discussed elsewhere in this Plan, the Program, through its integrative activities, will foster the development of researchers comfortable working across disciplines and scales and dealing with Earth system complexity so as to deliver the fundamental and use-inspired science base to support well-informed responses to global change.

Interconnected Components and Processes

The seemingly disparate elements of Earth system science (**see Table 1**) are in reality all connected across multiple dimensions and via multiple pathways. Similarly, global change has multiple linked and nested dimensions, including land-use and land-cover change; modification of the carbon, nitrogen, phosphorous, and sulfur cycles; pollution, loss of biodiversity and ecosystem functions and services; alteration of hydrologic systems; and human population dynamics, including growth, migration, and demographic shifts. To advance scientific understanding of the changing Earth system, USGCRP and its member agencies should consider all of these elements and their interdependencies.

As we move into the next phase of global change research, some of the most important and challenging areas of study will be located at the dynamic interfaces between components and processes—the ways in which one part of the Earth system influences the others. There are critical scientific issues that USGCRP and its member agencies cannot address comprehensively without adopting this systems perspective, such as the interaction between climate change and the other major drivers of global change described above, the impacts of global change on all aspects of biology (molecular and cellular, genetics and genomics, organismal and developmental, and population, community, and ecosystem ecology), and how human behavior at multiple scales, including responses to global change, feeds back to influence the rate and nature of the change. USGCRP will coordinate disciplinary and interdisciplinary research activities to foster integrated research into the links between climate change and land-use change, ecosystem processes, the water cycle, and key biogeochemical cycles, as well as the dynamical interactions among atmosphere, ocean, land, ice, and biosphere.

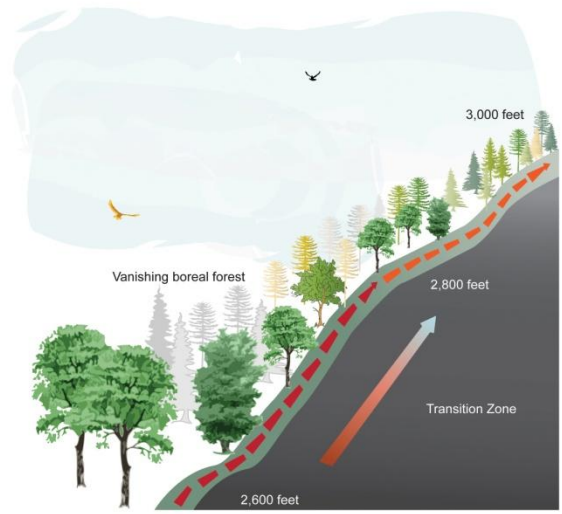
In the next decade, USGCRP will confront the challenge of integrating of the social and behavioral sciences with the physical, chemical, and biological sciences, in large part by fostering enhanced collaboration between natural and social scientists. Meeting this challenge will be difficult given the limited engagement of the social sciences in global change research to date, but it is a crucial step for achieving a deeper understanding of the vulnerabilities and responses to global change. Population dynamics, natural resource consumption, and economic development underlie the human drivers of change, while mitigation and adaptation activities will interact with the Earth system in complex ways.

Table 1. Major components of global change in the Earth system (intended to be illustrative rather than comprehensive). Equally crucial are the interactions among components.

Climate variability and change: • Natural climate variability, including multiple space and time scales, deep-time events. • Aerosols and their radiative effects on the climate system. • Cloud and aerosol processes and cloud-aerosol interactions. • Climate change impacts on ocean-atmosphere modes of variability. • Ocean dynamics and sea-level rise, including regional variability. • Climate-change effects on the hydrologic cycle, especially extreme events (storms, droughts, floods). • Changes in temperature extremes. • Cryospheric dynamics: ice sheets, sea ice, permafrost. • Feedbacks and abrupt change.	**Alteration of ecosystem structure and processes and land-use change:** • Urban systems and the built environment. • Development and urban encroachment. • Sustainability of agricultural ecosystems. • Fisheries dynamics and management strategies. • Tradeoffs between energy and food security. • Ecosystem sensitivity and resiliency. • Genomic resources of terrestrial and aquatic ecosystems. • Biodiversity, ecosystem resilience, and impacts of biological extinctions on ecosystem functions and services. • Economic value of ecosystem goods and services. • Conservation priorities for species and ecosystems. • Species abundance, range change, and invasive species.
Demographic and socioeconomic trends in human society that drive global change: • How human cognitions, structures, and actions interact with global change over spatial, temporal, and organizational scales. • Population growth and migration. • Technological change. • Human consumption and production patterns. • Socio-political changes. • Public understanding of global change, risk perception, and communication of risk.	**Human outcomes and actions in response to global change:** • Vulnerability (exposure, sensitivity, adaptive capacity) of human and natural systems. • Management options that effectively reduce greenhouse gas emissions and/or climate-change impacts. • Human health and vulnerable populations. • Decision making under uncertainty. • Compensatory reactions to mitigation and adaptation. • Assessment of mitigation and adaptation options.
Alteration of biogeochemical cycles: • Ocean acidification. • Carbon, nitrogen, and phosphorous cycles; sources and sinks. • Trace element cycles (e.g., iron, mercury, cadmium). • Changing atmospheric composition. • Nutrient imbalances, biogeochemical cycle interactions, and limitation. • Global resource extraction.	**Alteration of hydrologic systems:** • Groundwater resources, depletion, and pollution • Water supply, quality, and security. • Infrastructure changes (irrigation, water extraction, interbasin transfer, stormwater management, flood control). • Changing recurrence probabilities for extreme events. • Coastal wetlands.

Integrated natural and social science is also central to achieving the other goals of the Program. The cognitive and social basis for decision making governs societal responses to global change, and these actions occur within, and are constrained by, institutions, social networks, and economic and political contexts. These institutions, social networks, and contexts, in turn, interact with public understanding of science and risk perception and communication. Simultaneously, advances in technology have the power to transform public engagement with science and harness public participation in research. All of these issues will emerge as crucial for USGCRP over the next 10 years and necessitate a coordinated response from the Program and its member agencies. The Program will meet this challenge in part by seeking innovative approaches for fostering enhanced collaboration between natural and social scientists.

Box 3. Species' Ranges Shift in Response to Global Change.



Beckage *et al.*260/Schematic adapted from J. Abundis

As climate warms, hardwood trees out-compete evergreen trees that are adapted to colder conditions.

Figure B3-1: Global change is also resulting in major changes in the types of forests that will be most prevalent in different regions of the United States. Some common forests types are expected to expand, such as oak-hickory, while others, like maple-beech-birch, are expected to contract, or eventually even disappear from the United States altogether, like spruce-fir. A number of industries, such as the maple sugar and tourism sectors in the Northeast, would be strongly impacted by these shifts.

When the outside temperature gets too cold or too hot, humans can add or shed clothing, insulate their houses, and change thermostat settings. Other species do not have those options. Many plant and animal species have shifted their habitats poleward and upward in elevation in response to recent climate changes. A major concern with such changes in geographic range is that species may no longer be located with the resources essential to flourish and to provide an ecosystem service. For example, particular species of birds and butterflies needed for agricultural pollination in a particular region might no longer be around. In addition, as the ranges of species that carry human diseases change, disease risks to humans may shift and increase as well.

As global change drives changes in species' ranges, entire ecosystems will not remain intact. Each species will shift according to its sensitivity to climate change, its mobility, its lifespan, and the availability of essential resources. It will also depend on whether its migratory pathways are blocked by development and habitat fragmentation. In general, many existing ecosystems will be broken up and new ones formed, with uncertain consequences.

USGCRP research is addressing the need for improved understanding of the rates and consequences of shifts in species' ranges through new, more comprehensive on-the-ground observations. By bringing together multiple data sources of species occurrence (collected by scientists, local and national governments, and citizen scientists), and incorporating this data into models of ecosystem and climate functioning, we can help predict important shifts for agriculture and forestry, assist in the strengthening of protected areas, and more ably respond to outbreaks of invasive alien species.

Multiple Spatial and Temporal Scales

While global change can mean change at the scale of the entire Earth system, it can also mean the collection of local changes happening in many places around the world. In aggregate, these local changes can have global consequences. However, on the local level, the impacts of long-term global change will often be indirect, felt through complex interactions with extreme events as well as through the natural modes of interannual and interdecadal climatological variability (see **Text Box 4**).

USGCRP and its member agencies, in collaboration with its international partners, will foster greater scientific progress on fundamental science questions related to the effects of Earth system processes and behaviors at one scale on those at another, the potential for processes in one place to affect other regions around the world, and the implications of these scale interactions for our understanding of, and responses to, global change.

Text Box 4: Natural Climate Variations and Long-Term Climate Change.

Earth's climate varies naturally on time scales of a year, to a decade or more, as a result of complex interactions between the atmosphere and the ocean. The best-known example is the El Niño-Southern Oscillation, which causes significant year-to-year variations in temperature and rainfall in many different regions around the world, notably the western United States. Other similar phenomena, such as the Pacific Decadal Oscillation, the Northern and Southern Annular Modes, the North Atlantic Oscillation, and the Atlantic Multidecadal Oscillation, have similarly important regional impacts on agriculture, fisheries, transportation, and energy supply and demand. For example, the exceptionally cold temperatures and heavy snowfall in the U.S. Northeast during winter 2009–2010 (while, across the continent, the winter Olympics in Vancouver was simultaneously experiencing a snow shortage) were in part due to a strong North Atlantic Oscillation. Understanding how these natural oscillations control year-to-year and decade-to-decade variations in regional climate worldwide, and how they may change in the future as a result of climate change, is important for informing adaptation planning in agriculture, water resources, disaster management, and many other sectors.

Addressing this challenge calls for a focus on finer spatial and temporal resolution to link, for example, climate system processes with the dynamics of ecosystems and human communities. It will also take integrating the aggregate effects of small-scale, short-term processes and behaviors (both human and natural) into our understanding of the global system. And it will entail a focus, not just on long-term averages, but on the effects of global change on extremes and patterns of variability which have important impacts on society.

Complexity and Emergent Behavior

Understanding global change is difficult because the Earth system is complex, with behavior that emerges as a result of many interactions on multiple scales among the atmosphere, ocean, ice sheets, the land surface, and all life on the planet. People add to this complexity because they are a part of the Earth system, yet play a unique role in it. They not only influence, and are influenced by, Earth system changes, but they can consciously choose how to respond to these changes while considering and observing the implications of their response.

The multiplicity of interconnections among different Earth system components, and among processes occurring at different scales, can lead to changes that are difficult to observe, measure, monitor, or model as they are starting to occur. Thus, anticipating these changes and responding effectively are more challenging. Some system-wide changes can appear relatively slowly, on pace with changes in interacting components, such as land-use change associated with population growth. Some, however, can emerge abruptly, without prior warning. Such behavior results when conditions exceed a critical threshold in environmental stability—a tipping point—thereby leading to a major alteration of the system in a short period of time.

There is clear evidence that Earth's climate is capable of very rapid change, with cascading effects through natural systems documented in the records of ancient ice cores, tree rings, and lake and ocean sediments.[2] Over the past hundreds of thousands of years, Earth has repeatedly flipped between deep periods of glaciation and relatively ice-free states, with transitions sometimes occurring over periods as short as a decade. Even over the last 10,000 years of ice sheet stability, severe droughts and other regional climate events have occurred frequently, driven by oscillations in the atmosphere-ocean system, some characterized by abrupt onset and sustained duration, and often with deleterious effects on human settlements and civilizations.

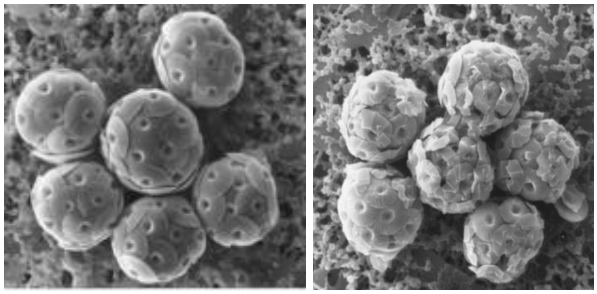
What makes the global changes happening in the 21st century uniquely significant are both their rapidity and potential magnitude on a planet now populated by billions of people. Research on the properties of complex systems suggests that large, abrupt change in the Earth system will become increasingly likely with increasing disturbance. We may approach new and as yet unidentified tipping points in Earth's biological systems, in the biogeochemical cycles that help regulate the concentrations of greenhouse gases in the atmosphere, in ocean circulation patterns, and in ice sheet stability. Such changes could occur so rapidly that they would challenge the ability of human and natural systems to adapt.[3] Our current scientific understanding must be improved significantly before these risks can be meaningfully assessed so as to support decision making about appropriate responses, as will be discussed below under Objective 1.2.

In response to this need, USGCRP will place a high priority on research into the rates, processes, mechanisms, and consequences of a changing Earth and the complex, nonlinear climate, ecological, and social system dynamics leading to abrupt changes, thresholds, and tipping points. Understanding of past changes gained from studying the paleoclimatic record, and integration of paleoclimate proxies with Earth system modeling efforts, will play an important role in this research. Simultaneously, the Program will foster advances in understanding of potential unintended consequences of actions taken in response to change, such as adaptation and mitigation efforts. A focus on these issues will be essential for managing the risks of global change and developing well-informed responses.

Box 4. Ocean Acidification.

Food from the ocean is the primary source of protein for more than a billion people worldwide. Many jobs and economies in the United States and around the world depend on sustaining healthy fisheries. This task, already difficult in a world with a rapidly growing population, is made more complicated because of changes to the ocean resulting from fossil fuel combustion and the release of large additional amounts of carbon dioxide into the atmosphere. The ocean absorbs a large fraction of this excess carbon dioxide, gradually increasing the acidity of its waters. If carbon dioxide emissions continue to grow at the present rate, it is estimated that by the end of this century, the ocean's surface waters will be about 150% more acidic than they were at the beginning of the Industrial Revolution in the mid-1800s. The magnitude of ocean acidification was recognized only recently, and its consequences are poorly known. Scientists estimate that this ocean acidity level would be the highest in more than 20 million years.

This increased acidity is affecting marine species to varying degrees. Currently, ocean acidification is affecting the growth and lifespan of carbonate shell-forming organisms such as many plankton, mollusks, crustaceans, and urchins. In addition, ocean acidification can affect these organisms in other ways, including shifting species distributions, reducing biodiversity, and increasing susceptibility to other stressors. Because these organisms form the base of the ocean's food web, these changes may negatively impact fisheries worldwide.



USGCRP and its member agencies are developing and deploying new ways to monitor ocean acidification, using both space-based and in-place approaches. They are also supporting new research programs to understand the effects of ocean acidification -for example, on key organisms in the marine food web and the ecosystems they support, its effect on coral reefs, and the extent to which species can acclimate and adapt to ocean acidification.

Figure B4.1. The coccolithophore Calcidiscus leptoporus grown under pCO_2 levels representing present (380 ppm, left) and future (780 ppm, right) conditions. Photo credit: Ulf Riebesell, IFM-GEOMAR.

Objective 1.2: Science for Adaptation and Mitigation

Advance understanding of the vulnerability and resilience of integrated human-natural systems and enhance the usability of scientific knowledge in supporting responses to global change

The strategy for advancing USGCRP science in the next decade has a dual aim. The first, as discussed under Objective 1.1, is to achieve a deeper, more fundamental understanding of the integrated Earth system—its physical, chemical, biological, and human components and the richness of behaviors that result from their interaction. The second, discussed in this objective, is to advance use-inspired science to assess vulnerabilities to global change, understand the societal and ecological characteristics that confer resilience in the face of these changes, and, in responding to change, make progress toward sustainability. In this context, "use-inspired" refers to science that is driven by a need to improve fundamental understanding in areas important to people and society. The knowledge and insights emerging from this use-inspired research should then be applied toward the evaluation of options to reduce the risks of global change. To accomplish this objective, the Program will leverage and support the varied capabilities and missions of its Federal agency members, as well as engage more deeply with other communities well versed in vulnerability and risk management, leveraging expertise from disaster management, public health, and national defense.

This objective, of advancing the science essential to understand and manage the risks of global change, is embedded within the broader concept of sustainability, which considers how to meet society's current needs without compromising those of future generations and the Earth's essential life support systems. USGCRP research relates to sustainability in two specific ways: first, because of the significant overlap between the knowledge base and practices of sustainable environmental and natural resource management and the knowledge base and practices expected to be useful for adaptation and mitigation; second, because of the potential for sustainability co-benefits of well-chosen adaptation and mitigation strategies.

The concept of vulnerability, referring to *the degree to which a system is susceptible to, and unable to cope with, adverse impacts of global change*, along with its sub-concepts of exposure, sensitivity, and adaptive capacity, provides a major thread linking science, society, and decision making about responses to global change.[4] It helps focus scientific research around key societal concerns and provides a framework for identifying the sectors, regions, resources, and populations that are most at risk from the impacts of global change. As such, it helps provide the foundation for strategically prioritizing basic research foci to address these concerns and respond to these risks.

Systematically identifying and characterizing the most urgent vulnerabilities and the biggest risks we face from global change, so as to respond effectively and sustainably, is a grand societal challenge. Scientific discovery and societal concern have complementary roles: science identifies emerging problems (e.g., the ozone hole or human-caused climate change), analyzes the feasibility of response options and proposes new options, and monitors to track progress; society communicates its requirements and the values that guide where and how urgently to respond and the preferred set of responses; both evolve together in a collaborative dialogue.

In the next decade, USGCRP and its member agencies will embody this multiway dialogue, in part by providing the scientific foundation for integrated vulnerability assessments

in the areas of greatest societal need. These activities will harness emerging understanding of global change, as guided by the strategic priorities of the decision makers and stakeholders the Program will engage with through new decision support and public outreach efforts.

Box 5. Sea Level Rise and Coastal Vulnerability.

Sea level rise directly affects the millions of people worldwide that live in coastal regions. In addition to flooding homes, sea level rise can increase coastal erosion, degrade wetlands, and make surface and ground waters salty and unusable as drinking water. We know from scientific measurements that sea level has been rising steadily over the past few decades (see Figure B5.2.). This rise is due primarily to expansion of the ocean as it warms and melting of land ice (glaciers and ice sheets), with each of these factors making a roughly equal contribution to the current rate of sea level rise. As global temperatures continue to increase, scientists expect that melting of the Greenland and Antarctic ice sheets—which hold an additional 64 meters (210 feet) of sea level—will accelerate, becoming the largest contributor to sea level rise.

Figure B5.1. Low bay sides of barrier islands are vulnerable to even a modest storm surge. Rising sea levels are projected to increase the frequency and severity of damaging storm surges and flooding. Ship Bottom, New Jersey. Photo credit: Jim Titus.

Protecting vulnerable coastal communities from sea level rise in the years ahead calls for a better understanding of the processes that influence sea level. This information can then be used to improve models that project the rates and patterns of sea level rise under a range of global change scenarios. The measured rate of global sea level rise over the past 20 years has been higher than that simulated by the models used in the last Intergovernmental Panel on Climate Change assessment, primarily because the current generation of models are unable to fully capture the processes that determine the melting of the Greenland and Antarctic ice sheets.

Over the next decade, USGCRP and its member agencies will help advance the models scientists and planners use to project future sea level rise and coordinate research efforts to improve scientific understanding of natural fluctuations in sea level and the mechanisms and rates by which ice sheets melt. The Program will also focus on linking improved scientific understanding and modeling capability with a greater understanding of additional influential factors, including the social, economic, and ecosystem dynamics of coastal areas to better support decision making about adapting to the consequences of rising sea levels.

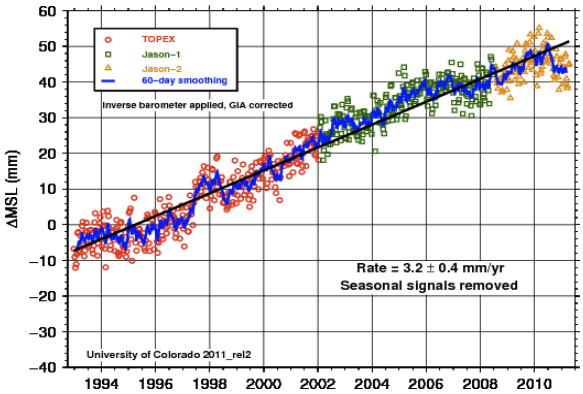


Figure B5.2: Global mean sea level time series: Documentation of this global change trend has been possible through a sustained commitment within USGCRP to maintaining strong satellite observing systems and through robust partnerships among USGCRP member agencies and international partners. (http://sealevel.colorado.edu/content/2011rel2-global-mean-sea-level-time-series-seasonal-signals-removed).

Understanding Vulnerability to Global Change

USGCRP and its member agencies will create a knowledge base and evaluation capability for identifying critical global change vulnerabilities across a continuum of scales: from global, long-term threats to the stability of the whole Earth system to regional, near-term threats to particular ecosystems, human communities and populations, and socioeconomic sectors. Understanding the magnitude and rate of change, the entities impacted, and how their responses to change feed back into the Earth system, are vital research requisites that span this continuum.

The interdependence of Earth system components and processes, as described above under Objective 1.1, dictates that such evaluation and assessment will be most effective when they focus on the larger system within which a particular ecosystem, human community, or socioeconomic sector is embedded, rather than on a single system in isolation. In this context, assessment of coupled human-environment systems, such as urban and agricultural systems, will be a major focus in the next decade. For example, water supply systems use large amounts of energy (e.g., for treatment and delivery), while, simultaneously, energy systems use large amounts of water (e.g., for hydropower and cooling). Both are expected to be under pressure from increasing demand in the future. At the same time, both will be affected by global change, including a changing climate. Changes in energy policy and production undertaken to mitigate human-caused climate change may have significant consequences for water availability and quality. Therefore, understanding of coupled human-environment systems, such as urban, agricultural, and coastal systems, as well as exploration of the interconnections and competition among water resources, food, energy, land-use change, and biodiversity under a changing climate, will be a major focus for USGCRP in the next decade.

Another key research theme for USGCRP will be the identification of differences in vulnerability across space and time. For example, global change impacts are, and will continue to be, distributed unevenly across nations, communities, households, and individuals, creating differing levels of vulnerability, with important implications for adaptation and mitigation. Similarly, as with human systems, the impacts of global change on natural systems are distributed unevenly across species, habitats, and ecosystems, with certain systems (e.g., coral reefs, wetlands, and high-latitude and high-altitude habitats) being particularly vulnerable. USGCRP and its member agencies will foster advances in research on the ecological dimensions of global change, as well as the interactions of this change with societal impacts. A key element of this focus will be the exploration of the implications of global change for biodiversity, as biodiversity is a crucial foundation for societal necessities such as food, fiber, and pharmaceuticals, as well as services such as clean air, freshwater, and waste disposal.

Managing the Risks of Global Change

The ultimate purpose of identifying and characterizing vulnerabilities is to develop and assess options to reduce and manage risk. Building from basic scientific understanding of global change and the associated vulnerabilities to key societal areas, it is possible to identify a research agenda for the two major and interlinked categories of global change responses: adaptation and mitigation. In the next decade, USGCRP and its member agencies will advance the development of actionable knowledge to support decision making about effective adaptation and mitigation responses.

Box 6. Food Security, Energy Security, and Climate Change.

Food, energy, and water are closely interconnected and their production both influences and is influenced by global change. Changing climatic conditions, including more frequent storms and droughts, stress food production systems. Moreover, as more energy is being used to produce food, more of our agricultural production is being used to produce energy in the form of biofuels. While enhancing energy security and climate mitigation, biofuels from corn and soybeans compete directly with food crops. USDA predicts that in 2011, more corn will go to ethanol than to animal feed for the first time ever[5]. The large-scale increase in biofuel feedstocks can also compete with forests, natural grasslands, and private conservation lands with implications for the many ecosystem services they provide and for net greenhouse gas emissions. These systems and others that produce biofuels ought to be balanced against the energy savings and potential greenhouse gas reductions of biofuels, as well as against the food demands of a growing population.

Figure B6.1 (top) Industrial Biorefinery in York County, Nebraska. Photo credit: DOE. (bottom) Crop irrigation. Photo credit: USDA ARS.

Greenhouse gas emissions are only one part of the complex interactions between food, energy, and climate. As climate changes challenge our ability to grow crops for food and energy, more irrigation and water management will be warranted. As precipitation patterns shift, available water for irrigating crops will decrease at the same time as there is greater demand for both growing and processing biofuel crops; more irrigation uses more energy, which results in more greenhouse gas emissions. Greater water demands for food and energy production also competes with changing demands for this precious resource for domestic and industrial applications due to economic development and changing demographics. The effects of changing land use patterns on local weather patterns and net emissions of greenhouse gases further complicates increased water demands. The link among food, energy, water, and climate change is one key example of the increasingly complex web within which physical, biological, economic, and social systems are embedded in our rapidly developing and globalizing world.

Society needs to manage tradeoffs among food, energy, and water demands in a changing climate while minimizing risks and unintended consequences of related decisions. To do so, the country needs a deeper understanding of the ways in which use and production of these critical resources are interdependent and how these interdependencies are affected by global change. Decisions that need to be made by farmers and land managers as well as national and international policy makers will benefit greatly from a synthesis of inputs from economists, social scientists, natural scientists and modelers. Decision making will also call for improved understanding of decision processes behind resource management and the potential role of improved scientific information in that process. USGCRP can address decision-making needs through the coordination of social and natural sciences research across its member agencies. One example is interdisciplinary research into the environmental footprints of existing and proposed biofuels that can inform smarter decision making about fuel choices. Aided by USGCRP support of integrated observational systems, researchers and decision makers will be able to simultaneously track food, energy, and water production and use, as well as climatic shifts and variability. Increasingly complex data input will provide the foundation for informed decision making that strives to maximize the benefits and minimize the regrets of the choices we make about our food, energy, and water resources in the face of global change.

In this context, the Program will foster new research on methods for assessing the adaptive capacity of ecosystems, places, human communities, and socioeconomic sectors in the face of change, with an emphasis on local-to-regional scales and particularly in the context of the interaction of climate change with the many other important global change stressors. Social and economic factors (e.g., economic status, age, gender, and health) can significantly affect people's exposure to global change impacts, how sensitively they respond, and their capacity for adaptation. Understanding these factors is also fundamental for addressing the equity issues associated with national and international mitigation policies. USGCRP and its member agencies will facilitate advances in social, behavioral, and economic sciences to improve understanding of

this differential adaptive capacity and to learn about the characteristics of resilient populations and communities. In addition, USGCRP and its member agencies will foster research to develop metrics, indicators, and frameworks to enable the transfer of knowledge about effective adaptation responses across sectors and regions.

Similarly, ecosystems that are degraded by overharvesting, habitat destruction, pollution, and other stressors may have less resilience in the face of global climate change and thus necessitate more aggressive conservation efforts. The desired level of societal adaptation will depend, in part, on the impacts of aggregate global change on biodiversity and ecosystem services, such as clean water, flood protection, and food production. However, in many cases, ecologists require significantly improved understanding of the detailed processes that lead from individual species to ecosystem functioning as a prerequisite for helping environmental and natural resource managers design and implement effective strategies for preserving and promoting natural ecological resilience to global change. The Program will therefore coordinate research to understand the resilience and adaptive capacity of ecosystems, with corresponding implications for people and societal choices about global change responses.

USGCRP and its member agencies will also enhance existing research, and foster new research, to support development of effective greenhouse gas mitigation strategies. This research will be aimed at improving understanding of carbon storage in the Earth system, the human actions that lead to greenhouse gas emissions changes, and the risks of extreme consequences of greenhouse gas-induced global climate and carbon cycle change.

For example, the Program will promote new forest, soil, agricultural, and ecosystem research that is fundamental to understanding carbon stocks, sequestration, and natural greenhouse gas fluxes. This research will include improving mechanistic understanding of how species interactions lead to healthy, functioning ecosystems, in recognition of the crucial role of restoration ecology in enhancing mitigation that is just becoming clear from new observational and technological advances. Other priorities include new research on ocean chemistry and circulation and their influence on oceanic uptake of carbon dioxide, as well as progress in understanding the role of radiatively active gaseous and aerosol species with shorter atmospheric lifetimes compared to most of the major greenhouse gases, because management and production of these species have the potential to complement or confound mitigation responses.

Making progress in the natural sciences needed to support mitigation efforts requires the Program to foster advances in the social, behavioral, and economic sciences. These advances will improve understanding of human actions, including choices about energy usage and technological change that lead to changes in emissions, and hence atmospheric composition, as well as the costs and benefits of addressing those changes. Improving understanding of the many interactions between climate and energy (such as the interaction between renewable energy technologies and production, water usage, and climate-related impacts on water availability, among many other examples) will be a particularly important element of this research and a key dimension of exploring the interactions and tradeoff between mitigation and adaptation. In coordinating this research, USGCRP will leverage its partnership with the interagency Climate Change Technology Program (CCTP). The purpose of CCTP is to accelerate development, reduce the cost, and promote the deployment of new and advanced technologies and best practices that could avoid, reduce, capture, or store greenhouse gas emissions. USGCRP will need to be informed by CCTP as new technologies are developed and implemented that affect

future emissions trajectories. Similarly, USGCRP will need to inform CCTP regarding the potential global change impacts of the implementation of these new technologies.

Furthermore, USGCRP and its member agencies will promote new research on catastrophic consequences of rapid global change, such as extreme global warming, collapse of major ice sheets, massive biodiversity losses, global natural resource collapse, or the loss of major infrastructure such as dams, seawalls, and transportation systems. To inform adaptation and mitigation efforts requires improved understanding of the potential for crossing thresholds and tipping points in physical, ecological, and social systems. . Improved understanding in these areas will also be crucial for informing research into assessing the feasibility, effectiveness, and unintended consequences of strategies for deliberate, large-scale manipulations of Earth's environment, including solar radiation management and post-emission carbon management, to offset the harmful consequences of greenhouse gas-induced climate change (often referred to as "geoengineering").

Across all categories of global change response strategies, advances in methods for estimating the damages associated with regional and sectoral impacts are required for informed analyses of the benefits of adaptation and mitigation efforts. The development of a new generation of environmental management tools and approaches will be a key frontier in supporting progress toward responding effectively to global change. Because of the long time horizons, varied levels of scientific uncertainties regarding how human-caused change will impact human and natural systems, and highly distributed impacts across systems and sectors (including those difficult to value economically), global change poses unique challenges for the foundational tools and approaches of environmental management, such as risk assessment and cost-benefit analysis. USGCRP and its member agencies will place a high priority on exploring new frameworks for assessing risks and benefits that account for these challenges and allow policy makers to make decisions based on a comprehensive understanding of the impacts, co-benefits, and potential unintended consequences of adaptation and mitigation options.

Similarly, another broad challenge for USGCRP in supporting global change responses and risk management in the coming decade is to help define best practices for transferring new scientific knowledge into actionable information that can be used for adaptation and mitigation decision making. As will be discussed in greater detail elsewhere in the Plan, a large literature about how decisions are made, and how innovations and new concepts are diffused, makes clear that scientific knowledge is only one part of a much broader process. Information may be scientifically relevant without being decision relevant.

To maximize relevance for adaptation and mitigation decision making, USGCRP and its member agencies will foster science that is coherent and meaningful within specific decision contexts, integrates across all relevant disciplines, and engages as participants all relevant stakeholders. Research that incorporates these considerations will be particularly important in the following areas:

- Developing models and tools to assess the environmental, social, and economic outcomes of alternative adaptation and mitigation options;
- Developing scenarios of possible changes and impacts and identification of the social and ecological thresholds that help define limits to adaptation and the options for mitigation;

- Developing improved methods for identifying, projecting, and managing for extremes and low-probability, high-impact events;
- Characterizing and managing uncertainties that will remain large for the many decisions necessary to respond to human-driven global change, particularly at the local scale (as they are for most of the important policy decisions faced by society).

Box 7. Science for Water Resource Decision Making and Management.

With the likelihood of drier, warmer seasons and increased droughts in the future as a result of climate change, society is faced with the challenge of continuing to supply fresh, clean water to growing populations. The ability to supply water is a particular concern in the U.S. Southwest, where the population has nearly doubled over the past 30 years. Eight USGCRP member agencies are part of a Federal consortium that supports the National Integrated Drought Information System (NIDIS). NIDIS operates a Drought Early Warning System for the Upper Colorado River Basin and Four Corners Tribal Lands. Created via the NIDIS Act of 2006 in response to the need for long-term drought planning and a call from the Western Governors Association, NIDIS provides the best available information to enable users to determine risks associated with drought and provides supporting data and tools to inform drought mitigation. Programs such as NIDIS are crucial input to decision makers who manage scarce natural resources, particularly in the face of the large uncertainties about the pace and magnitude of future climate change.

USGRCP provides scientific underpinnings for NIDIS, including new observing and modeling capabilities and products. The Strategic Plan emphasizes the role of USGCRP in better understanding the interactions between changes in climate and changing patterns in regional precipitation, runoff, and drought. In addition, USGCRP agencies will help improve drought predictions over seasons, and even years ahead of time, by developing and using new modeling capabilities and better observations. These capabilities will improve information systems like NIDIS, which will in turn lead to better adaptation approaches for infrastructure planning, ensuring food and water supplies, and fostering stewardship of natural and managed ecosystems.

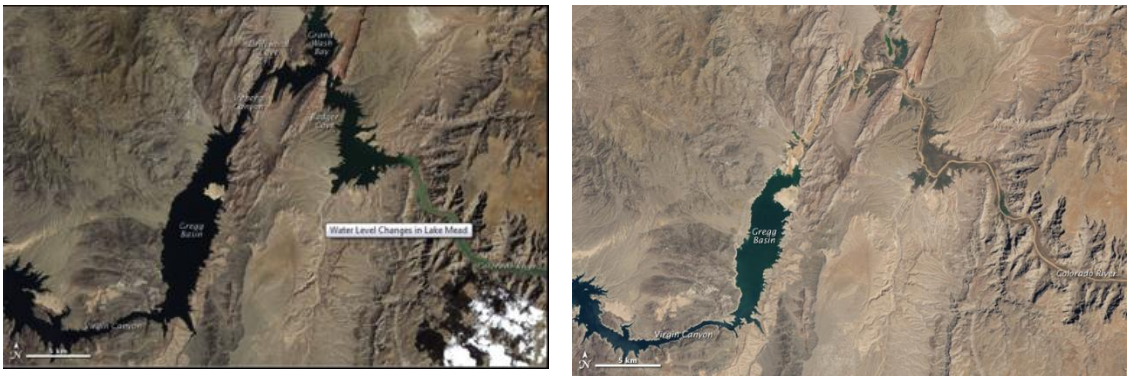


Figure B7.1. The eastern end of Lake Mead, August 1985 (left). In August 2010 (right), Lake Mead reached its lowest level since 1956, strained by persistent drought and increasing human demand. Lake Mead is the largest reservoir in the United States. Photo credit: NASA.

The Program will embed these and related considerations in its research design and delivery of global change assessments and services to inform decision making about responding to global change. In addition, as the number and scope of adaptation and mitigation decisions grows over time, the Program will seize the opportunity to sponsor vital social sciences research into evaluating the uptake of USGCRP research into these decisions and its effectiveness in informing good outcomes.

Objective 1.3: Integrated Observations

Advance capabilities to observe the physical, chemical, biological, and human components of the Earth system over multiple spatial and temporal scales to gain fundamental scientific understanding and monitor important variations and trends

All of the research proposed for USGCRP in the next decade depends on a comprehensive, coordinated, continuous, and sustained set of physical, chemical, biological, and societal observations of global change and its impacts.

Observing global change in the Earth system is an inherently integrative activity. Effective observation of the Earth system and its changes requires remotely sensed and in situ (in place) observations from all domains—atmosphere, ocean, cryosphere, land—that are then transformed into products and information through analysis and integration in both time and space. For most measurements, no single approach can provide all the needed observations of a given quantity, requiring coordination across platforms and instruments. In addition, such observations should integrate over time and space: they should be sustained in a well-calibrated state for decades (over multiple generations of observing systems) to separate long-term trends from short-term variability, and cover key geographic regions to account for variability across scales.

The National Climate Program Act of 1978, the Clean Air Amendments Act of 1990, and the Global Change Research Act of 1990 collectively established systematic and process-oriented observations of Earth's atmosphere, land, ocean, freshwater, and ecosystems. The current observational portfolio upon which USGCRP relies includes satellite, airborne, ground-based, and ocean-based missions, platforms, and networks that provide measurements of the Earth system variables important for monitoring global change. Revealing the characteristics and behaviors of Earth's component systems and establishing the existence of significant global changes is an outstanding success of the USGCRP. This success has been possible through collaboration and coordination among USGCRP agencies to harness their unique capabilities for in situ and remote-sensing observation and monitoring and to sustain these efforts (see **Text Box 6**). The Program will continue to explore and develop opportunities for partnerships that maximize the effectiveness and value of observing and monitoring systems to scientists, managers, and policy makers.

To achieve its goals in the next decade, USGCRP and its member agencies will build on these observational capabilities and achievements to:

- Sustain and strengthen the capacity to observe long-term changes in the global Earth system and improve fundamental understanding of the complex causes and consequences of global change;
- Assess the vulnerability of ecosystems and human systems to global change and inform national adaptation and mitigation efforts;
- Integrate observations and modeling to advance both scientific understanding and decision support.

In addition, USGCRP agencies have an important role to play in improving observational data access, sharing, harmonization, and credibility, as will be discussed in greater detail below under Objective 1.5.

Sustaining and Integrating Earth System Observational Capacity

As discussed above under Objective 1.1, the complexity of the global integrated Earth system is due, in large part, to the interconnections between its components and processes. Similarly, it is due to interactions across an extremely broad range of space and time scales. Understanding this complexity requires simultaneous recording of diverse observations, maintained over long time periods. USGCRP and its international partners have made remarkable progress in this area. In the next decade, USGCRP will sustain and further strengthen satellite and in-situ Earth system observations to document long-term Earth system changes, as well as advance the integration of observational networks and systems to improve understanding of the linkages across components, processes, and scales that create the complex behaviors of global change.

Continued investments in current networks are essential for this capacity and for achieving the necessary understanding of the Earth system and global change. These networks measure the Earth's radiation budget, temperature, concentration of greenhouse gases, leaf area index, land cover, albedo, precipitation, winds, and sea level. Sustaining, enhancing, prioritizing, and extending these observations over the long term will be important for tracking and assessing decadal-scale changes. Some observation systems are at risk because they require substantial investments that cannot be made incrementally. In addition, there are a number of measurements for which there are significant geographic or temporal gaps, such as ground-based snow cover measurements, especially in mountainous areas, and terrestrial observations of ice caps, ice sheets, glaciers, and permafrost. Budget constraints and aging equipment, with their combined deleterious effect on data quality, reinforce the need for the agencies to continue working collaboratively through USGCRP to leverage resources and set priorities.

For many of these observations, integration of in-situ and satellite measurements is crucial for calibration, validation, broader spatial coverage, and greater temporal resolution. One example for which these synergies are particularly important is greenhouse gases. Although we know that greenhouse gas concentrations are increasing in the atmosphere as a whole, we cannot yet reliably measure from space rapid fluctuations in their concentrations near the Earth's surface, leaving important gaps in our knowledge of the exchange of greenhouse gases among and between the atmosphere, the ocean, and terrestrial biosphere.

USGCRP will coordinate the many opportunities for leveraging existing platforms and resources to maintain the observational knowledge base and address these types of gaps. For example, there are a number of measurements for which better calibration of operational sensors, or the mounting of new sensors on existing platforms, can reduce the reliance on separate research sensors. These are important ways of enhancing data accuracy in high priority areas in the near term. In addition, there are many examples in which small initial investments can lead to major gains and lower life-cycle costs.

Box 8. The Carbon Cycle.

The primary cause of climate change is increasing greenhouse gases in the atmosphere, mainly carbon dioxide and methane. This increase is due to disruption of the carbon cycle whereby carbon is continually cycled throughout the Earth system. The ocean absorbs carbon dioxide, and land, freshwater, and marine biosphere take it up in their growth. This carbon is transformed and stored, and eventually released back to the atmosphere. The balance of this cycle is now being upset by fossil fuel use and land use change such as deforestation, both of which release previously stored carbon in the form of greenhouse gases such as carbon dioxide and methane. Rising atmosphere and ocean temperatures may lead to additional rapid inputs of carbon dioxide and methane, through thawing permafrost and release of methane from the seafloor. The ocean and biosphere take up some of this extra carbon, but most will remain in the atmosphere unless we find ways to remove and store it. Thus, the carbon cycle is central to three major global change issues: (1) impacts of climate on the carbon cycle that could accelerate increases in atmospheric greenhouse gas concentrations (independent of human emissions), (2) actions society will undertake that will affect amounts of greenhouse gases in the atmosphere, and (3) direct effects of carbon dioxide increases (independent of climate change), such as ocean acidification (see **Box 4**).

*Figure B8.1. Two major emissions sources: fossil fuel burning and land use change. (top) A coal-fired power plant in Germany. Photo credit: Bruno & Lígia Rodrigues. (bottom) A cleared forest in Brazil. Photo credit: Compton Tucker***.**

Understanding the many interacting elements of the carbon cycle is critical to decision making about policy and management strategies to control emissions from cars and power plants, reverse deforestation, and capture and store carbon that would otherwise build up in the atmosphere. In the next decade, USGCRP will foster the comprehensive research needed to gain this understanding of the changing carbon cycle. It will do so by coordinating measurements, models, and analysis of the principal interacting land, atmosphere, ocean, and human carbon cycle processes, building on existing national and international efforts such as the North American Carbon Program, the Ocean Carbon and Biogeochemistry Program, and the Global Carbon, as well as assessment products such as the First State of the Carbon Cycle Report. One of the key challenges USGCRP will tackle in the next decade is to more fully incorporate and integrate social science and economics with ongoing Earth system observations and modeling. The overall carbon cycle effort, engaging researchers and policy makers from Federal agencies, universities, and numerous international partners, will provide one of the most critical pieces of the knowledge base needed for informed decision making and action in the face of global change.

Furthermore, progress on global change science and response suffers from a lack of adequate time-series observations of variables never before measured, particularly for key ecological and socioeconomic variables. USGCRP will provide global leadership for developing these new observational capabilities, in addition to the global leadership it will provide for sustaining ongoing time series and addressing important coverage gaps.

USGCRP will coordinate with international programs to leverage investments and work toward a comprehensive international global climate observing system, as well as maintain effective partnerships with the other U.S. Federal interagency programs with responsibility for coordinating related aspects of science, technology, and the environment (see **Text Box 5**). Similarly, USGCRP will coordinate with complementary efforts of U.S. state government agencies, such as state weather station and soil moisture networks participating in the National Integrated Drought Information System, engage nongovernmental organizations and the private

sector in the design, deployment, and use of observations, and promote declassification of Earth observations for integration into the national civilian database.

Text Box 5: U.S. Group on Earth Observations (USGEO – http://usgeo.gov/

In 2005, USGEO was established under the White House Office of Science and Technology Policy's Committee on Environment and Natural Resources. USGEO is a sister subcommittee to USGCRP and coordinates Federal management of Earth observation and facilitates open and improved access for all of the programs of the U.S. government. It is chaired by representatives from the Smithsonian Institution and the National Oceanic and Atmospheric Administration.

Through USGEO, the United States further supports cooperative, international efforts to build the Global Earth Observation System of Systems (GEOSS). GEOSS is being developed through the intergovernmental Group on Earth Observations (GEO), a partnership of 80 countries, the European Commission, and nearly 60 international organizations.

Integrated Observations to Assess Vulnerabilities and Monitor Effectiveness of Responses to Global Change

This Plan highlights the importance of biological and social sciences research for understanding global change causes, vulnerabilities, impacts, and responses. As with research on the physical climate system, this research depends on the availability of high-quality, long-term, and readily accessible observations of biological and human systems.

For example, census data, along with data on economic productivity and consumption, health and disease patterns, insurance coverage, crop yields, hazards exposure, and public perceptions and preferences are relevant for developing an improved understanding of risk, vulnerability, resilience, and adaptive capacity. Continuous, sustained, research-quality measurements of land use and land cover, resource extraction, energy consumption, and pollutant emissions are crucial to improve understanding of human pressures on the environment. Similarly, observations of species ranges, migration, and interactions, biological productivity, ocean color, biomass, biodiversity, and ecosystem function are necessary to assess ecological vulnerability and resilience to impacts. As with observations of the physical climate system, long time series with broad spatial coverage are required to monitor changes and trends.

All of the above are important inputs to improved decision making about effective and sustainable responses to global change. However, informing mitigation and adaptation decisions will demand the integration and availability of these data on an ongoing basis. It will also entail that these measurements be matched to the scales of interest (for researchers and decision makers) and made available in ways that facilitate whole-system analyses of societal and environmental interactions. In the same way that economic decisions are based upon a broad and carefully developed set of indicators (e.g., gross domestic product, unemployment), global change-related decisions should be informed by a broadly recognized set of indicators that track changing environmental conditions, vulnerability, and adaptive capacity at local to international scales. Simultaneous, integrated monitoring of Earth system components will be necessary to track changes in agricultural productivity, energy production and use, water availability and quality, coastal hazards, biodiversity, and human health.

In addition, as discussed above under Objective 1.2, development of such metrics and indicators will be essential to help transfer learning about vulnerabilities and response strategies across sectors and regions. The potential exists for increased use of remote sensing (validated against in situ measurements) to develop indicators of change simultaneously over large areas; this activity is a priority of the National Climate Assessment, as discussed below under Objective

3.3. Improvements in this area have the potential to transform monitoring of the variations in space and change over time of integrated human-natural systems.

Achieving the integration vital to accomplish these USGCRP objectives will be challenging because of mismatches in the characteristic spatial and temporal scales of key processes and widely differing levels of maturity of physical, biological, and sociological observational networks. Furthermore, issues related to open availability and peer-review heritage for these disparate sets of observations make it more difficult to integrate them for specific applications. Meeting these challenges, however, will be essential for supporting assessment of vulnerability and informing decision making about responses.

Box 9. Impacts of Declining Arctic Sea Ice.

Summer sea ice in the Arctic Ocean has been declining rapidly over the past several decades, with consequences for climate, coastal communities, and marine ecosystems. Ice loss means that highly reflective ice cover is replaced with open water, which absorbs more heat, causing temperatures in this region to rise faster than anywhere else on the planet. This increased heating causes additional ice melt, perpetuating the cycle of sea ice decline. Another consequence of reduced sea ice coverage is that an important barrier to storm surge has been removed, making coastal Arctic communities and marine life more vulnerable to the increasingly stormy climate and increasing coastal erosion. Later formation of sea ice in the fall and earlier melting in spring also limits the use of sea ice as a travel route or as a platform for subsistence hunting. Changes in sea ice extent disrupt marine food webs, affecting fisheries and threatening the economic base and viability of coastal communities. At the same time, ice retreat increases shipping opportunities and could open up more regions to oil and gas exploration.

Figure B9.1. Arctic char fishing. Photo credit: Angsar Walk.

To address the causes and consequences of reduced sea ice cover in the Arctic, USGCRP agencies will work together over the next decade to develop more accurate sea ice forecasts that permit local governments and managers to prepare, enhancing the long-term security of residents and local economies. Just as vital, USGCRP scientists will work to identify best practices for building community and ecosystem resilience to the impacts of declining sea ice and help decision makers respond proactively to future changes.

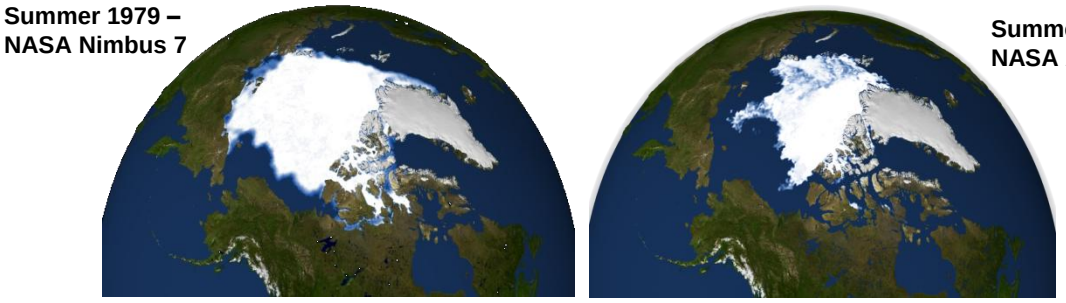


Figure B9.2. Summer sea ice extent in 1979 (left) and 2010 (right) as revealed by NASA satellites Nimbus 7 and its Scanning Multichannel Microwave Radiometer and Aqua and its Moderate Resolution Imaging Spectroradiometer.

Integration of Observations and Modeling

Modeling depends on high-quality observations. Integrated models of the Earth system have to be continuously updated with integrated suites of the latest observations to better understand their limitations—the fundamental science they may miss, or misrepresent. As model resolution and model complexity increase, new and improved observations of the Earth system should be considered for model evaluation, along with new metrics that provide meaningful measures of confidence in models and their outputs for both scientific and decision support applications.

In addition to sustained observation systems, USGCRP will continue to place a high priority on limited-duration observational campaigns to improve process representation in the next generation of integrated Earth system models. In addition, USGCRP and its member agencies will seek to ensure sufficient observational focus to improve understanding and modeling of fast-changing environments, such as the Arctic, mountainous areas, and coasts, as well as provide focused observations for model-based assessments of short-duration, high-impact events.

Furthermore, integrated Earth system models help inform improvements in observations. Models help fill gaps in observations and identify optimum observational and monitoring strategies. All such efforts in model evaluation, the assimilation of observational data into models, and the application of models to inform observational improvements come with enormous data challenges that will be compounded by the increases in model complexities and the multiplication of the observational data required to test them. These enhancements highlight the benefits of advances in information and data management and sharing, as will be discussed under Objective 1.5.

Many of the most important accomplishments of the next decade, for example, the most significant advances in understanding the dynamics of how human causes of climate change interact with natural climate system variability, will result directly from the integration of modeling and observational activities of USGCRP and its member agencies. In addition, the frontier of decadal climate predictability, as will be discussed immediately below, depends entirely on assimilating observations, particularly of the ocean, into state-of-the-art climate system models.

Objective 1.4: Integrated Modeling

Improve and develop advanced models that integrate across the physical, chemical, biological, and human components of the Earth system, including the feedbacks among and between them, to represent more comprehensively and predict more realistically global change processes

Modeling is an inherently integrative activity, synthesizing the understanding of the Earth system that we gain from measurement and theory. Efforts to develop models that integrate across Earth system components bring together researchers from many different disciplines. Efforts to use models in decision making bring scientists and stakeholders into close collaboration.

Though the atmospheric, oceanic, terrestrial, and cryospheric components of the Earth system have been part of coupled climate models for a number of years, work is still to be done to advance the capability of such models to fully represent important features of the physical climate system, such as mean tropical sea surface temperature, patterns of variability in the large-scale circulation, the diurnal cycle of precipitation, and monsoonal circulations, among others. In addition, a number of natural Earth system components, such as ice sheets, aerosols, land hydrology, vegetation, and biogeochemical cycles, have to be included more comprehensively and dynamically in models to address critical science questions and decision support needs.

Furthermore, there are many existing scientific models relevant for global change research that should be better integrated with climate system models—examples include crop models, energy demand models, food-web models, water-quality models, epidemiological models, models of human behavior, and models of the genetic diversity and dynamics of ecosystems, and econometric models, among others.

Text Box 6: Long-Term Observations Reveal Global Change.

Analyses of sustained observations, often supported by USGCRP member agencies and their international counterparts, are compared with pre-USGCRP observations, and demonstrate that the global integrated Earth system is undergoing significant and often challenging changes. Examples are:

- Annual mean atmospheric carbon dioxide concentration at the Mauna Loa Observatory in Hawaii is 20% higher in 2010 compared to 1960 and the rate of increase during the 2000s is twice as fast compared to the 1960s[6].
- The Antarctic ozone hole is starting to recover as atmospheric concentrations of CFC (chlorofluorocarbon) gases stabilized then decreased following the 1987 Montreal Protocol[7].
- The 10-year average global surface air temperature increased by 0.8°C over the past 100 years, with much larger rates of increase over the past 30 years[8].
- Annual minimum sea ice coverage and annual average sea ice thickness in the Arctic Ocean have declined over the past 30 years[9].
- Global sea level is rising nearly twice as fast in 1992–2010 as compared to 1950–2000[10].
- Greenland Ice Sheet melting increased 30% over the past 30 years.[11]
- Over the last 50 years, precipitation has decreased significantly (15 to 40%) in the southeastern and southwestern United States, and increased particularly in the Northeast (10 to 20%), with an average national increase of 5%.
- Northern Hemisphere snow cover has been decreasing over the past 80 years and the snowpack is melting earlier by as much as 20 days in the western United States[12].
- The areal extent of global drought regions has doubled since the 1970s[13].
- Large and long-duration forest fires increased four-fold over the past 30 years in the U.S. western states and the length of the fire season has expanded by 2.5 months[14].
- Locations of major fisheries in the Bering Sea shifted northward over the past 35 years[15].
- The ocean is acidifying at an unprecedented rate[16] with adverse effects on calcifying organisms (e.g., corals, clams, scallops, and oysters)[17].
- Strong wind speeds and higher wave heights have been observed across the world's ocean over the past 20 years[18].
- Nationwide, air quality improved significantly over the past 20 years for ground-level ozone, particulates, lead, carbon monoxide, nitrogen dioxide, and sulfur dioxide.[19]
- Tree growth rates are changing due to the rising levels of atmospheric CO2, higher temperatures and longer growing seasons[20].

Advances in integrated Earth system modeling to overcome such limitations are both disciplinary and interdisciplinary, as they involve the representation of specific processes and the representation of the coupling among diverse processes (and methods). Furthermore, as already discussed, USGCRP will promote greater coordination of integrated observations and modeling. To achieve all of its goals in the coming decade, the Program will address these issues by promoting greater scientific progress in (1) the development of complex, integrated modeling systems for improved richness, realism, and accuracy of simulations, (2) the development and adoption of simplified and conceptual models for improved interpretation, and (3) the advancement of integrated modeling of all types specifically for decision support.

Model Complexity

Our growing understanding of the complexity of the Earth system is reflected in the increasing complexity of the models we use to describe it. Earth system complexity creates a dynamic tension for modeling, between capturing as much of this complexity as possible for comprehensiveness and realism, and synthesizing and simplifying to grasp the fundamental aspects of a process, phenomenon, or system.[21] In the next decade, USGCRP will play a major role in managing this tension and promoting balance between these two poles.

The key to understanding the implications of and responses to global change is research that focuses on integration across Earth system components and processes and across spatial and temporal scales. Global change modeling reflects this integration, including the effect of human activities on the Earth system. USGCRP and its member agencies will foster the development of next-generation modeling systems that integrate more fully across all Earth system components and processes.

Continuing to place a high value on increasing model resolution in both space and time will be an important part of this effort. Increased resolution has important benefits for both scientific understanding and decision support. Most generally, it will often lead directly to increased realism of a simulation or accuracy of a prediction. Increased resolution can also dramatically improve the integration of model components, as more of this integration can occur by explicitly and dynamically modeling key processes rather than relying on parameterizations that represent those processes in a simplified manner.

In addition, high-resolution models can bridge the scale gaps inherent in global change, for example nesting regional models within global models. Such bridging of spatial scales can in turn create opportunities for eliminating some of the intellectual gaps between the science of the climate system and that of, for example, ecosystems, hydrologic systems, and social systems. This bridging of scale gaps can in turn foster bridging of the communication gaps that exist between global change science and the researchers and stakeholders dealing with issues of vulnerability, impacts, and adaptation at much finer scales. Similarly, incorporating additional process and impacts models into flexible Earth system modeling frameworks can enhance engagement, collaboration, and knowledge transfer across disciplines and the science-stakeholder divide.

Model Interpretation, Conceptual Modeling, and Hierarchies of Model Complexity

Just as large-scale processes have important effects at localized scales, small-scale processes in turn affect the larger-scale environment. It is important to emphasize that reaching down from coarse to fine resolution is not the only pathway for model improvement. Development of an improved understanding of how to scale up insights from fine-scale process and impacts models will also be important as will better understanding of the mechanisms that drive climate conditions, for example, ocean-atmosphere and land-surface interactions.

More generally, modeling refers not only to the development of complex numerical codes, but also to the crafting of conceptual models that, through simplification of complexity down to core essentials, help bridge the gaps between observations and theory and between theory and scientific prediction. In the next decade, USGCRP and its member agencies will promote the development of coordinated hierarchies of models, from simple to complex, to help the broader global change community derive the maximum scientific understanding and practical meaning from the large USGCRP investment in complex, computer-intensive, integrated modeling.

Similarly, given the great increases in model complexity and precision, it will become more and more difficult to define uncertainties in possible models, for both scientific understanding and decision support. Uncertainty is an inherent feature of decision making, and its characterization can provide decision makers with a better understanding of available options. Meeting this challenge will call for greater coordination among agencies and institutions nationally and internationally to address issues, including increasing the transparency of model assumptions and enhancing model reproducibility, including assuring the continuing availability of enough computational resources to run the suite of models at the desired resolution and ensemble size, and covering the range of scenarios necessary to support policy making.

Integrated Modeling for Decision Support

Insights gained from applying the next generation of integrated Earth system models will support decision making about responding to change at global, national, regional, and local scales, for near-term and long-term time horizons. To be most useful, however, model structures and outputs will in many cases have to be aligned more closely with the needs of decision makers. USGCRP and its member agencies will on the one hand draw from the large existing body of decision sciences research, and on the other hand draw from Earth system science to improve understanding of key uncertainties, as well as help develop and apply new frameworks, to maximize the usefulness of its modeling efforts in decision support. Focus areas will include the derivation of regionally specific model outputs through the improvement and application of downscaling techniques and the production of model-generated information on short-timescale processes as such extreme events that have acute impacts on natural and human systems.

In addition, a fuller integration of the societal and human components into Earth system models is a top priority. It is also especially challenging. A key opportunity for USGCRP is to build on the insights and experience gained in this area from the development and application of Integrated Assessment Models (see **Box 10**), as well as to ensure that fundamental advances in the modeling of Earth system components and impacts flow into advancing the sophistication

and capabilities of these models. This integration will have important benefits for both Earth system understanding and support for decision making about responding to global change.

Box 10. Integrated Assessment Modeling.

Governments around the world, including the United States, want to have as much knowledge and information as possible about how global change might affect the economies, jobs, public health, food and water availability, infrastructure, and natural resources of their countries. Integrated Assessment Models (IAMs) are key tools for helping scientists and policy makers understand the interconnections between both the natural and human components of the Earth system.

One of the greatest strengths of IAMs is that they allow researchers and decision makers to explore a range of "what if" questions about global change impacts and responses. In the past, IAMs have been used mainly to analyze the effects of possible greenhouse gas control policies and technological advances in energy production. Today, however, these tools are being adapted to help policy makers make better decisions about natural resource management, infrastructure fragility, public health, land development, food production, and coastal protection that are all affected by global change.

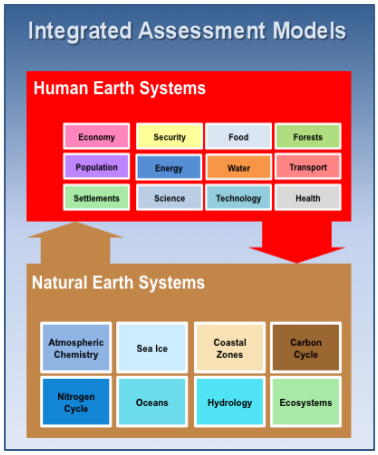


Figure B10.1. Integrated Assessment Models incorporate the connections between components of Human Earth Systems and Natural Earth Systems.

USGCRP plays a leadership role in coordinating the development and application of IAMs to address this broad range of impacts, adaptations, and vulnerabilities, bringing together the wide range of the necessary social and natural science expertise from its diverse set of participating Federal agencies. Over the next decade, USGCRP will work with its agency partners to develop IAMs at the appropriate space and timescales for these new applications, improve methods for risk and uncertainty estimation within the models, develop interoperable modeling frameworks, and standardize the input data sources for the many different IAM modules and components. These advances will have enormous benefits for both improving fundamental scientific understanding of the interactions between human and natural processes and for informing responses to global change.

The application of Integrated Assessment Models to date has made emissions and land-use scenarios available for use in studies applying global climate models and has permitted analysis of the consequences of national and international emissions policies. However, Integrated Assessment Models can reach far beyond this application to provide a common framework for exploring the costs and benefits of adaptation and mitigation actions, the interactive consequences of these responses, and a combined risk perspective for decision making. USGCRP has an opportunity to foster the development of the next generation of Integrated Assessment Models that combine, within a common modeling framework, both the drivers and consequences of global change. USGCRP and its member agencies have a critical role to play in this effort, as it will call for significant cross-agency coordination to incorporate ongoing improvements in Earth system and impacts modeling into Integrated Assessment Model development.

Regardless of the type of model being applied in a decision support context, one particular challenge for many stakeholders and scientists is to articulate a role for modeling at the research-decision interface that goes beyond asking the question, "What is going to happen (in my country, state, city) in the future?" This question can be an extremely useful for decision making, but difficult to answer for aspects of the Earth system for which predictive capability is

the most limited, such as biological and social systems, or for long time horizons for which uncertainties are large and potentially irreducible in the near term. A key focus of USGCRP modeling efforts over the next decade will be to better quantify these limits while expanding the range of benefits of modeling for decision support that do not explicitly depend on accurate, long-term forecasts of global change in specific regions and for specific socioeconomic sectors. These benefits include:

- Enhanced capabilities for generating "what if" scenarios to use in bounding analyses and scenario planning exercises;
- Better insight into tradeoffs among alternative policies;
- Identification of previously unanticipated vulnerabilities, including the potential for rapid or accelerating change and threshold-crossing;
- Improved understanding of unintended consequences.

The role of both scientific and operational prediction will of course continue to be crucial in both research and decision making contexts. In particular, USGCRP will foster ongoing improvements in regional climate prediction at synoptic, seasonal, and interannual timescales. As climate continues to change, information on these timescales will become important inputs into decision making for adaptation responses in particular, as this range encompasses key planning horizons in many sectors but is not so long that forecast accuracy is unverifiable, or that learning and feedback could not readily occur. In addition, it is widely expected that climate change over the next decades will lead to a world with more frequent and intense extreme weather and climate events, such as heat waves, storms, floods and droughts. In such a world, managing competing demands on scarce resources and increased risks to vulnerable populations will demand improved analytic capacity across the board, including an improved capability for making relatively near-term climate predictions.

Finally, the Program will coordinate and enhance efforts to study climate system predictability over timescales of a decade or more, as the necessary first step toward developing a practical climate prediction capability for longer planning horizons **(Text Box 7**). Fundamental improvements in regional climate prediction on synoptic, seasonal, and interannual timescales, Earth system observational capabilities, and data assimilation

Text Box 7: Decadal Climate Predictability.

Planners at all levels of government and across all sectors focus a great deal on looking ahead over time periods of a few months to several years. Examples include emergency preparedness, sustaining agricultural productivity, avoiding over-fishing, and maintaining infrastructure to ensure uninterrupted supplies of food, energy, and freshwater to communities and businesses. Planning outcomes in all of these areas and many more are very sensitive to the season-to-season, year-to-year, and decade-to-decade variations in weather and climate.

Traditional weather forecasts for a particular town or city only extend about two weeks into the future. Longer-term, less-focused predictions used in agricultural and emergency planning are only made about a year ahead of time. However, because of recent advances in computing technology, combined with a new generation of Earth observations (especially of ocean temperature and saltiness), there is now a great opportunity to explore the limits of climate predictability out to a decade and beyond.

Addressing the issue of decadal climate predictability will call for all of the coordination across Federal agencies, scientific disciplines, and U.S. and international researchers that USGCRP can provide. It will depend on USGCRP effectively implementing and sustaining ocean, atmosphere, land, and ice observing systems; developing improved methods for using these data in global climate models; and applying advanced computing capabilities. It will also depend on USGCRP enhancing cooperation between scientists and planners to ensure that development, testing, and communication of new scientific products and insights will ultimately be relevant for supporting better decisions.

approaches will provide the foundation for new activities at the leading edge of global change science and modeling.

Advances in decadal climate predictability have the potential to spur needed improvements in sector and regional impacts models, and lead to the development of new kinds of decision support tools for the new applications made possible by improved insights into climate variations and trends on these timescales.

Objective 1.5: Information Management and Sharing

Advance the capability to collect, store, access, integrate, visualize, and share data and information about the Earth system, the vulnerabilities of integrated human-natural systems to global change, and the responses to these vulnerabilities

Over the next decade, achieving the Program's goals will depend on making significant advances in the Nation's information management and sharing capabilities. They will be vital for addressing the many dimensions of collaboration and coordination called for in this Strategic Plan. These improved capabilities, to capture, store, and integrate the rapidly growing data streams, as well as facilitate access and analyses of these data, will improve scientific understanding and develop responses that will lead to effective and sustainable responses to global change.

Although many aspects of data management have evolved since the previous USGCRP Strategic Plan in 2003, many of the challenges identified there still remain. Increasingly centralized data management storage and portal systems have been developed, but it is necessary to improve their organization, track data sources, and indicate data quality. There is also a need to improve interoperability among distributed data systems and to develop interfaces that permit integrated analysis. The ongoing explosion in data volume dictates development of user-friendly tools for manipulation, analysis, and knowledge transfer. In the coming decade, USGCRP will provide a forum for its agencies to address all of these issues, sharing best practices as well as assuring interoperability, and maintaining the flexibility to seize new opportunities for information management and sharing provided by emerging technologies. The Program is also pursuing the development of a global change information system to support coordinated use and application of USGCRP knowledge and products (see **Text Box 8**).

Text Box 8: Global Change Information System.

The local-to-global-scale impacts of climate variability and change, as well as the broader issue of global change, have fueled a growing public demand for timely and accessible information about present and future changes. Providing scientific information about causes and effects of global changes helps people make informed decisions in their lives, businesses, and communities. USGCRP will lead an interagency initiative to build a new global change information system, providing timely and relevant data and information to stakeholders and the public. This system supports many objectives across the Federal government, including the National Climate Assessment and more timely access to information, the capacity to provide services to a much broader set of audiences, more transparency of data and results, and the ability to update information in real time.

Integrated and Centralized Data Access

With the advance of observational capabilities, computational power, and scientific research, there is both an opportunity for scientific progress in our study of the Earth system and a need to manage the data and information generated about it. With some important exceptions, USGCRP agencies have generally pursued a distributed data strategy over the last decade, in which individual

agencies have established centralized archives for collecting and storing observational data resulting from their respective observational campaigns. This strategy of individual agency archive management will likely continue, as each agency, and its unique stakeholders, has specific data and information requirements. However, there is an opportunity to integrate across these networks to provide improved access and interoperability, with the global change information system being an important step.

In the coming decade, USGCRP will take a leadership role in coordinating these networks, in part through the Program's new global change information system, as well as by providing shared analytic capabilities and modeling frameworks to support integrated research. Specific issues that are imperative to be addressed to accomplish this in an effective way include data volume, data transparency and quality, data discovery, analysis tools, and community modeling.

Data volume continues to grow at an accelerating rate. Satellite instruments continue to collect a high volume of high-resolution (in time and space) measurements that are synthesized to create a record of the Earth system and its changes. In situ long-term network measurements provide valuable records of climate and environmental changes, often at high temporal resolution. Paleoclimate and process-based studies extend the historical record back in time, beyond that of instrumental records. Data from intensive field campaigns provide detailed information in particular regions. It is crucial to continue to collect and store these records, but this will also continue to present data management challenges. As an example of the increase in the amount of observational data available, the NASA Earth Observing System Data and Information System (EOSDIS) archive alone has grown from ~100 terabytes in the year 2000 to ~4,600 terabytes in 2010, with comparable increases in other agencies' archives.

Similarly, as computational capabilities improve, increasingly sophisticated models provide the opportunity to evaluate regional global change impacts on multiple timescales. These models will continue to integrate more Earth system components, increase resolution, and be run in large ensembles. As a result, they will generate ever-more output to be stored, shared, and analyzed. For example, during the time period that separates Intergovernmental Panel on Climate Change (IPCC) assessments, climate model resolution typically doubles, and the number of climate experiments conducted and diagnostics saved increases as well. The IPCC Fourth Assessment Report (2007) generated 35 terabytes of model data, but the upcoming Fifth Assessment Report is expected to generate over 3,000 terabytes of data. There is a similar explosion in reanalysis data sets, seasonal reforecasts, and seasonal-to-interannual climate simulation ensembles.

Addressing this data-volume challenge will require advanced technology to link users to the various data providers. There are important existing USGCRP agency efforts upon which the Program can build. For example, the Earth System Grid Federation is a data distribution portal that is currently used by many of the USGCRP agencies and international modeling centers. Its unified, virtual data-sharing environment links international climate research centers and provides a range of users with model-generated climate data, transforming distributed climate simulation data into a collaborative community resource. USGCRP will promote the access, search, and sharing of data by enhancing and expanding the use of such portals, while reducing duplication of effort by the science and policy user community and directing users to the best available data.

In this context, organization of data according to standardized ontologies, along with standards for cataloguing and inventorying metadata, will enable timely data discovery. In addition, USGCRP should continue to address issues of data storage, transfer, and speed of manipulation. Such unified data portals will have to allow users to work with the data close to its storage repository and extract and transfer only the needed results, due to the impracticality of directly transferring and keeping up to date the metadata associated with these huge data sets. Additional priorities include continued development of standardized file storage formats for enhancing access to data elements, data transfer protocols that permit data subsetting and transfer, and service-oriented architecture at the data centers maintaining the portals. In addition, data centers will need to cope with the generation and distribution of high-level data sets, or processed data that are most needed or requested by users. Analysis of large data sets depends upon the development of parallelized input/output methodologies, to facilitate rapid access to multiple stored data files.

In addition, all of the above also suggest prioritizing issues of data and information transparency, provenance, and quality. USGCRP and its member agencies will play a leadership role in enhancing transparency and quality through efforts to ensure open access and provide authoritative products and portals. These endeavors will facilitate the efficient identification, access, and use of the highest quality data and information to support research about (and decision making about responses to) global change. In addition, there is a growing collection of higher-level information about global change, and assessing its reliability is difficult for nonspecialists. Therefore, USGCRP will provide sources of credible global change information, with attention to the depth of scientific detail appropriate for diverse audiences. In this context, USGCRP leadership in providing for an open data policy will be important, both nationally and internationally.

To help researchers keep pace with the growing data volume and the ongoing need to make information available to a variety of users, USGCRP will encourage the development of enhanced tools to manipulate, synthesize, analyze, and visualize the data. Tool development must match the data level, application, and user sophistication. For example, the research community will increasingly depend on distributed analysis software (e.g., statistical tools) that can simultaneously access multiple observational and/or model data sets, taking into account varying spatial and temporal grids and data formats. Such software will increasingly require parallelization, as the data sets it accesses increase in size. Development of new, user-friendly, distributed visualization tools (e.g., including two- and three-dimensional maps, two-dimensional slice selection from three-dimensional fields, scatter plots for comparison of data sets, and feature tracking) will also be important.

Finally, whether it is improving the representation of currently modeled Earth system components, or incorporating additional physical, chemical, biological, or human components, processes, and interactions, achieving the next level of Earth system model integration will depend on advances in modeling infrastructure and frameworks. USGCRP will coordinate the development of flexible frameworks that promote modularity and interoperability in coupling together diverse component and process submodels. Such frameworks will be important for enabling parallel development of different model components, optimizing resources, and minimizing duplication of effort. In part, these activities will involve building on and continuing to foster efforts such as the Community Earth System Model and Earth System Modeling

Framework that rely heavily on grass-roots participation. Promoting the development and widespread use of such frameworks is a central task for USGCRP so as to maximize collaboration, co-development of models, and, ultimately, coordinate integrated research efforts.

Integrated Knowledge for Stakeholders and Decision Makers

Data and information about Earth system processes and societal vulnerabilities in the context of global change will be demanded by an expanding pool of scientists, decision makers, and the public. Each of these groups presents a challenge to USGCRP and its member agencies to collect, store, publish, and serve this information in audience-appropriate forms. In general, these stakeholders often depend on information that is processed and synthesized.

In the next 10 years, the Program will address the unique information management and sharing challenges of providing integrated scientific knowledge in meaningful forms to global change stakeholders. Specific issues include integration of new types of data and information with Earth system data sets, and the development of new tools and methods for manipulating, synthesizing, analyzing, and visualizing integrated data sets.

As USGCRP supports efforts to respond to global change, new types of data and information will be generated that will be important to integrate with the Program's fundamental research findings and datasets. For example, USGCRP, via its sustained assessment process (see Goal 3) will encourage the development of databases of stakeholder needs and the details of their adaptation and mitigation projects, efforts, experiences, and best practices for supporting decision making. In addition, databases of information about diverse audiences and their perspectives on and understanding of global change will assist in the development of readily accessible, comprehensible scientific information and promote enhanced communication, education, and engagement.

As is the case for the research community, the multiple global change stakeholder communities will also benefit from distributed analysis and visualization tools to manipulate and synthesize these diverse data and information streams. Currently, Earth system data use typically requires an expert understanding of the available formats, data characteristics, software packages, calculation methods, and visualization software. Non-expert users would benefit greatly from user-friendly software and simple modeling tools for a variety of informational and decision-support applications.

Finally, USGCRP will embrace the power of advances in information technology to transform public engagement with science and harness public participation in research, as will be described in more detail below, under the Communicate and Educate Goal. Distributed computing, applications for mobile technology, and social networking have the potential to dramatically scale up "citizen science," where interested members of the public serve as observers, modelers, and analyzers of the Earth system, contributing to the scientific enterprise and broadening the meaning of global change in their own lives.

Goal 2: Inform Decisions

Provide the scientific basis to inform and enable timely decisions on adaptation and mitigation

Global change is affecting many aspects of our society, livelihoods, and environment. Across the United States and around the world, people are making decisions to effectively minimize (mitigate) and prepare for (adapt to) global change. USGCRP and its member agencies' past work on understanding the causes and consequences of global change has created a strong scientific foundation for informing decision makers who use science to understand and envision a range of potential impacts, risks, vulnerabilities, and trade-offs that are key for effective adaptation and mitigation actions. Over the next decade, USGCRP will add a more service-oriented element to the Program to better inform decision makers—one that will increasingly conduct fundamental, use-inspired research, while delivering credible, relevant, timely, and accessible information.

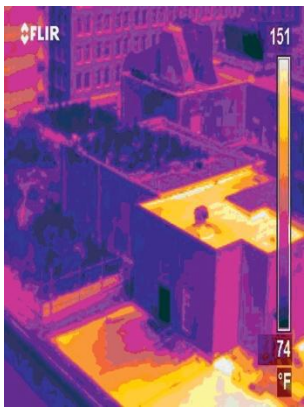
USGCRP's success in informing decisions on global change depends on strengthening the dialogue and engagement between the science and decision making communities, with assessment being an essential tool (see Goal 3). This collaboration and coordination at the interface of science and decision making requires new methods and a framework for multidirectional information exchange. Key elements of USGCRP's role in informing decisions are to:

- **Facilitate meaningful engagements between scientists and decision makers**, with a primary focus on assessing decision maker needs and science requirements, identifying critical gaps in knowledge and options for a use-inspired research agenda, and establishing new pathways for sustained dialogue.
- **Provide access to relevant and accurate science** through a platform of user-friendly global change information, tools, and services; manage risks by identifying uncertainties, and coordinate effective partnerships for multidirectional information sharing across scales (from local to international) and across sectors.
- **Guide and coordinate Federal science efforts through the USGCRP** to ensure they are useful and focused on relevant and beneficial societal outcomes.
- **Inform Federal responses to global change** through close, ongoing interaction with Federal agencies and departments as they develop and implement climate change adaptation plans, as well as mitigation measures and policies, built upon sound scientific understanding.

Objectives 2.1 (Inform Adaptation Decisions) and 2.2 (Inform Mitigation Decisions) present strategies and new approaches for informing global change-related decisions. Objective 2.3 (Enhancing Climate Services) describes how to facilitate these decisions by building an effective framework for climate services. Objective 2.4 (Enhance International Partnerships) articulates the coordination of partnerships that leverage the strengths of international agencies and organizations in support of informed decisions. Taken together, these strategic objectives will enable public and private leaders to routinely access and integrate USGCRP global change information, research findings, and assessments into their analyses and overall adaptation and mitigation decisions.

Box 11. Science to Inform Urban Adaptation.

Strong partnerships and informed leadership are helping Chicago develop a response to projected higher future temperatures (with heat waves potentially occurring up to once every three years) that may affect businesses and the general public. Using USGCRP member agency data, a multistakeholder task force developed the Chicago Climate Action Plan, which identifies adaptive strategies to long-term climate change trends, such as helping property owners prepare greener landscapes and improve energy efficiency, and implements a more climate-conscious urban design to manage heat and flooding. For example, the City of Chicago is working to reduce urban heat buildup and the demand for air conditioning by installing roofs covered with soil and vegetation that are up to 77°F (25°C) cooler than nearby conventional roofs (Figures B11.1 and B11.2).



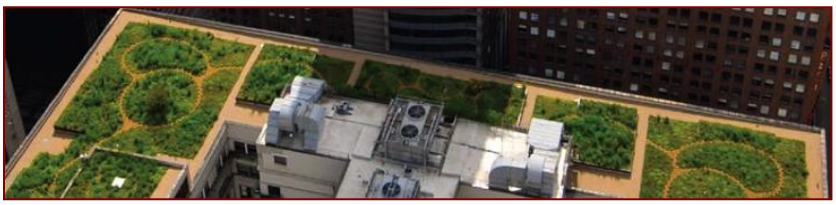


Figure B11.1 (above) The green roof on top of Chicago's City Hall is designed to cool the building and increase energy efficiency. Photo credit: City of Chicago, http://www.chicagoclimateaction.org/pages/research___reports/8.php

Figure B11.2 (left) This infrared image, with a temperature scale on the right, reveals that "green" roofs are cooler than the surrounding conventional roofs. Photo credit: Chicago Police Department and the Cook County Sheriff's Department.

In the future, USGCRP and its member agencies will continue to inform urban planning decisions by supporting the development of decision-relevant climate information. The Program will enhance the accessibility of this information through innovative knowledge-sharing tools like a global change information system (see **Text Box 8**). USGCRP-supported assessments will provide researchers and community stakeholders with the opportunity to engage in a strategic dialogue to help identify knowledge gaps, project future global change conditions, and share information needs.

Objective 2.1: Inform Adaptation Decisions

Improve the deployment and accessibility of science to inform adaptation decisions.

When considering options to reduce the risks of global change, decision makers need timely access to accurate and relevant information. Adaptation efforts underscore the need for a more strategic global change science agenda. This fundamental shift associated with the realignment of scope of the Program necessitates a sustained dialogue that enables information exchange and feedback among scientists, decision makers, and practitioners throughout the adaptation research, planning, implementation, and evaluation processes.

USGCRP will provide coordination functions to ensure that Federal science investments best address adaptation needs. Emphasis will be placed on a process for identifying on a continuing basis information gaps articulated by decision makers, developing options for filling these gaps through a use-inspired Federal research agenda for global change adaptation, and exploring pathways for improved integration of science to inform of adaptation actions. The National Assessment is explicitly including one approach to identifying these gaps in the research agenda. USGCRP and its member agencies will also explore ideas and options for building capabilities in the deployment of accessible, actionable science, tools, and services to

inform adaptation decisions. As described above under the Advance Science goal, these considerations will be particularly important in the development of methodologies and approaches to assess global change risks, impacts, and vulnerabilities, for use on local-to-regional scales where many management decisions are made. Such methodologies are also needed to assess the outcomes of alternative adaptation options and to improve approaches for identifying and managing for extremes, including low-probability, high-impact events.

Improved understanding of the vulnerability, resilience, and adaptive capacity of human and natural systems affected by global change will guide the setting of policy and management priorities for adaptation, and inform the development of next-generation adaptive management tools and approaches.

Defining best practices for transferring scientific knowledge to adaptation decision making will be guided in part by social science research evaluating the uptake of USGCRP research into decisions and its effectiveness in informing robust outcomes. This research will occur at the interface between the science, policy, and management communities, supported by USGCRP coordination.

Key components in facilitating an effective engagement between the science community and adaptation decision makers include:

- **Assess and address decision maker needs and science requirements** by establishing sustained pathways and partnerships for continuously identifying the needs of adaptation practitioners and ensuring that these needs are addressed through a use-inspired Federal science agenda.
- **Identify and communicate relevant information** by developing and deploying a "map" of existing Federal science and services in support of adaptation.
- **Develop new information exchange approaches** through efforts such as the creation of an online "clearinghouse" or knowledge-management network for global change adaptation and knowledge sharing.
- **Support public and private sector responses to global change** through close, ongoing interactions and by supplying timely data and information streams. Particular focus will be on supporting Federal agencies and departments as they develop and implement climate change adaptation plans, as well as mitigation measures and policies, built upon sound scientific understanding.

Governments at all levels play a crucial role in the development and implementation of global change adaptation measures and policies, and as such, provide immediate and long-term opportunities to institute and develop these components of engagement. USGCRP and its member agencies will work with state, local, and tribal governments, as well as Federal agencies, as one means to build the capabilities for engagement and support needed by all decision makers. One near-term opportunity for demonstrating these pathways is to provide information and assistance to Federal agencies as they work to develop and implement agency-wide climate change adaptation plans as mandated under Executive Order 13514: Federal Leadership in Environmental, Energy, and Economic Performance.

By improving connections between science and decision making, USGCRP and its member agencies will play a valuable role in informing decisions.

Box 12. New Tools Evaluate Sea Level Rise and Coastal Flooding Impacts.

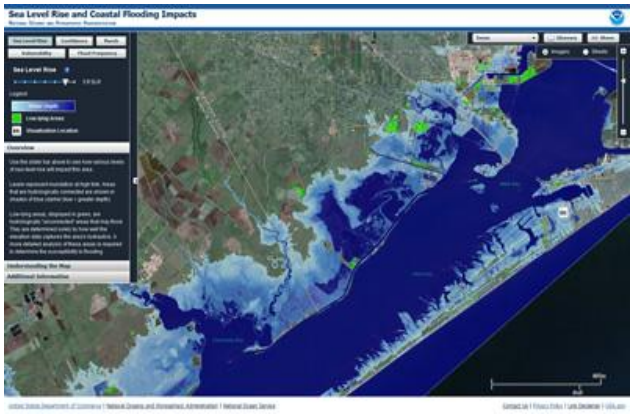


Figure B12.1. An image of a barrier island and coastline as seen via NOAA's Sea Level Rise and Coastal Flooding Impacts Viewer at http://www.csc.noaa.gov/digitalcoast/tools/slrviewer/index.html

Climate variability and change directly affect coastal communities. USGCRP member agencies are integrating multiple capabilities (observing, modeling, prediction, and decision support) and multiple scientific disciplines (climatology, meteorology, oceanography, economics, and social science) to provide these communities with a suite of climate service tools that will help them make important planning decisions. One example of a climate service tool is the Sea Level Rise and Coastal Flooding Impacts Viewer. Using data integrated from USGCRP member agencies, this tool provides simulations of sea level rise at local landmarks, communicates the uncertainty of mapped sea levels, models potential marsh migration, overlays social and economic data, and examines how tidal flooding will become more frequent. Communities can use this information to make stronger planning decisions in important areas such as infrastructure maintenance, ecosystem management, and local business development. This tool and other climate service products will provide the real-time data needed to build resilient communities in the face of sea level rise and other global changes.

Objective 2.2: Inform Mitigation Decisions

Improve the deployment and accessibility of science to inform decisions on mitigation and the mitigation-adaptation interface.

Efforts to mitigate climate change focus on reducing emissions of atmospheric carbon dioxide and other greenhouse gases. Options include the capture and sequestration of greenhouse gas emissions, altered agricultural and forestry practices, more efficient use of energy, and a transition to low-carbon energy sources, such as wind, solar, and nuclear.

To make informed decisions about mitigation options at multiple spatial scales, decision makers should understand the effects of policy options on greenhouse gas emissions, the costs of reducing emissions, and the benefits of avoiding greenhouse gas emissions. Tools to inform mitigation decisions will be built on new research aimed at improving understanding of carbon storage in the Earth system, the development of scenarios of possible changes and impacts, and the identification of the social and ecological thresholds that help define limits to adaptation.

To be helpful to the broadest range of users, science should be translated into tools, information and practices that decision makers can understand and use. When mitigation actions involve market-based approaches, frameworks and inventories should be in place to measure, monitor, and validate actual emissions reductions. Existing and improved inventories are important parts of regular assessments that help inform national, state, and local policies (see also Goal 3, Sustained Assessments). The key components in facilitating an effective engagement between the science community and mitigation decision makers include:

- **Explore and address decision-maker needs and science requirements** by serving as a "boundary" between the science and decision making communities, including initiating new engagements for specific mitigation research issues and building the capacity for translating science for specific decision contexts, particularly risk management frameworks.
- **Identify relevant scientific information** by analyzing and documenting current Federal capabilities for identifying, visualizing, and communicating existing environmental data to support management and mitigation science and service capabilities.
- **Integrate Federal agency data and estimates of greenhouse gas emissions and sinks** at multiple scales for all sectors and regions and provide such information to decision makers in an appropriate manner, and pilot new information products and tools for mitigation decisions, including tools and metrics for evaluating the effectiveness of mitigation actions and tradeoffs (e.g., local land-use impacts to ecosystems vs. global impacts from greenhouse gas emission reduction).
- **Coordinate Federal agency research to inform the analysis of the greenhouse gas impacts of mitigation approaches,** provide clear models and projections of potential impacts of policies, laws, and societal decisions on greenhouse gas impacts over time utilizing results of research to measure, report, and verify greenhouse gas emissions.

In the long term, the ability to manage greenhouse gas emissions through mitigation efforts will affect both the magnitude of the impacts to which we need to adapt, and the effectiveness of various adaptation options. Therefore, mitigation and adaptation actions are inextricably linked via the future costs of impacts versus current investments in mitigation. A better understanding of these linkages and interactions is necessary to develop effective adaptation and mitigation efforts and opportunities for co-benefits. Over the longer term, USGCRP and its member agencies will develop the scientific basis for understanding potential interactions, trade-offs, and consequences of coupled adaptation and mitigation strategies. This scientific basis will (1) advance coupled Earth system modeling that integrates across human and natural systems to assess the environmental, social, and economic outcomes of alternative adaptation and mitigation options; (2) advance social, behavioral, and economic research to improve understanding of human actions that lead to changes in emissions, and the costs of addressing those changes; and (3) improve understanding of policy and management decisions that build the resiliency of human and natural systems to global change impacts.

Objective 2.3: Enhancing Climate Services

Develop the tools and scientific basis to support an integrated system of climate services, supported by sustained, relevant, and timely data and information to support decision making.

Climate services are the development and timely provision of information products, including forecasts, based on accurate observations and model results that help people make informed decisions. These products support an integrated system of climate services, fueled by sustained, relevant, and timely data and information.

The local-to-global-scale impacts of climate variability and change have fueled a growing public demand for climate services. Climate services help people understand past, present, and likely future climate conditions (including natural variability), and how those conditions affect their lives, businesses and communities. Easy, intuitive access to these science-based services enables people to make informed decisions to support economic growth, reduce risks to lives and property, and manage natural resources.

USGCRP agencies have been providing climate information that is essential to many aspects of policy, planning, and decision making for the past two decades; however, historically, this information has not been well coordinated across the agencies. As a result, there are opportunities for improved accessibility to more comprehensive, consolidated, and user-relevant climate-related data and information. Global change observations, monitoring, modeling, predictions, and projections—underpinned by the best-available natural and social science—provide the information basis for a framework of national climate services. No single agency can provide the breadth of information needed and this provides a unique opportunity for USGCRP and its partners, including the private sector, academia, and other Federal agencies, to improve the effectiveness of its climate services that can meet the growing public demand for science that informs, but does not prescribe, decision making. There is also a need for better information in an adaptive management context, given the challenges in conducting deterministic predictions of future conditions.

To develop a set of accessible and useful climate services, USGCRP and its member agencies will combine their scientific assets with scalable new partnerships for sharing knowledge, increasing public understanding, and building professional capacity. USGCRP will participate in Federal interagency partnerships to capitalize on their unique and complementary strengths. Recognizing the diverse but complementary roles of various agencies, USGCRP is well positioned to connect climate science

Box 13. Construction and Climate.

The construction industry needs information on climate variability and change in order to adequately design new construction projects. An example of how USGCRP member agencies have served the construction industry is helping Boston evaluate the design and placement of their new sewage treatment plant.

Boston's Deer Island Sewage Treatment Plant was designed and built taking future sea level rise into consideration. Because the level of the plant relative to the level of the ocean at the outfall is critical to the amount of rainwater and sewage that can be treated, the plant was built 1.9 feet (0.6 meters) higher than it would otherwise have been to accommodate the amount of sea level rise projected to occur by 2050, the planned life of the facility.

The planners recognized the importance of using the best available information to plan future development. They assessed the sea level rise information to help make short- and long-term construction decisions that kept the project moving forward but would allow for improvements in later stages. For example, increasing the plant's height would be less costly to incorporate in the original design, or short-term construction phase, while protective barriers could be added at a later date, as needed, at a relatively small cost.

Figure B13.1. Deer Island Sewage Treatment Plant. Photo credit: Massachusetts Water Resources Authority.

to decision making in a highly structured and effective way. USGCRP coordinated agency climate services should provide data and information to established businesses seeking to specialize in the provision of services and products based on environmental and climate data. It is expected that as USGCRP improves the accessibility of climate information, entrepreneurs in the private sector will be able to find new opportunities to tailor services to meet the needs of manufacturers, farmers, retailers, wholesalers, planners, resource managers, and others regarding how to adapt their business or community development plans to a changing climate.

USGCRP will seek to work collaboratively with partners, including decision makers in the public and private sectors, to integrate outcomes from USGCRP's major goal areas in advancing science and sustaining assessments to inform decisions and promote understanding of global change vulnerabilities and opportunities. The key features upon which USGCRP agency climate services will be built include:

- **Observing Systems, Data Stewardship, and Climate Monitoring**. USGCRP agencies will collect, preserve, and analyze the global environmental record for continuous climate monitoring and developing periodic assessments in support of climate services. This readily accessible, long-term archive will serve the Nation's need for trusted climate-related information about the current and changing state of the climate system. A global change information system will be an important step in this direction (see **Text Box 8**).
- **Predictions and Projections.** USGCRP climate predictions and projections will provide information on multiple timescales for climate variability (from weeks to years), impacts, and longer-term changes (decades to centuries). Experimental analysis and translation tools will be developed with stakeholders to transform model projections into useful information at relevant spatial and temporal scales.
- **Integrated Service Development and Decision Support.** USGCRP and its member agencies will provide timely and relevant climate information to other Federal programs that address climate-related issues on various scales, from local, regional, and national to global. In addition, USGCRP will deliver data and information streams (that are designed to support specific decisions in regions and sectors) to the general public and to climate service providers that develop decision-support tools and other applications.

USGCRP will strive to ensure that the best-available climate information, tools, and services will be delivered to support public and private sector policy, planning, and decision making. Because many climate services are being provided today by individual agencies (national, state, and municipal) and outside the government, the key challenge for USGCRP will be to develop more effective coordination, communication and resultant synergy among these bodies (see **Text Box 10**). In addition, USGCRP will work closely with the Global Framework for Climate Services as it strives to incorporate a set of international arrangements that would establish an end-to-end system for providing climate services and applying them in decision making in an international context. The Nation's need for climate services exceeds the scope of any individual organization or agency. Accordingly, a strong framework of interagency and external partners is key to the success of delivering climate services.

Box 14. Growing Seasons.

The agriculture industry in the United States generates over $200 billion a year in food and commodities from a diverse range of crops and animals. Climate change affects this industry by contributing to increased productivity in certain crops and reducing productivity in others.

Crop responses in a changing climate reflect the interplay among three factors: changing temperatures, changing water resources, and increasing carbon dioxide concentrations. Warming generally causes plants that are below their optimum temperature to grow faster, with obvious benefits. For some plants, such as cereal crops, however, faster growth means there is less time for the grain itself to grow and mature, reducing yields. For some annual crops, adjusting the planting date to avoid late season heat stress is one strategy for adjusting to changes.

The grain-filling period (the time when the seed grows and matures) of wheat and other small grains shortens dramatically with changing temperatures. Analysis of crop responses suggests that even moderate changes in temperature will decrease yields of corn, wheat, sorghum, bean, rice, cotton, and peanut crops.

Changing numbers of freezing days provide an example of how agriculture is affected by climate change. Since the mid-1970s, observations show that the number of days per year in which the temperature falls below freezing has declined by four to seven days over much of the Southeast. Some areas, such as western Louisiana, have experienced more than 20 fewer freezing days. These observations can help inform farmers and others in the agriculture business to maximize their crop output. For scientists, these observations inspire future research around climate to continue to inform decision makers: Will these trends continue, accelerate, or change direction? How will next year's freeze-free period compare to these trends?

USGCRP will coordinate efforts of member agencies that, through observations, crop- and forest-growth models, and regional climate models, will provide authoritative information and tools that can be used by farmers and landowners to make decisions relevant to agricultural production in a changing climate.

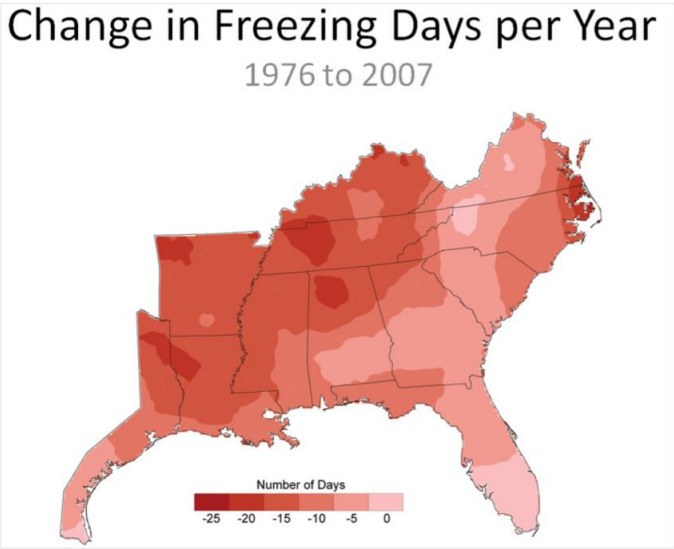


Figure B14.1. Since the mid-1970s, the number of days per year in which the temperature falls below freezing has declined by four to seven days over much of the Southeast. Some areas, such as western Louisiana, have experienced more than 20 fewer freezing days. Climate models project continues warming across the region, with the greatest increases in temperature expected in summer, and the number of very hot days increasing at a greater rate than the average temperature. Image credit: NOAA/NCDC

Objective 2.4: Enhancing International Partnerships

Provide leadership in international partnerships to enhance the scientific basis for decision making.

Global change is an international concern. Vital resources, such as water and food supplies, cross geopolitical boundaries, and the effects of global change likewise extend to social, economic, and political systems regardless of location. U.S. leadership on global change issues necessitates understanding impacts and opportunities from a global perspective. Active dialogues and cooperation with international partners will strengthen and inform U.S. global change research efforts, policies, and investments domestically and abroad. Through international partnerships, USGCRP can leverage the best-available science and practices from around the world to inform U.S. policy and program decisions.

International institutions and activities such as the United Nations have demonstrated successful integration of international partnerships and information exchange by harmonizing the various missions and efforts of governmental institutions, non-governmental organizations, academia, and the public and private sector. By strengthening international partnerships, USGCRP can enable the application of data and information to U.S. activities effectively and efficiently, without redundancy of effort. The key features of the USGCRP approach to enhance international partnerships include:

- **Promote scientific diplomacy.** Leveraging USGCRP and its member agencies' strength in science, assessment, and education with international cooperation to strengthen science and technology partnerships will be a catalyst to other U.S. initiatives in policy and security.
- **Support emerging "boundary" initiatives to meet the needs of appropriate decision makers.** USGCRP will provide support for international organizations that are bridging the gap between scientific research and policy and public action. This initiative aligns with USGCRP's commitment to the "end-to-end" delivery of information, where relevant and accessible science is used to inform decisions.
- **Inform U.S. humanitarian development efforts**. The ability to assist foreign countries requires integrating multiple information streams, including climate predictions with a variety of social scientific data sets, such as economic and public health information so as to inform decisions from a cost-benefit perspective. USGCRP coordination of timely and relevant information regarding global change will inform more robust decisions related to U.S. international development efforts such as the Presidential Policy Directive on Global Development, especially in basic areas such as food security and health.
- **Strengthen U.S. efforts to respond to global change.** The State Department's Quadrennial Diplomacy and Development Review identified climate change as a destabilizing agent that affects many U.S. interests. American businesses will be affected by disruptions to global economic markets. Improving coordination and information exchange on topics related to global change such as population demographics or economic tradeoffs can inform a range of policy and investment decisions.

Effective partnerships will maximize domestic and international scientific exchange and best practices, and allow decision makers to make more informed science-based decisions domestically and globally. From the collective knowledge and experience across its

participating Federal agencies, USGCRP is uniquely positioned to identify potential synergies with existing international organizations and pursue collaborative programs that bridge the environmental challenges faced by governments, businesses, and society. By leveraging domestic and international knowledge, USGCRP can achieve a global change research program that will support "end-to-end" delivery of products and services in climate science, assessment, education, and implementation. Through these activities, USGCRP will play a key role in informing decision makers about the impacts of international policies on various U.S. sectors and the international implications of U.S. policies.

USGCRP can profoundly advance the Nation's capacity to apply scientific information to the strategic choices faced by decision makers in the context of global change. The best science will only benefit society when there is an ongoing process that evaluates the accessibility and use of the science for decision makers and society. USGCRP will strengthen connections between global change science, assessments, and decision making by: ensuring a responsive science agenda that meets decision maker needs, developing information pathways that support institutional decisions, engaging in ongoing evaluations of program effectiveness, and leveraging domestic and international capabilities and partnerships.

USGCRP's activities to inform decisions in a changing global environment will be conducted in coordination with its other goals: advancing science, conducting sustained assessments, and enhancing communication and education. Together, these strategic efforts will ensure that scientific information is timely, credible, relevant, and accessible, and that science is continuously and effectively communicated to planners and decision makers across all levels and sectors.

Goal 3: Sustained Assessments

Build sustained assessment capacity that improves the nation's ability to understand, anticipate, and respond to global change impacts and vulnerabilities.

Assessments are an essential tool for linking science and decision making. They survey, integrate, and synthesize science, within and between scientific disciplines and across sectors and regions. Assessments support the critical analysis of issues, highlighting key knowledge that can improve policy choices and identifying significant gaps that can limit effective decision making. They are vehicles for sustained dialogue among stakeholders across the country. Assessment activities also track progress by identifying changes in the condition of the integrated Earth system over time, advances in the underlying science, and changes in human response. As a result, they are a critical element in achieving USGCRP's vision.

Assessments have been an integral component of USGCRP since its inception. Individual agencies regularly use assessments to ensure that the agencies are meeting their legal mandates, and to deploy the best available science toward achieving their mission. Additionally, along with its strategic role as coordinator of Federal global change research, USGCRP is required by the Global Change Research Act of 1990 to conduct a National Climate Assessment (**see Text Box 9**). USGCRP also coordinates and supports U.S. participation in appropriate international assessment efforts, such as the Intergovernmental Panel on Climate Change. USGCRP has the capacity, resources, and interest for comprehensive national and international assessment of global change, and provides a link to U.S. participation in other assessments.

Text Box 9: National Climate Assessment.

The USGCRP is required on a periodic basis (not less frequently than every 4 years) to submit to the President and the Congress a report that:

1. *Integrates, evaluates, and interprets the findings of the USGCRP and discusses the scientific uncertainties associated with such findings;*
2. *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; and*
3. *Analyzes current trends in global change, both human- induced and natural, and projects major trends for the subsequent 25 to 100 years.*

- Global Change Research Act of 1990

The National Context

USGCRP agencies have long employed assessments as a central tool to support decision making based upon scientific outcomes. Keys to success include a careful stakeholder engagement process, development of indicators to quantify the effectiveness of policies, and adaptive management. Climate change adds an additional stress to environments already experiencing multiple other global change stresses (e.g., population growth, land use change, urbanization, and industrialization). Encompassing climate in assessments is further complicated by the need to account for regional differences in climate change impacts. Many entities are conducting assessments and preparing strategies for adaptation and mitigation. Of particular importance are the adaptation efforts within the Federal government, efforts that will be supported by explicitly focusing on the science and decision support needs of the Federal agencies as information is developed for the National Climate Assessment. Not only is the Federal government a key partner in the nation's efforts to adapt to climate change, it also has a direct stake in adaptation because climate change directly affects Federal services, operations, and programs across the country.

Text Box 10: The Federal Role in Making Regional Knowledge Accessible.

The USGCRP Strategic Plan calls for enhanced coordination and cooperation among the Federal global change science and service programs to realize its vision and contribute to a government-wide "end-to-end" approach to global change. This vision is responsive to a shared and clearly expressed need from communities across the United States for climate information and services to enable better planning and management of the risks of global change to people, places, and the economy. As a part of this vision, USGCRP and its member agencies will meet regional needs arising from local communities' specific socio-economic, environmental, and cultural contexts.

Planning is already underway, guided by the Council on Environmental Quality (CEQ) and the Office of Science and Technology Policy (OSTP), to better use the capacity of existing institutions of the Federal government and key partners to more efficiently and effectively deliver regional knowledge. The USGCRP Strategic Plan goals for Informing Decisions and Sustained Assessments are carefully designed with this regional coordination effort in mind. For instance, the eight regional networks of climate-related programs for the National Climate Assessment are identical to those used in the CEQ and OSTP adaptation efforts. This shared approach will result in USGCRP being better able to improve access to Federal climate information, tools, and resources specific to each region and across regions, and engage information users in a collaborative and inclusive process of both using and creating knowledge. USGCRP will support the development of regional adaptation strategies by strengthening the connections between Federal science and information users, and strengthening the pathways by which stakeholder needs are incorporated into research priorities.

To improve effectiveness and regional coordination, the Council on Environmental Quality, the Office of Science and Technology Policy, and USGCRP are working together to improve regional coordination to leverage capacity and expertise of our existing institutions, while providing flexibility to reflect the regional context, including differences in issues, assets and capabilities. Strong Federal research programs in eight identified regions (or "hubs") will engage with existing Federal and non-Federal partners throughout each region to coordinate climate science and services, connect decision makers and climate experts, and engage a broad range of stakeholders (see **Text Box 10**). This "hub and spoke" network approach should greatly facilitate employing common standards and information. Employing common standards will, in turn, enhance understanding of projections of climate impacts and promote best practices to adapt to future climate.

USGCRP is responsible for satisfying the legal mandate of the Global Change Research Act for a National Climate Assessment. The National Climate Assessment (National Assessment) is the USGCRP process that will produce an ongoing, comprehensive assessment of climate change for the Nation, including impacts, vulnerabilities and response strategies, within a context of how communities and the nation as a whole create sustainable and environmentally sound development paths.

In addition to the requirements of the Global Change Research Act to address specific components of natural and societal systems, assessments must account for the effects of global change where it directly impacts citizen's lives—their geographic region—and so the National Assessment includes analyses within regions of the country as an integral component. The National Assessment is also nested within a global context and connected to the international assessments whose activities are also supported by USGCRP. The National Assessment develops focused investigations of regional and sectoral topics, as well as integrated topics that have high priority due to existing or anticipated climate stresses. These "nested" investigations allow for a more detailed and focused assessment of issues in specific locations and within natural and human systems. Finally, because of the complexity of climate change, national and international assessments are expected to prioritize issues that cut across traditional topics and political boundaries. Tackling issues that cut across political boundaries requires consideration

of both geographically and biophysically defined regions (e.g., arid lands, coasts) and interactions between the natural and built environments (e.g., the nexus of energy, water, and land).

The strategic vision for the National Assessment differs in multiple ways from previous U.S. climate assessment efforts[22]. Building on the recommendations of the National Research Council, it will implement a long-term, consistent, and ongoing process for evaluation of climate risks and opportunities, and informing decision making processes within regions and sectors. An essential component of this process is to establish sustained assessment capacity both inside and outside of the Federal government that draws upon, and sustains, the work of stakeholders and scientists across the country. It will also be more focused on evaluating the current state of scientific knowledge relative to climate impacts and trends, and on supporting the Nation's activities in adaptation and mitigation. The National Assessment will lead the development of a small, consistent suite of indicators of climate change that encompass metrics for progress in adaptation and mitigation activities using a risk-based framing. The National Assessment will also be the initial focal point for development of an interagency global change information system that will provide timely, authoritative, and relevant information, and permit production of a set of reports and web-based products that are useful for decision making at multiple levels (see **Text Box 8**). The benefits of these new approaches to assessment include increased efficiency and leveraging of existing resources within USGCRP, deeper stakeholder involvement, spread of new ideas and best practices, a way to feed back information from users into the science priorities, and improved capacity to cope with global change. The resulting infrastructure, protocols, and tools will be available more widely to enable assessment processes across multiple scales and sectors, conducted outside the USGCRP umbrella.

The International Context

USGCRP recognizes the international context of climate trends and the connections between risks and vulnerabilities to the United States that are generated by climate impacts elsewhere. Adaptation and mitigation decisions within the United States have impacts on other countries, and vice versa. There are other kinds of interactions, because some adaptation options may increase greenhouse gas emissions, and some kinds of mitigation efforts increase risks associated with climate impacts. These impacts occur within ecological, physical, social and political systems that affect countries across the globe, and so the United States should remain fully engaged with the international community given the strategic importance of global trade, security, and diplomacy.

USGCRP and its member agencies will continue to play a pivotal role in coordinating and supporting the active engagement of the Nation's scientific community in appropriate international assessments, to ensure that national interests are represented. The Program also coordinates and supports U.S. scientist participation in the global assessment of the climate through the Intergovernmental Panel on Climate Change, providing strong intellectual input to the process. The National Assessment activities will be coordinated with the efforts of the Intergovernmental Panel on Climate Change and especially its North America chapter, to coordinate modeling activities, to maximize the benefit of work products from each to the other, and to better coordinate the involvement of U.S. volunteer scientists in both national and international assessments. Similarly, USGCRP will continue to act as a nexus for agency

participation in other international assessments of global change, such as the Arctic Climate Impact Assessment and the Scientific Assessment of Ozone Depletion (see **Box 17**).

In addition to global-scale assessments, USGCRP will also work to ensure that we understand how our neighbors are addressing global change, and to communicate with them to enhance our joint successes. The regional "hubs" will need to engage with their international neighbors on issues ranging from water resources, to biological invasions and habitat shifts, to energy and transportation. Promoting scientific diplomacy can be a catalyst for other U.S. initiatives while also streamlining implementation of adaptation and mitigation activities. Extending beyond the Nation's immediate boundaries, USGCRP assessments should also account for climate impacts on markets and people worldwide due to the increasingly complex fabric of international commerce.

Connections to Other Goals

Assessments support achievement of all of the other goals of the USGCRP Strategic Plan. For instance, they identify gaps in scientific understanding and highlight new scientific findings (Goal 1: Advance Science), which can then be transformed into policy-relevant information to inform decisions (Goal 2: Inform Decisions). Another important overlap with Advance Science is the critical issue of data management and deployment, as well as promoting interoperability and integration of climate-related information that is generated from a variety of sources. Similarly, the National Assessment will help synthesize and integrate scientific information for decision making related to global change across all sectors, regions, and scales, and improve the deployment and accessibility of science-based information to inform adaptation and mitigation decisions (Goal 2: Inform Decisions). Finally, successful assessment should establish sustained engagement among multiple stakeholders to enable effective decision making, which clearly overlaps with the central features of Goal 4: Communicate and Educate—to reach diverse audiences and to establish effective engagement. Additionally, the National Assessment process will promote a workforce capable with coping with a multi-stressor environment that requires an adaptive risk management approach.

In addition to coordination with the other USGCRP Strategic Plan Goals, achieving this Goal requires successful responses to four objectives whose interacting elements support a comprehensive national assessment process, respond to the Global Change Research Act and provide a platform for U.S. participation in international assessments. These elements include:

- Fully integrating the best scientific knowledge;
- Developing and deploying an ongoing assessment process;
- Ensuring the assessments captures relevant information to inform decision making;
- Continuously evaluating its progress and employing adaptive management over time.

Box 15. Vulnerability Assessment and Climate Change Adaptation in New York City.

Projections for New York City (NYC) suggest that by mid-century, up to two feet (0.6 meters) of sea level rise will greatly increase the frequency of flooding and the impacts of storm surge in many areas of the city if adaptation measures are not taken. In preparation for such a scenario, NYC undertook a city-wide risk assessment using historical tide gauge data, climate model outputs, recent ice melt and paleoclimate data. NYC decision makers were engaged throughout the risk assessment to ensure climate information was linked to adaptation planning. This engagement is helping to foster novel approaches to NYC's long-term adaptation to sea level rise that include urban planning and architectural perspectives, and it serves as a model for the science-stakeholder interaction that will increasingly inform USGCRP science and the development of user-friendly climate information.

Sea level and climate modeling supported by USGCRP agencies and included in Intergovernmental Panel on Climate Change projections are critical for risk assessment efforts such as the one New York City undertook. USGCRP will develop global change models that provide information at regional scales— the scales at which many adaptation decisions are made. USGCRP will also develop information services to ensure that scientific advances are useful and accessible to decision makers and managers.

Figure B15.1. The light blue area above depicts today's FEMA 100-year flood zone for the city (the area of the city that is expected to be flooded every 100 years). With rising sea levels, a 100-year flood at the end of the century (not mapped here) is projected to inundate a far larger area of New York City, especially under the higher emissions scenario. Critical transportation infrastructure located in the Battery area of lower Manhattan could be flooded far more frequently unless protected. The increased likelihood of flooding is causing planners to look into building storm-surge barriers in New York harbor to protect downtown New York City. Image credit: New York City, Applied Science Associates, Inc.

Objective 3.1: Scientific Integration

Integrate emerging scientific understanding of the integrated Earth system into assessments and identify critical gaps and limitations in scientific understanding.

Through the scientific endeavor, we continue to develop the capacity to understand observed climate events and trends, as well as to realistically project forward into the future (Goal 1: Advance Science). Assessments provide the opportunity for regular analysis and synthesis of the wealth of scientific data and understanding collected across the breadth of USGCRP agencies, all levels of government, the academic community, and the nonprofit and business sectors. Integrating and synthesizing our knowledge base, including "traditional" knowledge on a regular basis is crucial for informed adaptation, mitigation, and planning decisions, both nationally and internationally.

Integrating climate science into assessments also provides the requisite information to identify gaps in knowledge. For instance, Impacts, Adaptation, Vulnerability (IAV) models help formulate our understanding of the impacts of change, and the scope for adaptation of vulnerable populations or ecosystems (see Objective 1.4: Integrated Modeling), but need improvement to cope with the longer time scale of climate change. This information can then be used to assess options and prioritize investments in science and other Federal activities to maintain a sustained and coordinated research program that is responsive to both the Global Change Research Act and other ongoing assessment needs. The identification of science needs should include physical, ecological, and social science components that will allow prioritization of investments in adaptation and mitigation activities over the next decades. There is a particular need to continue to build the social science base for analysis of risks, vulnerabilities and adaptation options, as developed under Advance Science and Inform Decisions goals.

As the Nation moves forward to adapt to global change, the National Assessment needs to synthesize knowledge associated with adaptation and mitigation and to identify best practices from around the country and the globe, including risk-based approaches to community resilience and disaster preparedness. Components of the assessment reports should also integrate information to derive the latest knowledge how to facilitate making the best decisions under uncertainty given the long time line of global change and its impacts. This activity also has significant overlaps with Objective 3.3.

Scientific understanding will be applied to regional, sectoral, and crosscutting issues within the National Assessment to identify sustainable and environmentally sound development pathways as part of a comprehensive assessment of global change impacts, adaptation, and vulnerability. To achieve this understanding requires coordinated development of future visions of climate, societal, and related environmental conditions that provide common assumptions and scientific information to assessment teams in regions and economic sectors. These scenarios are not intended to predict the future, but to better understand the implications of uncertainties in decision making. A common, coordinated suite of scenarios is useful, but these scenarios can also provide input assumptions to various computer models that project forward in time to create an envelope of possible future climate states. The National Assessment and the U.S. components of the Intergovernmental Panel on Climate Change should facilitate the appropriate use of scenarios and technical guidelines and tools to enable regional and sectoral analyses that are useful to stakeholders and scientists. Nested assessments within the centrally developed scenario-driven model outputs should also be supported to provide analysis at a variety of spatial scales. These assessments will help establish common bounding assumptions across the Nation, but they do not preclude using alternative scenarios developed for more specific reasons.

In addition, a major challenge for our scientific understanding, and assessments generally, is the strongly voiced need from policy makers for realistic projections at decision-relevant spatial and temporal scales. As the desired temporal and spatial scales shrink from long term and global toward a more local scale, in some cases uncertainties in model output can increase and hence the value of the information may be more limited. Providing multiple timescale (e.g., seasonal to decadal) and spatial-scale information, while maintaining scientific rigor, is a strategic priority that will require significant effort over the coming decade (see **Text Box 7**). It will also be crucial to clearly communicate the current status of uncertainties in understanding and in the modeling efforts. Over the next decade, USGCRP will coordinate closer integration of IAV models and global climate models, as well as the National Assessment

and Intergovernmental Panel on Climate Change efforts, which historically have developed independently.

Increasingly, international collaborations on observations, scientific assessments, and model intercomparison projects are crucial components for understanding the U.S. context of climate change and ozone depletion. Such collaborations synergistically enhance the capabilities of the U.S. science effort, and broaden the science basis for international assessments. USGCRP will continue to play a key role in leading, coordinating, and responding to international assessments, fostering U.S. participation and leadership in global efforts, such as the International Panel on Climate Change and the Arctic Climate Impact Assessment (see **Box 17**). USGCRP will also support scientific involvement within the context of international collaborations that fulfill U.S. obligations to treaties such as the Vienna Convention for the Protection of the Ozone Layer, and other assessments that are critical for efforts towards environmental treaty verification.

Box 16. Assessments to Improve Conservation Action.

State, Federal, Tribal and nongovernmental organizations are responding to USGCRP findings on climate change and other landscape-scale changes, using them to identify opportunities for conservation and restoration at multiple scales. Nationwide, conservation organizations are partnering with government agencies on assessments to understand the combined impacts of climate change and other stressors and to integrate that knowledge into conservation actions. Assessments, particularly when repeated or sustained, evaluate the effectiveness of the science, decision-support tools, and approaches, and the progress they allow. Through its goal of "Sustained Assessments," USGCRP is creating a framework to enhance coordination and integration of various efforts across the country. The intent is to provide decision makers with authoritative information about natural resource management opportunities and constraints.

For example, Figure B16.1 displays wildlife corridors identified by State fish and wildlife agencies. Such corridors permit wildlife adaptation (such as migration) to a multitude of stressors, including climate change. Interagency cooperation promotes efficient assessment of existing corridors that facilitates effective placement of adaptation actions, such as the wildlife-crossing overpass (Figure B16.2), to permit migrations hindered by human barriers.

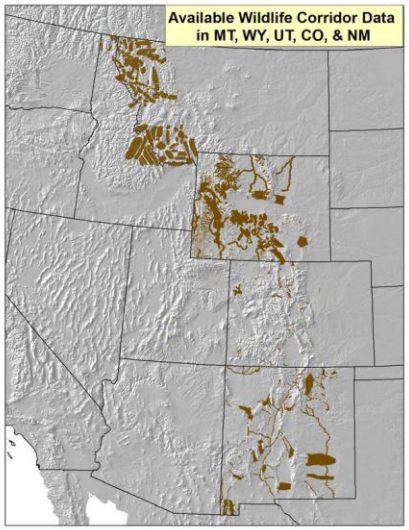


Figure B16.1. Wildlife corridors in the western United States. Photo credit: Western Governors Association.

Figure B16.2. A wildlife overpass in Montana. Photo credit: Scott Jackson.

Objective 3.2: Ongoing Capacity

Strengthen and evolve ongoing capacity to conduct assessments with accessible, transparent, and consistent processes and broad participation of stakeholders across regions and sectors.

Fostering an ongoing capacity to conduct assessments across the Nation requires the cooperation of a broad network of entities outside the government as well as the efforts of USGCRP agencies. One approach to broad engagement is to establish a network of partners or "network of networks" that links and aligns Federal capacity with a wide range of interested communities. The intent is to partner with groups with both interest in climate and the capability to provide capacity to support the National Assessment and other assessments, such as governmental bodies (state, local, tribal), regional entities (e.g., Governor's associations), nongovernmental organizations, trade associations (e.g., the Water Utility Climate Alliance), and academic institutions. The National Assessment intends to strengthen capacity to conduct assessments in a number of ways (e.g., training, technical assistance, partnerships with states, communities, nongovernmental organizations, and stakeholder groups) to improve institutional capability for, and commitment to, regular assessments.

Establishing a continuing, adaptive approach to national and international assessments, and an efficient and effective delivery of climate science and services (Goal 2: Inform Decisions), starts with better coordination of Federal agency climate science, assessments, and services in each region and economic sector (see **Text Box 10**). Many Federal agencies have regional offices and programs with unique assets and capabilities, through which they actively engage with extensive networks of partners at the local-to-regional scale, including partners in academia, state, local and tribal governments and in the private sector. Harmonizing efforts within each region, and providing benchmark scenarios of future conditions, benefits both decision makers and information providers by avoiding duplication of efforts and leveraging existing capabilities. Coordination of these efforts must be founded on a commitment to sustained engagement and collaboration with public and private sector decision makers in a process of shared learning and joint problem solving. Additionally, USGCRP, via its international alliances, will be able to provide a valuable interface with international science, assessment, adaptation, and mitigation experience and promote improved access to information that supports climate services at multiple scales.

National coordination of Federal climate activities therefore requires a framework that provides effective regional and cross-regional coordination to meet the overall national needs, while preserving the necessary flexibility for enabling different approaches within any given region. The Federal effort should focus in particular on supporting regional and international adaptation capacity and thus extends beyond both the National Assessment and USGCRP.

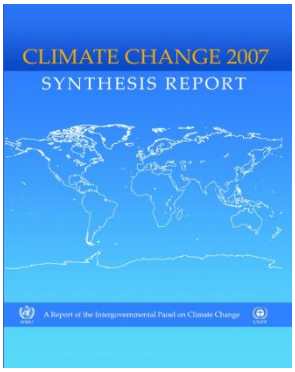
USGCRP will coordinate national assessment efforts across regions and sectors at multiple scales and build a sustained, collaborative network of public and private partners and stakeholders who are engaged in the National Assessment process, maximizing integration with related public and private sector efforts and institutions and supporting both regional and sectoral assessment capacity. The National Climate Assessment Development and Advisory Committee has been designed to foster the ongoing capacity of the assessment process and more fully engage all regions, sectors, and perspectives across the country as well as internationally.

Objective 3.3: Inform Responses

Inform responses to global change with accurate, authoritative, and timely information that is accessible to multiple audiences in multiple formats.

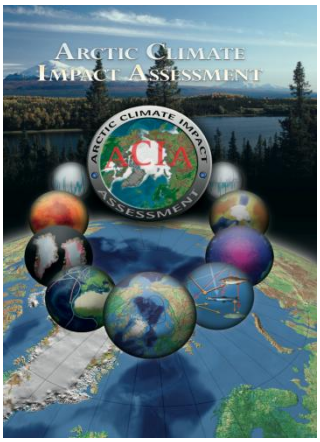
Many decision makers, whether in government, nongovernmental organizations, or private industry, require information about global change. These audiences need scientific insights into the status, risks, and opportunities for adaptation and mitigation at a variety of scales, as well as the capacity to evaluate the utility of alternative approaches. A key role for USGCRP agencies is providing accurate, authoritative, and timely climate-related information, developed as part of Goal 1 (Advance Science) and Goal 2 (Inform Decisions), across the nation and the world. Consistent scenarios of the future (Objective 3.1) provide a concrete example of this USGCRP role, and national indicators of global change should be developed to act as a benchmark across federal to local planning efforts. The network designed to foster an ongoing capacity for assessment (Objective 3.2) must be intentionally designed to provide an information foundation for climate services so that best practices can be strengthened, needs identified, and tool developed to meet needs at all scales of decision making. These efforts will maximize equitable access to information that supports adaptation and mitigation decision making, especially for regions, sectors, ecosystems, populations, and systems (e.g., transportation, energy) that are identified as most vulnerable.

Box 17. International Assessments.



USGCRP and its member agencies coordinate a wide range of scientific participation in international assessments, where U.S. scientists play an important role in analyzing the current state of science and adaptation efforts worldwide. For instance, USGCRP supports participation of U.S. scientists on the International Panel on Climate Change (IPCC), and the activities of the IPCC Working Group on Impacts, Adaptation, and Vulnerability. USGCRP coordinates participation of U.S. contributors to all IPCC working groups, and leads the coordination of author nominations and government and expert reviews of IPCC products in cooperation with other federal entities.

Another example of an important U.S. contribution coordinated through USGCRP was the development of the Arctic Climate Impact Assessment (ACIA). ACIA was an international project to evaluate and synthesize knowledge on climate variability, climate change, and increased ultraviolet radiation and their consequences. The United States is a member of the eight-nation Arctic Council, a high-level intergovernmental forum that requested this major assessment in response to clear evidence of major impacts on the Arctic and its people. Working through the International Arctic Science Committee, USGCRP agencies supported the requisite activities to bring this critical effort to fruition. Looking ahead, the United States will chair the Arctic Council in 2017, during which significant related activities, including the ongoing Arctic Change Assessment, and other relevant activities, including the development of the U.S.-chaired Sustained Arctic Observation Network, will be well underway. USGCRP will closely coordinate the Alaska regional assessment chapter of its 2017 National Climate Assessment report with U.S. participation in these next pan-Arctic assessment and monitoring efforts.



Assessment Panels have been integral to the United Nation's Environment Programme's ozone protection regime since the very beginning of the implementation of the "Montreal Protocol on Substances that Deplete the Ozone Layer." Its panels for Technology and Economic Assessment, Scientific Assessment, and Environmental Effects Assessment have helped the Parties to reach informed decisions and mitigation actions that have led to a reduction in the ozone hole. The United States, as one of the parties, relies on USGCRP science and observations to monitor the ozone layer and understand its dynamics.

USGCRP will continue building rigorous processes to ensure the quality and transparency of data, information, and knowledge that are provided from the wide range of sources (see also Objectives 1.5 and 2.3). The network (Objective 3.2) will provide not only traditional sources of information such as peer-reviewed literature but will also use information services to incorporate Federal government data and multiple other sources of useful information, including state governments, businesses, or nongovernmental organizations, as well as traditional knowledge from tribal sources. All of these sources will need to be evaluated prior to inclusion in assessment products with a consistent, clear, and objective procedure that not only exceeds the requirements of the Federal Information Quality Act, but also holds up to critical external appraisal.

It is critical for USGCRP to develop and deploy effective and efficient communications, outreach, education, and engagement processes including web-based data and tools and new media (e.g., social networking) to help make assessment information accessible and useful to the wide array of Program stakeholders. Successful implementation will include a national discourse on global change that involves scientists and other stakeholders and promotes a more literate citizenry relative to climate issues. Online access will increase the usefulness of the data and information collected for the assessments as well as support development of climate-related educational curricula. The development of a comprehensive and user-friendly website will be a critical component of the assessment, requiring a data architecture that supports robust archiving, retrieval, and quality assurance. Indeed, the needs of the National Climate Assessment will be an initial test bed for development of a Federal interagency global change information system that will provide timely and relevant data and information to stakeholders, including the public (see **Text Box 8**). Development of this information system will require close coordination with implementation of Goal 4 (Communicate and Educate).

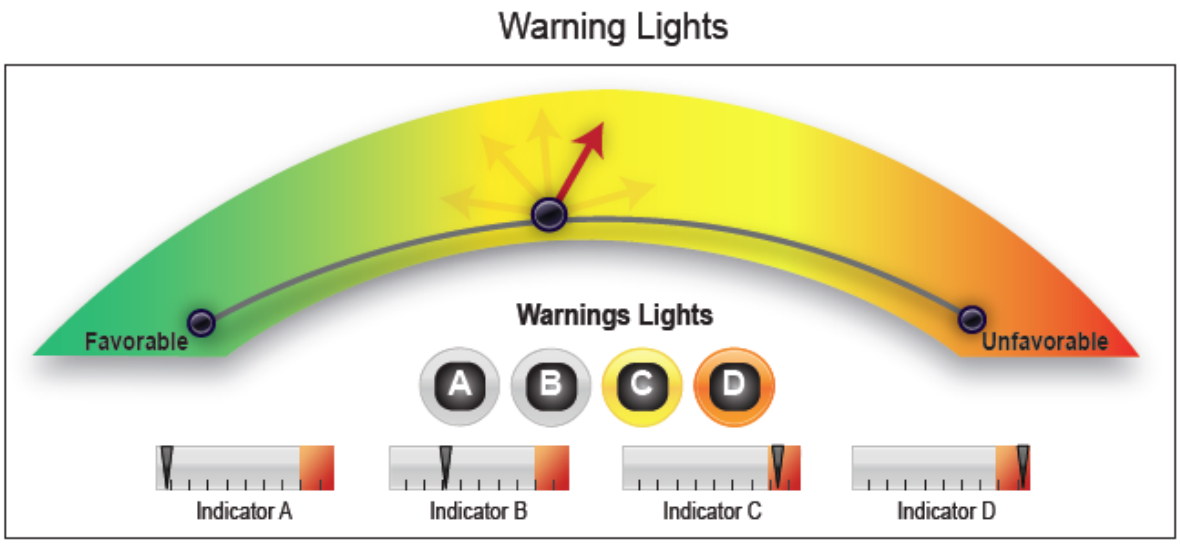
Informing responses to global change requires ongoing evaluation of key issues for the Nation and evaluating progress towards reducing the Nation's vulnerability and risk. USGCRP, through the National Assessment process, will engage in designing and sustaining a small, coordinated suite of climate-related physical, ecological, and societal indicators that are easily communicated to interested parties. They will be tracked as a part of ongoing, long-term assessment activities, with adjustments as necessary to adapt to changing conditions and understanding. These indicators should:

- Provide meaningful climate-relevant information about the status and trends in of key physical, ecological, and social variables and values to inform decisions on management, research, and education at regional to national scales, for key sectors identified by the National Assessment process.
- Provide an early warning of changes in climate-related conditions of selected resources and valued systems to help develop effective mitigation measures and reduce costs of management.
- Provide data to better understand the climate-driven dynamic nature and condition of Earth's systems and societies and to provide reference points for comparisons.

The resulting national metrics will help decision makers understand progress being made in adapting to and mitigating climate change effects based on implemented policies and activities. The metric dashboard in **Figure 3** provides a user-friendly method to understand the cross-cutting indicators on a broad, comprehensive level, but also permits the user to focus on

specific indicators that may contain information more applicable to their particular region of the country. By having this information easily accessible on a timely basis, decision makers around the nation can more quickly develop new ideas and practices to improve their ability to respond and adapt to climate change.

Figure 3: National Indicators to Inform Decisions



Objective 3.4: Evaluate Progress

Ensure ongoing evaluation of assessment processes and products, and incorporate the findings into an adaptive response for systemic improvement.

A full evaluation of the national and international components of the USGCRP assessment process and products will be undertaken in an iterative and adaptive fashion. Assessment products and processes to be evaluated include those mandated by the Global Change Research Act of 1990, the corresponding and relevant processes and products described in this USGCRP decadal strategy, the U.S. components of the International Panel on Climate Change, and the National Assessment processes and products. Evaluation of progress toward achieving the objectives of the National Assessment, and USGCRP participation in other assessments, will be institutionalized into the annual USGCRP work plan to support improvements in methodologies, process, and products of the assessments. The National Climate Assessment Development and Advisory Committee, a Federal advisory committee responsible for producing Assessment reports, will provide ongoing advice on Assessment processes. Finally, the National Research Council will be engaged to conduct an independent, external review of the National Assessment and other USGCRP assessment involvements.

Public peer review of the assessment reports will likely involve academic, state, industry, international, and other groups conducting global change research. Criteria and metrics for peer review should include: scientific integrity of products and processes; evaluation of the degree of integration, evaluation, and interpretation of findings; evaluation of the scientific adequacy of

analysis of global change effects; transparency and credibility of data and sources evaluated within the context of the Federal information quality requirements; and others.

Consultation with actual and potential users of the results prior to, during, and upon completion of assessment processes and product development will ensure that such results are useful in developing policy responses to global change. Criteria could include, for example, evaluations of the degree to which products are used and useful by targeted stakeholders, a review of the "salience, credibility, and legitimacy" of products and processes, and measures of increases in capacity.

Evaluation of participatory processes includes assessment of the quality, effectiveness, and sustainability of participation, and the extent of geographic and sectoral participation. The criteria for evaluation will in part consist of assessing how the various participation processes have contributed to the goals of the assessments. Other potential criteria for evaluating participation include assessing the breadth of representation in various activities, the nature of the relationships developed among the individuals and organizations that participate in National Assessment and other assessment activities, and the success in achieving the objectives and outcomes outlined in the National Assessment strategic plan. Evaluating progress toward building sustained assessment processes will come through a variety of formal and informal channels as part of a logical process that tracks participation from the time that an activity is initiated through the ultimate outputs, outcomes, impacts of the participation, and evaluation of the process and products. Each activity that includes participation should include the opportunity for participants to provide feedback on their experience, minimally through a written evaluation, but also through mechanisms such as pre- and post-activity surveys of knowledge and capacity, more focused written or oral evaluations, and follow-up discussions with organizers.

Goal 4: Communicate and Educate

Advance communications and education to broaden public understanding of global change and empower the workforce of the future.

From our communities, to our businesses, to our government agencies, global changes increasingly need to be considered when making decisions. Decision makers and leaders are the focus of USGCRP's Inform Decisions Goal. The Communicate and Educate Goal will address public understanding and workforce development.

The public is best served when connections between research outcomes and the things people care about (e.g., clean drinking water or shifts in their community's coastline) are clear and shown explicitly. Public surveys and assessments on the state of environmental literacy indicate that new approaches to communication and education efforts are needed to engage citizens in global change and related societal issues, such as energy and food security, and water availability.[23]

In the next decade, USGCRP will focus not only on fostering greater public understanding of the science through the dissemination of relevant, timely, and credible global change information, but also on gaining greater understanding of the public's science and information needs through engagement and dialogue. This dialogue will be accomplished by the Program integrating communication, education, and engagement into its core activities.

As the leading Federal authority on global change science, USGCRP and its member agencies are uniquely positioned to serve as the gateway to global change information. Many Federal agencies have the capacity to communicate with citizens on specific aspects of global change information. However, it is important to recognize that the great strength of USGCRP is in its ability to coordinate those Federal agencies in combined communication and education efforts.

The USGCRP strategy for communication, education, and engagement efforts in the next decade will build on the strengths of the participating agencies. The Program will coordinate the development of multi-agency products and programs, grow and expand the reach of information beyond single agencies, and ensure that feedback and input from public engagement is shared broadly within the Federal global change science community.

USGCRP will accomplish its Communicate and Educate goal through four objectives that will be used to guide Program activities:

Objective 4.1 (Strengthen Communication and Education Research): Strengthen global change communication and education research to enhance practices.

Objective 4.2 (Reach Diverse Audiences): Enhance existing and employ emerging tools and resources to inform and educate effectively, providing for information flow in multiple directions.

Objective 4.3 (Increase Engagement): Establish effective and sustained engagement to enable a responsive and wholly integrated Program.

Objective 4.4 (Cultivate Workforce): Cultivate a capable, diverse workforce that is knowledgeable about global change.

The first three objectives address the need for broadening public awareness and understanding of global change through better understanding of citizens' existing knowledge and information needs. They also address the need to (1) employ a robust combination of tools and methods to effectively meet those needs, (2) build and sustain relationships to foster greater understanding of USGCRP programs and activities, and (3) develop methods and processes for engagement and dialogue. Objective 4.4 focuses on communication and education activities that will help build the diverse national workforce needed to fill jobs in areas of global change science. The U.S. Department of Labor estimates that jobs requiring science expertise are expected to grow much faster than the average for all occupations through 2018.[24] USGCRP agencies can play a key role in making sure that the workforce has the broad scientific expertise necessary to respond to future needs.

Box 18. Building Climate Literacy.

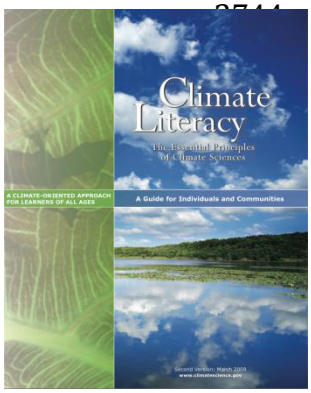


Figure B18.1. Cover of the report Climate Literacy: The Essential Principles of Climate Science, *published in 2009 (for a copy, go to http://www.climatescience.gov/Library/Literacy/)*

Climate literacy is knowledge and understanding of the concepts and processes that control Earth's climate; the influence of climate on individuals, communities, and society; and the influence of humans on climate. In partnership with scientific and educational organizations, USGCRP developed *Climate Literacy: The Essential Principles of Climate Science* (2009). The publication continues to be used as a valuable resource for teachers, students, and community leaders as a topic for discussion within local communities, and as a guide for the development of informal learning resources and science curriculum content standards around the country.

Figure B18.2. High school students watch a demonstration at a "Science Careers in Search of Women" conference. Photo credit: Argonne National Laboratory.

Objective 4.1: Strengthen Communication and Education Research

Strengthen global change communication and education research to enhance practices

A major goal for USGCRP is to understand the connections among the environmental knowledge, opinions, attitudes, and behaviors of its diverse audiences. Such information will help USGCRP and its member agencies share scientific information effectively with the Program's different audiences, including Federal, state, local and tribal organizations; local adaptation planners; scientists; green businesses; students; and climate-interested citizens. Knowing the interests and background of the audiences at any given juncture is an important factor for communicating and educating effectively, as are the many important lessons that are

provided by social science.[25] As USGCRP plans its communication, education, and engagement activities for the next 10 years, understanding the motivations, needs, and learning styles of our diverse stakeholders will be a key in developing tools and resources that are successful and widely used.

Research to Assess Global Change Communication Effectiveness

Over the past decade, numerous agencies and institutions have invested in research on global change science knowledge and communication. USGCRP and its member agencies will develop an understanding of what this research shows about the audiences and stakeholders the Program wants to reach, and identify priority areas where additional research is needed. Information gathered using a variety of research tools and methods, such as large-scale surveys, literature reviews, and listening sessions will form the groundwork for prioritizing our efforts. USGCRP will work with its member agencies to analyze the additional social science and education research that should be prioritized.

Establishing a global change information system (see **Text Box 8**), assisting agency communications efforts using a variety of social media tools, and effectively coordinating national education programs are just a few areas where research and coordinated communications activities can help the public understand options for shaping future directions. Developing global change science communicators and science storytellers, and creating a strategy for how best to communicate using new tools, are other areas that research can also strengthen.

Objective 4.2: Reach Diverse Audiences

Enhance existing and employ emerging tools and resources to inform and educate effectively, providing for information flow in multiple directions

Supporting research to understand audiences and gain insight into what sorts of tools and strategies will work to reach those audiences is only the first step in developing a strong communications and education program within USGCRP. USGCRP and its member agencies will develop and use the methods and tools for translating the science, and bringing it to those who need it, in the most efficient, straightforward, and engaging manner, as needed to support all the other goals.

Employ Technological and Human Advances

The fields of communications and education are changing quickly in the 21st century, with new technologies for building social networks and interactivity that are reaching vast new audiences. The USGCRP of the future will need to adopt many existing technological advances, as well as embrace emerging ones, to provide global change educational information and communications. Social media will play a growing role in USGCRP communications activities, and communicators and educators within the Program will work to develop other new media tools that can engage the public in global change science. With its coordination role among the Federal agencies, USGCRP has the advantage of being able to combine and build upon the existing skills and considerable technological capacities of individual agencies to cooperate in devising cutting-edge communication and education tools. In addition, USGCRP will promote

people-driven capabilities, such as agency extension services and community-based outreach to reach a more diverse audience. And above all, flexibility will be key for developing the most relevant, usable, and timely resources. USGCRP communications and education should remain up-to-date and build in adaptability to emerging technologies as a main component of its communications and education programs, including the evaluation of their effectiveness.

Box 19. Science Learning.

Learning is a life-long process. Museums, botanical gardens, zoos, aquariums, and libraries, as well as TV, the Internet, and other communications technologies help to generate awareness of and interest in the natural world. By taking advantage of these information resources, where new concepts may be introduced or others elaborated upon, people can increase their scientific understanding and use it to enrich their interactions with the world around them.

USGCRP Federal agency members use informal environments for science learning, through activities such as developing community-educator partnerships and direct engagements with diverse audiences. For example, a resource package, *The Climate Change Wildlife and Wildlands Toolkit for Formal and Informal Educators* (http://www.globalchange.gov/resources/educators/toolkit) was developed by multiple USGCRP agencies based on the award-winning and very popular toolkit first published in 2001. The updated 2007 toolkit includes an easy-to-understand overview of the science of climate change, a DVD, classroom activities aligned with national science standards, and information on habitats and wildlife in 11 ecoregions, as well as information on what kids can do to help.

Figure B19.1. A citizen science backyard bird-banding program run by Smithsonian Migratory Bird Center. Photo credit: Smithsonian Institution.

Future directions for USGCRP informal education activities could include contributing to:

- Museum exhibits and programs, including citizen science projects, to educate and engage citizens on the environmental changes happening around them
- Online resources for students and parents that include short presentations on a series of scientific topics and the opportunity to ask questions of scientists who are working for/with USGCRP agencies
- Resources and activities for K–12 learners based on recent science findings that can be used in science-rich out-of-school settings by facilitators who know how to organize and support science learning

Support Forums

Such communications tools are not just limited to technological resources, but also include resources that define new ways of communicating and educating. As such, an important component of USGCRP communication and education will be developing communities of practice, where communications and education experts will have the opportunity to discuss projects that have the potential to span agencies and scientific specialty fields, and leverage skills that exist within each agency for the benefit of the greater whole. USGCRP will support interagency groups that function as communities of practice, bringing together diverse education, communication, public information, extension services, engagement, and new media experts together to share research findings, tools, and practices, and work together to develop interagency projects.

Promote Interdisciplinary Education

Finally, essential to the USGCRP mission is the improvement of the scientific accuracy, educational effectiveness, and usability of communication and education materials and resources. These resources must incorporate an integrated Earth system science approach, social science, and educational research findings and promote an interdisciplinary framework. Education and communications practices must reinforce the main ideas of the climate literacy framework, they must be aligned with National and state standards, and they must be developed in collaboration with state and local entities. USGCRP will coordinate its efforts with other education initiatives to provide students and educators with innovative learning opportunities.

Further, USGCRP and its member agencies will provide the knowledge base for informal science learning programs at zoos, botanical parks, arboretums, museums, aquariums, community organizations, and similar institutions. Such informal settings can provide ideal opportunities to citizens of all ages and backgrounds to explore ways in which global change are affecting local communities. With an appropriately forward-looking approach, global change education and communication efforts within USGCRP agencies will serve the broader need to invest in our next generation of scientists, engineers, and educators so America can remain at the forefront of innovation and competition in the 21st century global marketplace.

Objective 4.3: Increase Engagement

Establish effective and sustained engagement to enable a responsive and wholly integrated USGCRP

Effective engagement with a person, group, or organization requires a dialogue to better understand stakeholder needs, issues, understanding, and expectations. Transparency and openness in communication and education builds credibility and trust. USGCRP will seek to engage a broad array of stakeholders, both within the United States and internationally, to ensure that Federal science is effective in addressing their issues and needs. The Program is uniquely positioned to broaden and expand existing relationships with stakeholders as well as forge new relationships through the extension of participating Federal agencies.

Build and Maintain Relationships

USGCRP will develop programs and forms of engagement to facilitate communication and education among citizens, stakeholders, partners, and the participating agencies. Providing timely, reliable, and credible information products and services to these audiences, which are relevant and easy to use, will be the key to establishing long-lasting relationships. Providing these products is important across the program and in the context of the National Climate Assessment.

Tailoring engagement methods to stakeholders' needs supports effective engagement, and positive outcomes. USGCRP and its partner agencies will use current knowledge of audiences, including understanding of their interests, motivations, and needs as related to global change science (Objective 4.1) to develop effective engagement tools and technologies (Objective 4.2). USGCRP will employ appropriate methods and processes for engaging with and seeking feedback and input from partners, participating agencies, and constituents. Engagement

activities will create pathways for public feedback and information needs that will be considered during the development of annual science priorities (see Goal 1: Advance Science), and to help guide development of more effective decision support tools (see Goal 2: Inform Decisions).

Box 20. Global Change in Your Backyard.

Phenology is a scientific term for the timing of activity of plants and animals, such as the appearance each year of leaves and flowers, maturation of crops, emergence of insects, laying of eggs, timing of hibernations, and the migration of birds. Knowledge of phenology is critical for helping farmers and gardeners know when to plant or harvest, helping environmental managers anticipate drought and wildfire risks, and helping public health officials anticipate allergy season or the spread of mosquito-borne diseases. Phenology is, fundamentally, nature's calendar.

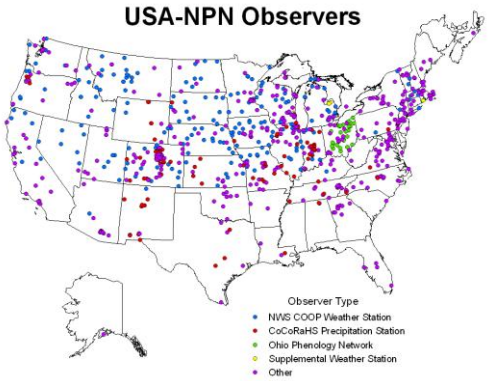


Figure B20.1. Image courtesy of the National Phenology Network

We know that changes in phenology are among the most sensitive biological indicators of global change. Across the world today, many springtime events are occurring earlier—and fall events happening later—than in the past. These changes are happening quickly for some species and more slowly, or not at all, for others, altering relationships and processes that have been stable for thousands of years. Scientists need more and better information about the pace and patterns of these changes to answer key scientific questions and to build the tools and models needed to help people understand and adapt to the changes.

Figure B20.2. Citizen scientists at work in Sonora, Mexico. Photo credit: D. Rosemartin.

The USA National Phenology Network (USA-NPN) monitors the phenology of plants, animals, and landscapes and provides key data to uncover trends and changes on a national scale. USA-NPN is a partnership among governmental and nongovernmental science and resource management agencies and organizations, the academic community, and the public. These groups and institutions work together to collect and organize species and timing information to inform research, education and outreach, agriculture, tourism and recreation, human health, and natural resource conservation and management. USA-NPN encourages people of all ages and backgrounds to observe phenological events as a way to discover and explore the world. By providing a place for people to enter, store, and share their observations, it also makes it possible for the general public to help researchers improve our understanding about how changes in phenology relate to climate change.

USA-NPN activities—which are supported by a number of USGCRP agencies—are organized through its National Coordinating Office at the University of Arizona. Continued support will be critical to help USA-NPN engage even more members of the public in the scientific enterprise and make it easier for their observations to become part of the large body of Earth system data used by researchers, farmers, government officials, and businesses. Harnessing new technologies, such as applications for mobile devices and social networking sites, will be key for future progress. Overall, increasing public involvement in the process of science, including data collection, analysis, and interpretation, will strengthen our national global change research enterprise and increase public literacy in global change science.

Develop Methods and Processes

USGCRP and its member agencies will take specific actions to better understand information pathways and channels by conducting audience analyses to learn how audiences create, receive, and use information. The Program will expand its reach by leveraging existing communications and engagement channels established by the participating Federal agencies. USGCRP will use collaboration technologies, such as tools that help people share different perspectives, collaborate across disciplines, and facilitate the creative process. The development of both virtual and actual communities of practice will provide the opportunity for communication and education professionals to network and identify counterparts and partners as well as to share knowledge and best practices.

Objective 4.4: Cultivate Workforce

Cultivate a capable, diverse workforce that is knowledgeable about global change.

Cultivating a capable, diverse national workforce that is knowledgeable about global change and is environmentally literate in general will take significant strategic collaborations and systemic efforts. The complexity of the science requires input and knowledge from many different disciplines to prepare such a workforce. To have new scientists and future leaders with a strong understanding of the interrelated nature of coupled human-natural systems, they should receive academic preparation and professional development. An interdisciplinary approach is essential, combining physical, biological, and socio-economic sciences. Furthermore, the green jobs critical for adaptation and mitigation of global change will encompass many levels of expertise, from scientific discovery, to business, to facilitation in the implementation of environmental technologies. Students and others interested in environmental science and green careers are going to be looking for high-quality academic programs and cutting-edge research to prepare them for this growing employment sector of the future.

USGCRP is uniquely positioned to coordinate an effort to raise environmental literacy and develop a future workforce that actively integrates global change and environmental considerations into future activities. USGCRP will also work to promote workforce gender, racial, ethnic, cultural, and physical diversity. Focusing on diversity will ensure that distinct perspectives, talents, and skills are fully used and will permit the development of a more adaptable, creative, and relevant workforce.

Build Federal Workforce Knowledge and Capabilities

The scope of the workforce to be addressed by USGCRP and its member agencies includes the private sector and the federal workforce. USGCRP will continue to work with cadres of federal employees and contractors so that they are knowledgeable about the connections between natural and human systems, build linkages across disciplines, and are skilled in communication and engagement with targeted stakeholders and decision makers. They must be capable of using science to develop tools and resources that are useful to communities, and the public and the private sector as they make decisions informed by the science of global change.

Through USGCRP discussions, member agencies can collaborate to assess what skills are necessary to ensure the workforce can meet all of these needs. USGCRP agencies can then apply that information to design appropriate learning and development activities to allow the federal workforce to respond to global change needs now and into the future.

Develop a Next-Generation Workforce

USGCRP will leverage partnerships among the Federal agencies to support workforce development needs and interests at the federal, state, and local levels as well as at universities and in the private sector. USGCRP member agencies will promote interdisciplinary opportunities at the undergraduate, graduate, and postdoctoral levels to ensure a knowledgeable and well-trained workforce for continued advances in sustainability, climate, and global change science; provide the knowledge base for teaching and training programs at colleges and universities with particular emphasis on bridging physical, biological, social sciences, and engineering; and support educators' professional development in science, technology, engineering, mathematics (STEM) and social sciences as they inspire and educate the next generation to achieve in career paths relevant to global change, in and beyond the STEM fields.

The pace and impacts of global change are occurring outside the range of past experience, rendering many of our current adaptive mechanisms insufficient. Incorporation of science is essential for successful planning, implementation, and evaluation of the U.S. adaptation and mitigation strategies. The intimate interactions within the natural-human system also call for full-scale multidecadal engagement with stakeholders, decision makers, and citizens. USGCRP and its member agencies will provide timely, relevant, and accessible information to the Nation and its international partners, and will use the feedback from such engagement to inform its directions for scientific research, as well as the provision of information and services.

The communication and education objectives and directions outlined in this section represent a commitment to include communication, education, and engagement as a foundational and integral component of everything USGCRP does. USGCRP and its member agencies will build from existing capabilities, incorporate existing and new findings from communication and education research into its practices, and expand partnerships within and beyond the Federal government. USGCRP will also integrate robust evaluation in all its processes and be nimble and flexible in its implementation.

IV: COORDINATING WITH OTHER NATIONS AND INTERNATIONAL ORGANIZATIONS

USGCRP cooperates internationally because it enhances and complements the strengths, interests, and needs of USGCRP and its partner agencies. The issues and challenges that USGCRP faces are global and are larger than the United States can deal with on its own. For any field of science, this vast scope would imply that international engagement is critical. For USGCRP science, however, the importance of international engagement is even greater.

Recognizing the strategic benefits of collaborating with international partners, USGCRP is required, in the Global Change Research Act of 1990, to: (1) coordinate U.S. activities with other nations and international organizations on global change research projects and activities, (2) promote international cooperation and access to scientific data and information, and (3) participate in international global change research by developing nations. Through international engagement, USGCRP and its member agencies can effectively leverage existing and future scientific capabilities to more effectively use resources to accomplish goals and strategic priorities.

USGCRP engages in many international global change activities by supporting a variety of international programs such as the World Climate Research Program (WCRP), the International Geosphere-Biosphere Program (IGBP), the International Human Dimensions Program (IHDP), the Earth Systems Science Partnership (ESSP), DIVERSITAS, and the SysTem for Analysis, Research and Training (START). In addition, individual USGCRP agencies support other programs and projects that provide coordination of multidisciplinary research relevant to global environmental change.

These activities have resulted in substantially improved understanding of the Earth system processes that underlie global change. They have provided both scientific results and data that have improved models of global change and scenarios that predict such change and its impact, and these activities have made major contributions to the work of the

Text Box 11: International Cooperation.

Understanding and responding to environmental change at global and regional levels requires far greater scientific expertise, technological capabilities, and resources than any one country can manage alone. Congress recognized the need for international cooperation at the outset of the USGCRP.

The international scientific community has recognized the need for a new unifying vision to coordinate global change research at the international level. The leadership of the International Council for Science (ICSU), with input from USGCRP, is shaping the development of an international vision with support and contributions by agencies that fund global environmental change research. The Belmont Forum and the International Group of Funding Agencies for Global Change Research (IGFA) are working with ICSU and the International Social Science Council (ISSC) to redefine what is needed to understand global and regional change.

In parallel, long-standing international organizations such as the World Meteorological Organization (WMO), the United Nations Environment Program (UNEP), and the Consultative Group on International Agricultural Research (CGIAR) system are restructuring their organizations to develop new programs that address climate and global change. Best available scientific practices and observations at local and regional scales are essential for these organizations to successfully deliver actionable information to end users and decision makers globally.

Although the United States and other major industrialized countries presently conduct the great majority of research on climate and global change, to understand such change on global and regional scales will require scientific information and observations from some regions of the globe where scientific capabilities are not well developed. Therefore, it will be increasingly important to help the countries in these regions, their scientists, and their institutions build capabilities and knowledge that will enable them to contribute to regional and global programs.

Intergovernmental Panel on Climate Change and to its assessments (see **Box 17**). In addition, support of the international programs has helped introduce social science perspectives, and has promoted science engagement and capacity building in developing countries. These programs and their associated infrastructure provide an essential framework within which U.S. scientists lead, conduct, and participate in a wide range of international global change research projects that advance key scientific objectives of the USGCRP. In addition, these global efforts have provided the U.S. science community with opportunities to develop long-term collaborative partnerships with their international colleagues.

USGCRP will identify potential synergies with existing international partners and investigate collaborating with new programs to the extent that these programs help meet the USGCRP needs. For example, there are opportunities for USGCRP to effectively coordinate research in specific geographical regions by cooperating with specific international research networks such as the Inter-American Institute for Global Change Research, the Asia-Pacific Network for Global Environmental Change and the African Network for Environmental System Science.

Another example of an international effort to advance cooperation among the international global environmental change community can be found in the outcomes of the World Climate Conference-3 (2009; http://www.wmo.int/wcc3/page_en.php), which decided to establish a Global Framework for Climate Services (GFCS) to strengthen the application of science-based climate prediction and services around the world. Such a framework could be tremendously valuable in managing global climate-related risks because it maximizes the existing global investments in observing, monitoring, and modeling systems, and climate service delivery, and has the potential to offer significant economic, public health and safety, and security benefits for participating countries. The GFCS vision aligns well with the new USGCRP focus on providing end-to-end capacity, and is highly relevant to the natural, physical, and social science research that is being undertaken in USGCRP agencies. USGCRP is already working with WCRP to develop the modeling and understanding components of GFCS that will emphasize linkages to adaptation and observations. USGCRP can further contribute to, and benefit from, this emerging framework through increased coordination with the international community on climate services.

USGCRP science is also related to issues of domestic and international policy, which require a close connection between the physical and biological sciences traditionally emphasized by USGCRP and the social and behavioral sciences. Although the natural sciences can provide insight into how the environment may change, the social sciences provide the critical information about the sources of these changes, as well as how people and societies behave in the face of change, and how their societal values may address the policy decisions that are made in a given country. Given that such values and behavior may vary from one country to the next, it is important that the global dimensions of the social sciences relevant to the relationship with the environment are understood, and this can only be done through international cooperation.

Global Earth observations are another area in which international partnerships leverage investments and increase useable science. Sustained global observing systems, including both surface-based networks (including measurements made from aircraft, balloons, and mobile oceanic observing platforms) and satellites, are critical components of global environmental research, as are shorter-term, intensive field-based research. Although many countries have their

own capabilities, to provide a comprehensive global data set, there is a need to develop an intelligently integrated and consistent observing system that addresses both sustained and shorter-term ("intensive") observations, with transparency relative to aspects such as calibration, algorithms, and data utilization.

Many U.S. global change observing systems have benefited greatly from highly substantive international collaborations. Eleven countries are partnering with NASA on currently operating satellite instruments, which are producing invaluable data for studies of global change. Many more countries allow deployment of U.S. global change equipment within their borders (or provide their own capability) for calibration and validation of satellite measurements and/or gathering of complementary data.

In the case of process-oriented field campaigns, access to the territory and airspace of other countries, the ocean, and Arctic is crucial to comprehensive data collection. Field campaigns in these areas typically require the joint efforts of multiple countries to achieve critical mass in terms of comprehensiveness of observations, including data collection among multiple platforms, such as ships and/or aircraft.

Text Box 12: International Observations.

Many U.S. global change observing systems benefited greatly from highly substantive international collaborations. Some illustrations provide a view of the important role played by other countries.

- NASA and the French space agency Centre National d'Etudes Spaciales (CNES) designed, built and launched three research satellite missions to establish stable, high-accuracy, and well-calibrated global sea level time series measurements, now operated by NOAA in the United States and European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT). A fourth satellite mission to continue the sea level -climate data record is being planned.
- NASA worked with international partners in the design of its Global Observing System, for example, the Netherland's Ozone Monitoring Instrument (OMI) instrument (which includes contributions from Finland) flies on NASA's Aura satellite, and Japan's Advanced Spaceborne Thermal Emission and Reflector Radiometer (ASTER) instrument is on NASA's Terra satellite.
- The Aquarius satellite, built jointly by the United States (NASA) and Argentina's Comisión Nacional de Actividades Espaciales (CONAE) to record sea surface salinity measurements, was launched in June, 2011.
- In situ observing systems have benefited through international collaboration. U.S. agencies depended on international investments in the 3,000-element free-floating Argo float array to deploy U.S. floats and to contribute additional floats.
- Data integration initiatives, such as the Global Biodiversity Information Facility (GBIF), bring data from disparate sources together for use by scientists and citizens.

Sustained observing systems external to the traditional USGCRP membership are another increasingly important supply of data and information for USGCRP interests. Acquiring these measurements requires close collaboration with other international organizations and increasingly with the private sector. Examples include global marine and meteorological measurements as well as social science information, such as census data and economic impact information.

For these reasons, USGCRP works with its sibling interagency groups such as USGEO and the Interagency Working Group on Digital Data, which help set the standards and coordinate collection and distribution of Earth observation data in a long-term, durable, and usable fashion.

To effectively participate in future international efforts, USGCRP will continue to evaluate relevant activities and articulate a clear role for itself in programs that benefit the goals and missions of the USGCRP and its partner agencies.

V. IMPLEMENTATION STRATEGY

This decadal Strategic Plan builds toward a program for USGCRP that explicitly links scientific discovery to society's needs, thereby contributing to a government-wide "end-to-end" approach to global change. It articulates the Program's research goals, provides a framework for informing decisions and assessing progress, and outlines shared capabilities to support interagency activities. USGCRP's set of strategic goals and objectives provide a strong research foundation for understanding global change, and a basis for expanded partnerships with other parts of the government, academia, and the private sector. This chapter outlines guiding principles that the Program will use in making decisions on implementing this next-generation Strategic Plan. It also discusses approaches for updating the Plan as progress is evaluated. Two important mechanisms to achieve this vision are discussed, including updated research strategies every three years using best practices from adaptive management, and an annual process for use by OSTP, OMB, CEQ, and member agencies as future annual budgets are developed.

Guidelines for Implementing the Strategic Plan

USGCRP goals are ambitious yet necessary, and include much greater emphasis on decision support than was included in previous plans. Not all aspects of this Plan can be implemented simultaneously, particularly in the current economic climate. Because the Plan is a 10-year vision for Program directions, USGCRP will use a phased approach to implementing its goals and objectives. The following set of guiding principles will assist agencies and USGCRP in assessing progress and balance and developing near-, intermediate-, and long-term priorities over the next 10 years. The guiding principles will help ensure that implementation of the Strategic Plan is both realistic and flexible while maintaining research excellence and increasing the development and application of use-inspired tools and activities. These guiding principles include:

- Ensure continuing strength at the scientific foundation of USGCRP (observations, modeling, and process research), and that the foundation is used to support all four goals.
- Develop flexible plans for phasing in new activities and priorities over the decade that accommodate budget realities and build upon member agencies' strengths. Develop a portfolio of essential foundational and new activities that:
  - Promote scientific progress that achieves results having direct societal benefit;
  - Have strong interdependencies among the USGCRP agencies that are facilitated through USGCRP leadership and coordination;
  - Build the capacity within USGCRP for interdisciplinary research and related activities, especially between the natural science and human components of the earth system, and translation of science for societal benefit and related risk management decision making;
  - Enable discoveries through transformational research that can lead to breakthroughs in how the country understands and responds to global change.
- Build connections within and beyond USGCRP member agencies, and with other interagency bodies, that leverage federal investments and promote the widest use of Program results in supporting the country's responses to global change;
- Focus on international partnerships that enhance science assessment and response activities in the United States and globally;

- Review progress regularly of interagency activities to evaluate priorities and the balance between research and service goals;
- Use adaptive management principles of evaluation and learning to improve Program outcomes.

Adaptive Program Management

The Global Change Research Act (GCRA) requires that USGCRP provide an updated Strategic Plan (referred to as the Revised Research Plan in legislation) every three years and make it available for public comment prior to its release. USGCRP will use these triennial updates, which will incorporate the findings of the ongoing National Assessment, as an opportunity to evaluate Program directions, effectiveness, and balance, and to modify plans as necessary to respond to changing conditions and Program progress. USGCRP will also consult with the National Research Council to ensure that a broad perspective is considered.

To achieve the goals of the Program, USGCRP will need to incorporate the perspectives of those using the research to inform decisions. Questions about who needs the research, what research is needed to inform decisions, and in what form the research results are needed will provide guidance to USGCRP as it implements this Strategic Plan.

Interagency Collaboration

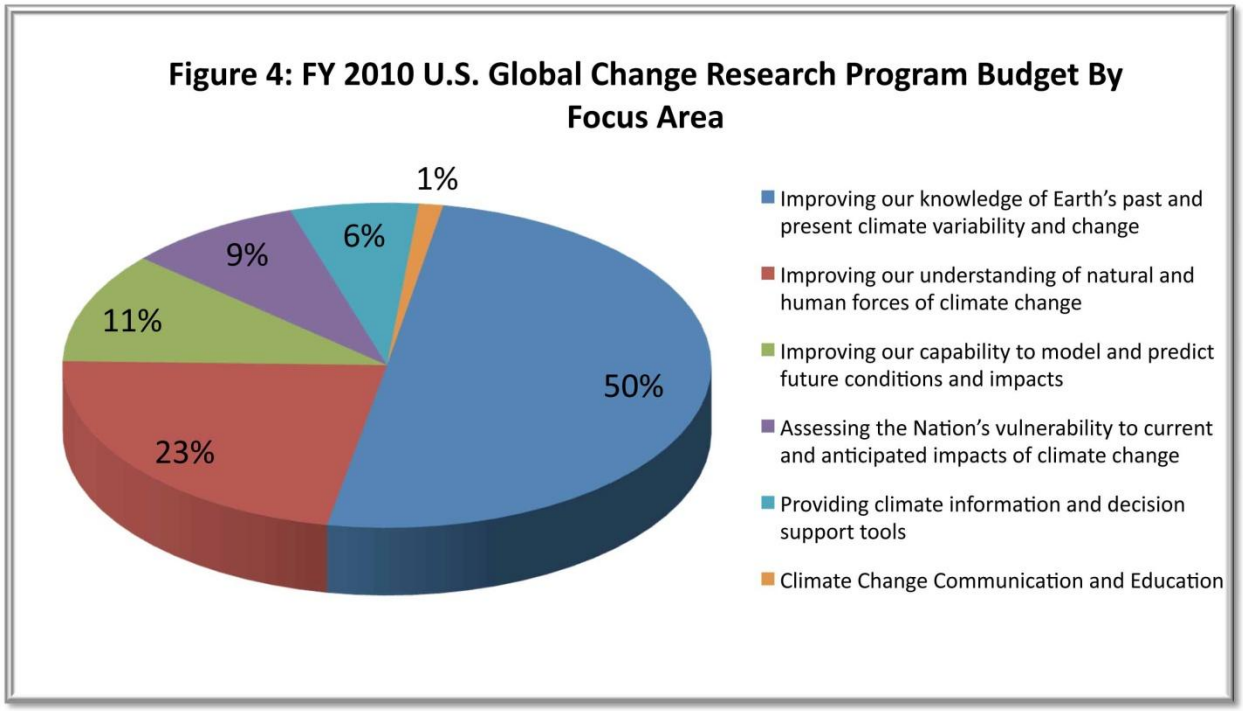
Collaboration is central to implementation of the shared priorities of USGCRP and its member agencies. The collaboration stems from the involvement of multiple agencies in a given area, whose programs have been carried out with full knowledge and appreciation of all the agencies' related activities. The history of such collaboration is reflected in the Program's annual report to Congress, *Our Changing Planet*. **Table 2** provides an overview of six focus areas for USGCRP for fiscal years 2009–2011, and shows agency participation in the different areas. The pie chart in **Figure 4** uses budget information from FY 2010 and shows the percentage of Program investments in the focus areas, relative to the total FY 2010 budget for USGCRP of $2.18B.

Table 2: Primary Areas of USGCRP Interagency Collaboration 2009–2011

* USGCRP participating organizations from the Department of Commerce (DOC) are the National Institute of Standards and Technology (NIST) and the National Oceanic and Atmospheric Administration (NOAA).

Focus Areas	Participating Agencies
Improving our knowledge of Earth's past and present climate variability and change.	DOC*, DOE, DOI, NASA, NSF, SI, USDA
Improving our understanding of natural and human forces of climate change.	DOC, DOE, DOI, DOT, EPA, NASA, NSF, USDA
Improving our capability to model and predict future conditions and impacts.	DOC, DOE, DOI, HHS, NASA, NSF, SI, USAID, USDA
Assessing the Nation's vulnerability to current and anticipated impacts of climate change.	DOC, DOE, DOI, DOT, EPA, NASA, NSF, USDA
Providing climate information and decision support tools.	DOC, DOI, DOT, EPA, NASA, NSF, SI, USAID, USDA
Climate Change Communication and Education.	DOC, NASA, NSF, SI, USDA

The Subcommittee on Global Change Research Principals will use the guiding principles for implementation in their assessment of Program structure and governance to make modifications that may be needed to enhance interagency collaboration (see *Next Steps*, below).



Prioritization

The Global Change Research Act (Section 105) sets requirements for USGCRP to follow in developing shared priorities, linked to annual budget development. Such shared priorities advance the collective goals of the Program, and also support global change activities in the agencies (and parts of agencies) that fall outside the purview of the current USGCRP program and budgetary portfolios.

Each year, the USGCRP Principals develop global change research priorities that address science gaps and opportunities and emerging societal and scientific needs. These priorities are compiled in a guidance memorandum that is intended to provide a framework for the USGCRP participating agencies for use in setting priorities, with the goal of promoting interagency cooperation and connectivity to the broad USGCRP directions.

In addition to feasibility of implementation, the Program also uses the following criteria in framing priority areas: (1) their role in advancing the goals and objectives of the Strategic Plan, (2) the need for multi-agency participation and USGCRP coordination to achieve the priorities, and (3) the magnitude of their contributions to fundamental understanding and improved decision making.

Next Steps

In 2012, the Subcommittee on Global Change Research Principals will evaluate structural and governance aspects of the Program and develop an Implementation Framework for a USGCRP that effectively implements its research portfolio. The Framework will be used to assess and modify, as needed, the mechanisms and operational process of the USGCRP enterprise, including the Principals, the National Coordination Office, and the Interagency Working Groups. The Framework will also be developed with the intent of providing appropriate connectivity to National Science and Technology Council and Committee on Environment, Natural Resources, and Sustainability subcommittees, the National Climate Assessment, agency adaptation activities, interagency taskforces, and other types of interagency working groups. Reflective of the adaptive program management structure in the new strategic plan, the Implementation Framework will include periodic internal assessments to ensure that form follows changing function.

APPENDIX I: PROGRAM ACTIVITY DESCRIPTION BY AGENCY/DEPARTMENT

The following pages present information about the contributions to USGCRP. For each department, the section titled "Principal Areas of Focus" highlights and summarizes activities ongoing within that department.

Department of Agriculture

Principal Areas of Focus

The U.S. Department of Agriculture's (USDA's) global change research program aims to empower land managers, policy makers, and Federal agencies with science-based knowledge to manage the risks, challenges, and opportunities posed by climate change; reduce greenhouse gas emissions; and enhance carbon sequestration. Meeting USDA's goals for expanded economic opportunity, helping rural America thrive, promoting the sustainability of agricultural production, and conserving natural resources requires understanding climate change's influences and the options for managing them. USDA is unique among many Federal agencies in the broad spectrum of its missions, which include research, applications, technology transfer, public land management, technical assistance, and communications and delivery. USDA draws upon this diversity to identify climate change challenges and priorities in continuing to meet the needs of its stakeholders, decision makers, and collaborators. This work is important to ensuring sustained food security for the Nation and the world; maintaining and enhancing forest and natural resource health; and identifying strategic risks to agricultural production from changing temperature and precipitation as well as pests, disease, and invasive species.

USDA supports USGCRP on multiple fronts. The Department conducts in-house research and sponsors extramural investigations focused on understanding climate change effects on natural and managed ecosystems, developing the knowledge and tools to enable adaptation under a changing climate, enhancing mitigation of atmospheric greenhouse gases, and providing science-based information for decision support. USDA conducts assessments and projections of climate change impacts on agricultural and natural systems, and develops greenhouse gas inventories. Conservation systems promoted by the USDA integrate USGCRP research findings into farm and natural resource management, and help build resiliency to climate change on both private and public lands. Development and deployment of decision support tools is a cornerstone of the Department's climate change efforts. USDA maintains critical long-term data collection and observation networks, including the Snowpack Telemetry (SNOTEL) network, the Soil Climate Analysis Network (SCAN), the National Resources Inventory (NRI), and the Forest Inventory and Assessment (FIA). Analysis and modeling work includes biophysical subjects as well as economic analysis of climate change effects and adaptation options. Finally, USDA engages in communication, outreach, and education through multiple forums, including its vast network of agricultural extension services.

Department of Commerce

Principal Areas of Focus

The National Oceanic and Atmospheric Administration (NOAA) and the National Institute of Standards and Technology (NIST) comprise the Department of Commerce contribution to USGCRP.

NOAA's strategic climate goal is "an informed society anticipating and responding to climate and its impacts." This is an end-to-end endeavor, and the overall objective is to provide decision makers with a predictive understanding of the climate and to communicate climate information so that people can make more informed decisions in their lives, businesses, and communities. These outcomes are achieved through implementing a global observing system, focused research to understand key climate processes, improved modeling capabilities, and the development and delivery of climate information services. NOAA aims to achieve its climate goal through the following strategic objectives:

- Improved scientific understanding of the changing climate system and its impacts.
- Assessments of current and future states of the climate system that identify potential impacts and inform science, service, and stewardship decisions.
- Mitigation and adaptation efforts supported by sustained, reliable, and timely climate services.
- A climate-literate public that understands its vulnerabilities to a changing climate and makes informed decisions.

NOAA will advance this goal as it continues to build upon its strong scientific foundation and decades of engagement and collaboration with interagency, academic, international, and private sector partners.

NIST provides measurements and standards that support accurate, comparable, and reliable climate observations. NIST also performs calibrations and special tests of a wide range of instruments and techniques for accurate measurements. In FY 2009, NIST is included as a discrete element of the USGCRP crosscut to provide specific measurements and standards of direct relevance to the program.

Department of Defense

Principal Areas of Focus

The Department of Defense (DOD)—while not supporting a formal mission dedicated to global change research—continues a history of participation in the USGCRP through sponsored research that concurrently satisfies both national security requirements and the goals of the USGCRP. All data and scientific results obtained using DOD basic research funds are routinely made available to the civil science community. DOD science and technology investments are coordinated and reviewed by the Office of the Secretary of Defense (Office of Basic Sciences) and the individual research agencies—the Office of Naval Research (ONR), the Air Force Office of Scientific Research (AFOSR), the Army Research Office (ARO), and the Defense Advanced

Research Projects Agency (DARPA). Together they have the responsibility to jointly develop the DOD Basic Research Plan (BRP), which undergoes a biennial program review by a panel of experts from universities, industry, and nonprofit research institutions (Defense Basic Research Review). As the performance of DOD systems, platforms, and operations may be influenced by the natural environmental conditions, understanding the variability in the Earth's environment is of interest to many DOD science programs. Much of the research performed under the ONR's Operational Environments focus area and the ARO's Environmental Sciences Division, for example, lead to fundamental understanding of physical processes that are of particular relevance to USGCRP.

In the 2010 Quadrennial Defense Review (QDR), the DOD formally recognized the need to understand and adapt to the impacts of climate change on DOD facilities and military capabilities. The DOD relies on the Strategic Environmental Research and Development Program (SERDP), a joint effort among DOD, the Department of Energy, and the Environmental Protection Agency, to develop climate change assessment tools. The DOD will regularly reevaluate climate change risks and opportunities in order to develop policies and plans to manage its effects on the Department's operating environment, missions, and facilities.

Department of Energy

Principal Areas of Focus

The Department of Energy (DOE) Office of Science supports DOE's climate research to discern the relationship between the global climate system and energy production and use. The DOE climate research mission is to advance a robust predictive understanding of Earth's climate system with sufficient certainty and spatio-temporal resolution that decision makers can adopt climate projection outputs to develop and deploy secure and sustainable solutions for the Nation's energy and environmental challenges. The integrated portfolio of research ranges from molecular-level to regional-scale studies with emphases on multidisciplinary experimentation/observations and the development/evaluation of advanced computer models. DOE provides national leadership in climate-relevant process research and modeling of the atmosphere, including clouds and aerosols, and of the terrestrial carbon cycle; climate and Earth system modeling for both global and regional scales, and enhanced by DOE's leadership high-performance computing capabilities; experimental research on the effects of climate change on ecosystems; integrated analysis of climate change impacts; and analysis and distribution of large climate data sets through the Program for Climate Model Diagnosis and Intercomparison and the Earth System Grid.

DOE supports three primary research activities along with a national scientific user facility. The areas of research are: (1) Atmospheric System Research that focuses on the basic science and process studies governing aerosols, clouds, and radiative transfer; (2) Terrestrial Ecosystem Science that focuses on long-term field experiments and in situ modeling in regions of critical concern to climate predictability; and (3) Climate and Earth System Modeling to integrate and assess all critical components into a high-resolution interdependent prediction system. The Atmospheric Radiation Measurement (ARM) Climate Research Facility is a scientific user facility. DOE's high-profile research activities include the Program for Climate

Model Diagnosis and Intercomparison, the Earth System Grid, and the AmeriFlux carbon cycle observational network.

Department of Health and Human Services

Principal Areas of Focus

The Department of Health and Human Services (HHS) supports a broad portfolio of research related to environmental health and the health effects of global change. The National Institutes of Health (NIH) and the Centers for Disease Control and Prevention (CDC) provide the focus for this effort.

The potential health effects of climate change are not fully understood. Complex interactions between humans, ecosystems, and the changing environment will lead to a variety of complicated health effects. Some of these effects are already occurring. Higher temperatures will likely increase tropospheric ozone concentrations that contribute to cardiovascular and pulmonary illness. Droughts and floods can cause injury and lead to sanitation problems as well as mold and chemical exposures. The ranges of vector-borne and zoonotic pathogens and the transmission of food- and water-borne pathogens are likely to be impacted. Extreme heat events are predicted to become more frequent and intense, and such events will have a major impact on areas and populations that are not well adapted to them. The limited set of activities and projects identified in the FY 2009 through FY 2010 USGCRP HHS budgets are focused on improving our capability to model and predict the impacts of climate change on human health. These activities are briefly described relative to the USGCRP goals. More extensive HHS efforts not identified in the USGCRP budget are described further on in this agency description. The full scope of HHS activities and projects will help to predict and address these and other health consequences of climate change.

Department of the Interior

Principal Areas of Focus

Like several other USGCRP agencies, the Department of the Interior (DOI) is both a natural resource management agency and a science agency. DOI global change research is conducted though the U.S. Geological Survey (USGS), but several other DOI bureaus contribute to the goals of the USGCRP Strategic Plan through activities such as monitoring, impact assessments, and adaptation planning.

Evolving from an organization that was created to inventory the Nation's public lands and natural resources, the mission of the 21st century USGS is most simply expressed in its maxim "Science for a Changing World." Emphasis on climate and land-use change has increased substantially over the past five years as USGS scientists have worked in collaboration with other USGCRP agencies to meet the pressing needs of the U.S. Department of the Interior, policy makers, and resource managers for scientifically valid state-of-the-science information and predictive understanding of global change and its effects. The USGS Climate and Land Use Change mission leads research, adaptation, and mitigation activities to help the Nation

understand, adapt to, and mitigate global change and its impacts on society, resource availability, and economic development.

USGS studies of the interactions among climate, Earth surface processes, and ecosystems across space and time contribute directly to the strategic goals and core competencies of the U.S. Global Change Research Program. The USGS Climate and Land Use Change Research and Development Program supports fundamental scientific research to understand processes controlling Earth system responses to global change over broad temporal and spatial scales and model impacts of climate and land-cover change on ecosystems and other natural resources in a range of environments, from the Arctic to the tropics. USGS geographic analyses and land remote-sensing programs (such as the LANDSAT satellite mission and the National Land Cover Database) provide basic data that can be used to assess changes in land use and land cover, ecosystems, and water resources resulting from the interactions between human activities and natural systems. The science products and data sets from these programs are essential for conducting quantitative studies of carbon storage and greenhouse gas flux in the Nation's ecosystems. Over the past three years, the USGS has developed scientifically based methods for assessment of biologic and geologic carbon sequestration, and the USGS is currently conducting the assessments called for in the Energy Independence and Security Act of 2007.

The USGS National Climate Change and Wildlife Science Center is leading the establishment of eight DOI regional Climate Science Centers and responds to the research and management needs of partners by providing science and technical support regarding the impacts of climate change on fish, wildlife, and ecological processes. The DOI Climate Science Centers will provide robust predictive and empirical tools for natural resource managers to test adaptive strategies, reduce risk, and increase the potential for hydrologic and ecological systems to be self-sustaining, resilient, or adaptable to climate change and related disturbances.

Department of State

Principal Areas of Focus

Through Department of State (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)—the principal international 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 these organizations provide substantial support for global climate observation and assessment activities in developing countries. DOS also works with other agencies in promoting international cooperation in a range of bilateral and multilateral climate change initiatives and partnerships.

Department of Transportation

Principal Areas of Focus

The Department of Transportation (DOT) conducts research and uses existing science to improve decision-making tools to address climate change. DOT supports research that (1)

examines the potential impacts of climate variability and change on transportation infrastructure and services, (2) examines increasing energy efficiency and reducing greenhouse gases, and (3) improving transportation greenhouse gas data and modeling. DOT has many programs that have either direct or indirect climate benefits, and is working to develop cross-modal strategies to reduce greenhouse gas emissions.

DOT's Center for Climate Change is the Department's focal point for information and technical expertise on climate change. The Center coordinates research, policies, and actions related to transportation and climate change with DOT's component organizations. While also supporting DOT's core goals of safety, mobility, environmental stewardship, and security, the Center promotes comprehensive approaches to reduce greenhouse gases, to prepare for the potential impacts of climate change, and to develop necessary adaptations to transportation operations and infrastructure. The Center supports the USGCRP focus areas through these objectives.

The Federal Aviation Administration (FAA) participates in the Center and also has programs to identify and assess and identify potential measures to reduce fuel consumption and greenhouse gas emissions. FAA conducts research to support USGCRP Core Competency area 2; leveraging research with other U.S. Government agencies to reduce uncertainties surrounding aviation emissions and their effect on climate change. More specifically, FAA works with NASA, NOAA, and EPA in the Aviation Climate Change Research Initiative (ACCRI), which is a practical-need-driven research program with an objective to identify and address key scientific gaps and uncertainties regarding aviation climate impacts while providing timely scientific input to inform optimum mitigation actions and policies. FAA also works with NASA and Transport Canada in the Partnership for Air Transportation Noise and Emissions Reduction (PARTNER) Center of Excellence, which fosters advances in alternative fuels, emissions, noise, operations, aircraft technologies, and science and decision making for the betterment of mobility, economy, national security, and the environment.

FAA has a number of ongoing operational initiatives to reduce fuel consumption and thus the amount of greenhouse gas emissions produced by aviation, including improved air traffic management, reduced vertical separation minimums, and the voluntary airport low-emissions program that assists in deploying low-emissions technology to airport operations. Additionally, FAA participates heavily in the work program of the International Civil Aviation Organization's Committee on Aviation Environmental Protection, and provides technical expertise and data to the Intergovernmental Panel on Climate Change (IPCC) and the United Nations Framework Convention on Climate Change (UNFCCC) in support of the overall DOT mission on international climate change work.

Other Departmental initiatives also address climate change and improve the overall sustainability of the U.S. transportation sector but are not specifically part of the USGCRP budget crosscut for DOT. Examples are as follows:

The FAA, with support from NASA, has developed the continuous lower energy, emissions, and noise (CLEEN) program as a government industry consortium to develop and mature environmentally promising technologies for more efficient energy use, reduction in aircraft noise and emissions as well as advancing alternative fuels for civil subsonic jet aircraft. Similarly, the Commercial Aviation Alternative Fuels Initiative (CAAFI) is a forum that engages

national and international stakeholders and coordinates their activities to advance exploration, qualification, certification and deployment of aviation alternative fuels.

DOT is developing models to predict future conditions and impacts of climate on the nation's transportation system. The Federal Highway Administration (FHWA) is leading strategies for risk and vulnerability assessments as well as providing climate information on regional impacts of climate change in order to assist the transportation community in making decisions. FHWA, in collaboration with other agencies provides climate change information to the transportation community. An example is the recent FHWA publication *Regional Climate Change Effects: Useful Information for Transportation Agencies (May 2010)*. In addition, FHWA is in the process of developing official risk and vulnerability assessment tools for transportation professionals.

Through the National Highway Traffic Safety Administration (NHTSA), DOT is improving the fuel economy of the nation's on-road vehicles, including a recent joint rulemaking with EPA to establish fuel economy and greenhouse gas emission standards for MY 2012–2016. Transit Investments for Greenhouse Gas and Energy Reduction (TIGGER) is a grant program from the American Recovery and Reinvestment Act of 2009 that is awarding $100 million in funding to transit agencies that reduce energy consumption and/or greenhouse gas emission.

DOT is working with EPA and the U.S. Department of Housing and Urban Development (HUD) in the Partnership for Sustainable Communities to ensure that housing and transportation goals are met while simultaneously protecting the environment, promoting equitable development, and helping to address the challenges of climate change.

The Center for Climate Change leverages resources by building strategic partnerships and reaching out to state and local agencies, environmental advocates, industry, and academia. This effort ranges from simple information exchange to ongoing partnerships in major research initiatives and conferences. The Center builds DOT capacity and awareness by conducting educational forums and establishing a clearinghouse for research and policy coordination related to transportation and climate change.

Environmental Protection Agency

Principal Areas of Focus

The core purpose of EPA's Global Change Research Program is to develop scientific information that supports stakeholders, policy makers, and society at large as they respond to climate change and associated impacts on human health, ecosystems, and socioeconomic systems in the United States. EPA's research is focused on topics driven by the Agency's mission and statutory requirements, and includes: (1) improving the scientific understanding of global change effects on air quality, water quality, ecosystems, and human health in the context of other stressors; (2) assessing and developing adaptation options to effectively respond to global change risks, increase resilience of human and natural systems, and promote their sustainability; and (3) developing an understanding of the potential environmental impacts and benefits of GHG emission reduction strategies to support sustainable mitigation solutions. EPA's program emphasizes the integration of knowledge across the physical, chemical, biological, and social sciences into decision-support frameworks that recognize the complex interactions

between human and natural systems at national, regional, and local scales. This information is further leveraged by EPA Program Offices and Regions in support of mitigation and adaptation efforts and to promote communication with external stakeholders and the public.

National Aeronautics and Space Administration

Principal Areas of Focus

The National Aeronautics and Space Administration (NASA) conducts a program of breakthrough research to advance fundamental knowledge on the most important scientific questions on the global and regional integrated Earth system. NASA Earth Science conducts and sponsors research, collects new observations from space, develops technologies, and extends science and technology education to learners of all ages. NASA's goal is to understand the changing climate, its interaction with life, and how human activities affect the environment. In association with national and international agencies, NASA applies this understanding for the well-being of society. The NASA program encompasses most of the core competency areas of the U.S. Global Change Research Program (USGCRP).

NASA presently has 14 on-orbit satellite missions: Active Cavity Radiometer Irradiance Monitor (ACRIMSAT), Aqua, Aquarius/SAC-D, Aura, the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO), CloudSat, Earth Observing (EO), the Gravity Recovery And Climate Experiment (GRACE), Jason, Landsat-7, the Ocean Surface Topography Mission (OSTM), the Solar Radiation and Climate Experiment (SORCE), Terra, and the Tropical Rainfall Measuring Mission (TRMM). On March 4, 2011, NASA's Glory satellite did not reach orbit altitude when the launch vehicle malfunctioned. On June 9, 2011, the Aquarius sea surface salinity instrument was launched on Argentina's SAC-D satellite.

NASA has five missions in development for launch in 2010–2015. Three missions (NPOESS Preparatory Project [NPP], Landsat Data Continuity Mission [LDCM], and Global Precipitation Measurement [GPM]) are foundational missions, which the Decadal Survey[1] assumed would be precursors to Decadal Survey missions. Two missions, Soil Moisture Active Passive (SMAP) and the Ice, Cloud, and land Elevation Satellite-2 (ICESat-2), are Tier I Decadal Survey missions. The Decadal Survey is the principal determinant of the priorities of NASA's Earth Science satellite missions beyond those currently in development.[2]

The President's FY 2012 Budget Request continues the acceleration, which had begun in FY 2011, of NASA's formulation, development and launch of Decadal Survey missions; all are relevant to research on global climate change. The augmentation makes possible a larger number of Decadal Survey missions in the coming decade.

The President's FY 2012 Budget Request recognizes the need for continuity in critical climate observations and data records, and continues funding to develop an Orbiting Carbon

[1] National Research Council (2007) Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond. National Academies Press, Washington, DC, 428 pp.
[2] NRC, 2007: *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond*. The National Academies Press, Washington, DC, 418 pp.

Observatory (OCO-2) mission to measure atmospheric CO_2 to replace the mission that failed to reach orbit in 2009, with a target launch date of early 2013. NASA continues development of a GRACE-Continuity mission working towards a launch in 2016; refurbishes a Stratospheric Aerosol and Gas Experiment (SAGE-III) instrument to measure aerosols, ozone water vapor and other trace gases in the upper troposphere and stratosphere as early as 2014; and, develops a Pre-Aerosols, Clouds, and Ecosystems Pre-ACE, or PACE) mission to measure ocean color, clouds, and aerosols as early as 2018.

The Decadal Survey recommended creation of a Venture class program of small, frequent, predictably scheduled science mission opportunities to spur innovation and enable the training of future Earth science leaders. Four of five Earth Venture-1 (EV-1) extended airborne science observing campaigns, which had been selected in FY 2010, had flight operations in 2011, and some activities will conduct operations through 2015. In June 2011, NASA released the first call for proposals for a complete space flight mission, EV-2, with selections to be made in 2012. The solicitations for suborbital and orbital missions will continue in alternate years. The first annual solicitation to develop satellite instruments for a mission of opportunity, called EV-I, occurred in 2011, with selection scheduled for 2012.

NASA aircraft- and surface-based instruments are used to calibrate and enhance interpretation of high-accuracy, well-calibrated, stable satellite measurements. NASA supports state-of-the-art computing capability and capacity for extensive global integrated Earth system modeling. NASA, in recording approximately 4 terabytes of data every day, maintains the world's largest scientific data and information system for collecting, processing, archiving, and distributing Earth system data to worldwide users.

National Science Foundation

Principal Areas of Focus

National Science Foundation (NSF) programs address global change issues through investments that advance frontiers of knowledge, provide state-of-the-art instrumentation and facilities, develop new analytical methods, and enable cross-disciplinary collaborations while also cultivating a diverse highly trained workforce and developing resources for public education. In particular, NSF global change research programs support the 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 approaches to studying Earth system processes and the consequences of change, including how humans respond to changing environments and the impacts on ecosystems and the essential services they provide. NSF programs promote the enhancement of models to improve understanding of integrated Earth system processes and to advance predictive capability. NSF also supports fundamental research on the processes used by organizations and decision makers to identify and evaluate policies for mitigation, adaptation, and other responses to the challenge of a changing and variable environment.

Smithsonian Institution

Principal Areas of Focus

Within the Smithsonian Institution, global change research is primarily conducted at the National Air and Space Museum, the National Museum of Natural History, the National Zoological Park Smithsonian Astrophysical Observatory, the Smithsonian Environmental Research Center, and the Smithsonian Tropical Research Institute. 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, to 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) timescales to resolve human-caused modification of natural variability.

U.S. Agency for International Development

Principal Areas of Focus

The U.S. Agency for International Development (USAID) supports a number of programs that enable decision makers to apply high-quality climate information to decision making. USAID is the lead contributor to bilateral assistance, with a focus on capacity building, civil society building, and governance programming, and creating the legal and regulatory environments needed to address climate change. USAID leverages its significant technical expertise to provide leadership in development and implementation of low-emissions development strategies, creating policy frameworks for market-based approaches to emission reduction and energy sector reform, promoting sustainable management of agriculture lands and forests, and mainstreaming adaptation into development activities in countries most at risk. USAID has long-standing relationships with host country governments that enable it to work together to develop shared priorities and implementation plans. USAID's engagement and expertise in agriculture, biodiversity, health, and other critical climate sensitive sectors provide an opportunity to implement innovative cross-sectoral climate change programs. Finally, USAID bilateral programs work in key political and governance areas that multilateral agencies cannot.

APPENDIX II: GLOSSARY OF TERMS

Abrupt climate change: Rapid climate change occurring at time scales faster than the typical time scale of the responsible *forcing*. (IPCC, 2007, WGI)

Adaptation: Adjustment in natural or *human systems* to a new or changing environment that exploits beneficial opportunities and moderates negative impacts.

Adaptive capacity (in relation to climate and global change impacts): The ability of a system to adjust to *climate* and *global change* (including *climate variability* and *extremes*) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (IPCC, 2007).

Adaptive management: Operational decisions principally for managing entities that are influenced by *climate variability* and change.

Adaptive management decisions: Operational decisions, principally for managing entities that are influenced by *climate variability* and change. These decisions can apply to the management of infrastructure (e.g., a wastewater treatment plant), the integrated management of a natural resource (e.g., a watershed), or the operation of societal response mechanisms (e.g., health alerts, water restrictions). *Adaptive management* operates within existing policy frameworks or uses existing infrastructure, and the decisions usually occur on time scales of a year or less. See *policy decisions*.

Aerosols: A collection of airborne solid or liquid particles, with a typical size between 0.01 and 10 μm that reside in the *atmosphere* for at least several hours. *Aerosols* may be of either natural or *anthropogenic* origin (IPCC, 2007).

Albedo: The fraction of solar radiation reflected by a surface or object, often expressed as a percentage (IPCC, 2007).

Anthropogenic: Resulting from or produced by human beings.

Arctic Climate Impact Assessment (2004): An international project of the Arctic Council and the International Arctic Science Committee, to evaluate and synthesize knowledge on *climate variability*, climate change, and increased ultraviolet radiation and their consequences.

Assessments: Processes that involve analyzing and evaluating the state of scientific knowledge (and the associated degree of scientific certainty) and, in interaction with users, developing information applicable to a particular set of issues or decisions.

Atmosphere: The gaseous envelope surrounding Earth (IPCC, 2007).

Biodiversity: The total diversity of all organisms and ecosystems at various spatial scales (IPCC, 2007).

Biofuel: Any liquid, gaseous, or solid fuel produced from plant or animal organic matter, for example, soybean oil, alcohol from fermented sugar, and wood. Second-generation *biofuels* are products such as ethanol and biodiesel derived from *biomass* by chemical or biological processes.

Biomass: The total mass of living organisms in a given area or volume (IPCC, 2007).

Biosphere: The part of the Earth system comprising all ecosystems and living organisms, in the *atmosphere*, on land or in the ocean, included derived dead organic matter, such as litter, soil organic matter, and oceanic detritus (IPCC, 2007).

Biogeochemical cycle: A pathway by which a chemical element, such as carbon, or compound, like water, moves through Earth's *biosphere*, *atmosphere*, hydrosphere, and lithosphere (NSF).

Carbon cycle: The term used to describe the flow of carbon (in various forms, e.g., as carbon dioxide) through the *atmosphere*, ocean, terrestrial *biosphere*, and *lithosphere* (IPCC, 2007).

Carbon, nitrogen, and phosphorous cycling: See *biogeochemical cycle*

Climate: The statistical description in terms of the mean and variability of relevant measures of the *atmosphere*-ocean system over periods ranging from weeks to thousands or millions of years (IPCC, 2007).

Climate change: A statistically significant variation in either the mean state of the climate or in its *variability*, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or to external forcing, including changes in solar radiation and volcanic eruptions, or to persistent human-induced changes in atmospheric composition or in land use. See also *climate variability* (IPCC, 2007).

Climate feedback: See *feedback*.

Climate model: A numerical representation of the *climate system* based on the mathematical equations governing the physical, chemical and biological properties of its components and including treatment of key physical processes and interactions, cast in a form suitable for numerical approximation making use of computers. (IPCC, 2007, and National Snow and Ice Data Center)

Climate prediction: A *climate* prediction or climate forecast is the result of an attempt to produce an estimate of the actual evolution of the climate in the future, for example, at seasonal, interannual, or long-term timescales (IPCC, 2007).

Climate projection: A projection of the response of the climate system to emission or concentration scenarios of *greenhouse gases* or *aerosols*, or *radiative forcing scenarios*, often based upon simulations by climate models. Climate projections are distinguished from *climate predictions* in order to emphasize that climate projections depend upon the emission/concentration/radiative forcing scenario used, which are based on assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realized and are therefore subject to substantial uncertainty (IPCC, 2007).

Climate scenario: A plausible and often simplified representation of the future *climate*, based on an internally consistent set of climatological relationships, that has been constructed for explicit use in investigating the potential consequences of anthropogenic *climate change.*

Climate system: The highly *complex system* consisting of five major components: the *atmosphere*, the hydrosphere, the *cryosphere*, the land surface and the *biosphere*, and the interactions among them (IPCC, 2007).

Climate variability: Variations in the mean state and other statistics of climatic features the climate on temporal and spatial scales beyond that of individual *weather* events. These variations are often due to internal processes within the *climate system* (internal variability), or to variations in natural or *anthropogenic* external forcing (external variability).

Climate scenario: A plausible and often simplified representation of the future *climate*, based on an internally consistent set of climatological relationships, that has been constructed for explicit use in investigating the potential consequences of *anthropogenic climate change*, often serving as input to impact models.

Climate services: The timely production and delivery of useful climate data, information, and knowledge to decision makers.

Committee on Environment, Natural Resources, and Sustainability (CENRS): A subcommittee of the *National Science and Technology Council* (NSTC) established to assist the NSTC in increasing the overall productivity and application of federal research and development efforts in the areas of environment, natural resources, and sustainability, and to provide a formal mechanism for interagency coordination in these areas. CENRS encompasses the *Subcommittee on Global Change Research*, the steering committee of the *United States Global Change Research Program.*

Community Earth System Model: A global climate model based out of the National Center for Atmospheric Research that can be used to simulate the many components of Earth's climate system, including the ocean, atmosphere, sea ice, and land cover.

Complex system: A system composed of interconnected parts that as a whole exhibit one or more properties not obvious from the properties of individual parts.

Cryosphere: The component of the *climate system* consisting of all snow, ice, and frozen ground (including *permafrost*) on and beneath the surface of the Earth and ocean.

Data assimilation: The process of combining a model with observational data to provide an estimate of the state of the system that is better than could be obtained using the data or the model alone (NOAA/GFDL).

Decision support: The provision of timely and useful information that addresses specific questions.

Downscaling: A method that derives local- to regional-scale (10 to 100 km) information from larger-scale models or data analyses (IPCC 2007).

Earth system: The unified set of physical, chemical, biological, and social components, processes and interactions that together determine the state and dynamics of Planet Earth, including its biota and its human occupants (ESSP).

Earth System Modeling Framework: Open-source software for building and coupling weather, climate, and related models.

Ecosystem: A system of living organisms interacting with each other and their physical environment as an ecological unit.

Ecosystem services: Ecological processes or functions having monetary or nonmonetary value to individuals or society at large. There are supporting services such as productivity or biodiversity maintenance; provisioning services such as food, fiber, or fish; regulating services such as climate regulation or carbon sequestration; and cultural services such as tourism or spiritual and aesthetic appreciation.

El Niño-Southern Oscillation (ENSO): A basin-warming of the tropical Pacific Ocean east of the dateline associated with a fluctuation of a global-scale tropical and subtropical surface pressure pattern called the Southern Oscillation, occurring on an approximately two to seven year timescale. The alternate cold phase of the Southern Oscillation is known as La Niña (IPCC, 2007).

Emergent behavior: The feature of *complex systems* by which cause-effect relationships between individual components at the subsystem level are not additive or aggregate in simple ways when all of the components are linked to form the system. Emergent properties of the system as a whole appear (*Global Change and the Earth System*, IGBP).

Emissions: In the *climate change* context, emissions refer to the release of *greenhouse gases* and/or their precursors and *aerosols* into the atmosphere over a specified area and period of time.

End-to-end: The nature of research needed to address the "end-to-end" *climate* and *global change* issue, from understanding causes and processes to supporting actions needed to cope with the impending societal problems of climate and global change (NRC 2009).

Executive Order 13514 (Federal Leadership in Environmental, Energy, and Economic Performance): A 2009 Executive Order to establish an integrated strategy towards *sustainability* in the Federal government and to make reduction of *greenhouse gas emissions* a priority for Federal agencies.

Exposure: In the context of *vulnerability* to *climate change*, exposure refers to the climate-related *stressors* that influence particular systems, and can include stressors such as droughts (e.g., in the context of water resources, agriculture, forestry) or sea level rise (e.g., coastal flooding, habitat loss) (National Climate Assessment Report Series, Volume 9)

Extreme weather event: An event that is rare within its statistical reference distribution in a particular place. Definitions of "rare" vary, but an extreme *weather* event would normally be as rare as or rarer than the 10th or 90th percentile.

Feedback: An interaction mechanism between processes such that the result of an initial process triggers changes in a second process and that in turn influences the initial one. A positive feedback intensifies the original process, and a negative feedback reduces it (IPCC, 2007).

Forcing: A natural or human-induced factor that influences climate.

General Circulation (GCM) or Atmosphere/Ocean Global Climate Model: A numerical representation of the *climate system* based on the physical, chemical, and biological properties of its components, their interactions and *feedback processes*, and accounting for all or some of its known properties (IPCC, 2007).

Geo-engineering: Deliberate large-scale manipulation of the planetary environment as a strategy to counteract *anthropogenic* climate change (NRC's America's Climate Choices: Advancing the Science of Climate Change).

Global change: Changes in the global environment (including alterations in *climate*, land productivity, oceans or other water resources, atmospheric chemistry, and ecological systems) that may alter the capacity of the Earth to sustain life (Global Change Research Act of 1990)

Global change information system: An information system that establishes data interfaces and interoperable repositories of *climate* and *global change* data which can be easily and efficiently accessed, integrated with other data sets, maintained over time and expanded as needed into the future.

Global change research: Study, monitoring, assessment, prediction, and information management activities to describe and understand the interactive physical, chemical, and biological processes that regulate the total *Earth system*; the unique environment that the Earth provides for life; changes that are occurring in the *Earth system*; and the manner in which such system, environment, and changes are influenced by human actions.

Global Change Research Act (GCRA): A 1990 act establishing the *United States Global Change Research Program*, an interagency program aimed at understanding and responding to global change, including the cumulative effects of human activities and natural processes on the environment, to promote discussions toward international protocols in global change research, and for other purposes.

Global Earth Observing System of Systems (GEOSS): A "system of systems" linking together existing and planned *observing systems* around the world and promoting common technical standards so that data from thousands of different instruments can be combined into coherent data sets.

Global Framework for Climate Services: An outcome of the World Climate Conference (WCC-3) of the United Nations World Meteorological Organization, with the goal of the development and provision of relevant science-based climate information and prediction for climate risk management and adaptation to climate variability and change, throughout the world.

Greenhouse effect: Trapping and build-up of infrared radiation (heat) in the *atmosphere* (troposphere) near the Earth's surface. Some of the heat flowing back toward space from Earth's surface is absorbed by water vapor, carbon dioxide, ozone, and several other gases in the atmosphere and then reradiated back toward Earth's surface. If the atmospheric concentrations of these *greenhouse gases* rise, the average temperature of the lower atmosphere will gradually increase (US EPA).

Greenhouse gas (GHG): Any gas that absorbs infrared radiation (heat) in the atmosphere. Greenhouse gases include, but are not limited to, water vapor, carbon dioxide, methane, nitrous

oxide, chlorofluorocarbons, hydrochlorofluorocarbons, ozone, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride (US EPA).

Human system: Any system in which human organizations play a major role. Often, but not always, the term is synonymous with "society" or "social system," for example, agricultural system, political system, technological system, or economic system (IPCC, 2007).

Human-natural system: Integrated systems in which human and natural components interact, such as the interaction between socioeconomic and biophysical processes in urban ecosystems (Urban Ecology Research Laboratory, University of Washington)

Hydrologic cycle: The flow of water through the *Earth system* via the processes of evaporation, vertical and horizontal transport of vapor, condensation, precipitation, and the flow of water from continents to the ocean.

Hydrological systems: The systems involved in movement, distribution, and quality of water throughout Earth, including both the hydrologic cycle and water resources (IPCC, 2007).

Impacts, Adaptation, and Vulnerability Models (IAV): Models of specific socioeconomic sectors or systems of particular societal interest, such as agriculture, coasts, energy, transportation, health, forestry, fisheries, and water resources, that can be used to investigate the sensitivity of these sectors and systems to climate and global change to support both process understanding and decision making.

In situ: Measurements obtained through instruments that are in direct contact with the subject (e.g., a soil thermometer), as opposed to those collected by remote instruments (e.g., a radar altimeter).

Integrated Assessment Models: A method of analysis that combines results and models from the physical, biological, economic, and social sciences, and the interactions between these components, in a consistent framework, to evaluate the status and consequences of environmental change and the policy responses to it.

Intergovernmental Panel on Climate Change (IPCC): an international scientific body for the assessment of *climate change*, established by the United Nations Environmental Programme and the UN World Meteorological Organization.

IPCC AR4: The fourth in a series of reports by the *Intergovernmental Panel on Climate Change*, intended to assess the most recent scientific, technical, and socio-economic information produced worldwide concerning *climate change*, its potential effects, and options for *adaptation* and *mitigation*.

Land cover: The vegetation and artificial built-up materials covering the land surface, including areas of vegetation (forests, shrublands, crops, deserts, lawns), bare soil, developed surfaces (paved land, buildings), and wet areas and bodies of water (watercourses, wetlands).

Land use: The total of arrangements, activities and inputs undertaken in a certain land cover type (a set of human actions). The term land use is also used in the sense of the social and economic purposes for which land is managed (e.g., grazing, timber extraction and conservation).

Land use and land cover change: A change in the use or management of land by humans that may lead to a change in land cover (IPCC, 2007).

Metadata: Information describing properties of data.

Mitigation (climate change): An intervention to reduce the causes of change in *climate*. This intervention could include approaches devised to reduce *emissions* of *greenhouse gases* to the *atmosphere*; to enhance their removal from the atmosphere through storage in geological formations, soils, biomass, or the ocean; or to alter incoming solar radiation through several *"geo-engineering"* options.

Monitoring: A scientifically designed system of continuing standardized measurements and observations and the evaluation thereof.

Nonlinearity: A process in which there is no simple proportional relation between cause and effect (IPCC 2007).

National Academy of Sciences (NAS): An honorific society of distinguished scholars engaged in scientific and engineering research established by an Act of Congress in 1863, which calls upon the NAS to "investigate, examine, experiment, and report upon any subject of science or art" whenever called upon to do so by any department of the government.

National Climate Assessment (NCA): An assessment conducted under the auspices of the Global Change Research Act of 1990, which requires a report to the President and the Congress every four years that evaluates, integrates and interprets the findings of the *United States Global Change Research Program*.

National Research Council (NRC): The operating arms of the *National Academy of Sciences.* NRC enlists committees of the nation's top scientists, engineers, and other experts to provide independent advice to the government on matters of science, technology, and medicine.

National Science and Technology Council (NSTC): A Cabinet-level Council established by Executive Order that is the principal means within the executive branch to coordinate science and technology policy across the diverse entities that make up the Federal research and development enterprise.

Observations: Standardized measurements (either continuing or episodic) of variables in *climate* and related systems.

Observing system: A coordinated series of instruments for long-term observations of the land surface, *biosphere*, solid Earth, *atmosphere*, and oceans to improve understanding of Earth as an integrated system.

Ocean acidification: The phenomenon in which the pH of the ocean becomes more acidic due to increased levels of carbon dioxide in the atmosphere from human activities, which, in turn, increase the amount of dissolved carbon dioxide in seawater. Ocean acidification may lead to reduced calcification rates of calcifying organisms such as corals, mollusks, algae and crustacea.

Office of Science and Technology Policy (OSTP): A division of the Executive Office of the President (EOP) established by Congress in 1976 with a broad mandate to advise the President and others within the EOP on the effects of science and technology on domestic and international affairs. The 1976 Act also authorizes OSTP to lead interagency efforts to develop and implement sound science and technology policies and budgets, and to work with the private sector, state and local governments, the science and higher education communities, and other nations toward this end.

Ozone: A very active colorless gas, readily reacting with many other substances. See *ozone hole* and *scientific assessments of ozone depletion*.

Ozone hole: A depletion of the ozone layer in the Earth's atmosphere over the Antarctic region caused by anthropogenic chlorine and bromine compounds in combination with the specific meteorological conditions of that region. See *scientific assessments of ozone depletion.*

Paleoclimate: Changes in *climate* on the scale of the entire history of Earth as opposed to human-recorded data using instrumentation. Historical climate data—paleodata—are preserved within natural resources such as corals, rocks, ocean and lake sediments, ice cores, tree rings, shells, and microfossils and extend the archive of weather and climate back hundreds to millions of years.

Parameterization: In *climate models*, this term refers to the technique of representing processes that cannot be explicitly resolved at the spatial or temporal resolution of the model (subgrid-scale

processes) by relationships between model-resolved larger-scale flow and the area- or time-averaged effect of such subgrid-scale processes (IPCC, 2007).

Permafrost: Ground (soil or rock and including water, ice, and organic material) that remains at or below freezing for at least two consecutive years (IPCC, 2007).

Prediction: A probabilistic description or forecast of a future *climate* outcome based on *observations* of past and current climatological conditions and quantitative models of climate processes (e.g., a prediction of an El Niño event).

Projection: A description of the response of the *climate system* to an assumed level of future *radiative forcing*. Changes in *radiative forcing* may be due to either natural sources (e.g., volcanic emissions) or human induced causes (e.g., emissions of *greenhouse gases* and *aerosols*, or changes in *land use* and *land cover*). Climate "projections" are distinguished from climate "predictions" in order to emphasize that climate projections depend on *scenarios* of future socioeconomic, technological, and policy developments that may or may not be realized.

Radiative forcing: A process that directly changes the average energy balance of the Earth-atmosphere system by affecting the balance between incoming solar radiation and outgoing or radiation. A positive forcing tends to warm the surface of the Earth and a negative forcing tends to cool the surface.

Remote sensing: The technique of obtaining information about objects through the analysis of data collected by instruments that are not in physical contact with the object of investigation.

Resilience: The ability of a system to recover its capacity to function after disturbance.

Scenario: A coherent description of a potential future situation that serves as input to more detail analyses or modeling. Scenarios are tools that explore, "if…, then…." statements, and are not predictions of or prescriptions for the future.

Scientific assessments of ozone depletion: Periodic assessments of the latest scientific findings related to the ozone layer that fulfill the requirements of an 1987 international agreement known as the Montreal Protocol on Substances That Deplete the Ozone Layer.

Seasonal time scale: On the order of 100 days (a season).

Seasonal-to-interannual timescales: Timescales longer than those associated with individual weather systems (i.e., beyond the range of credible day-to-day forecasts), up to a few years. The *El Niño-Southern Oscillation* (ENSO) is an example of seasonal-to-interannual variability.

Sensitivity: The degree to which a system is affected, either adversely or beneficially, by *climate*-related stimuli. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea-level rise).

Sequestration: The process of increasing the carbon content of a carbon reservoir other than the atmosphere.

Sink: Any process, activity, or mechanism that removes a *greenhouse gas*, an *aerosol*, or a precursor of a greenhouse gas or aerosol from the atmosphere.

Spatial and temporal scales: *Climate* may vary on a large range of spatial and temporal scales. Spatial scales may range from local (less than 100,000 km^2), through regional (100,000 to 10 million km^2) to continental (10 to 100 million km^2). Temporal scales may range from seasonal to geological (up to hundreds of millions of years).

Stakeholders: Individuals or groups whose interests (financial, cultural, value-based, or other) are affected by *climate variability*, *climate change*, or options for *adapting* to or *mitigating* these phenomena. Stakeholders are important partners with the research community for development of decision support resources.

Storm surge: The temporary increase, at a particular locality, in the height of the sea due to extreme meteorological conditions (low atmospheric pressure and/or strong winds) (IPCC, 2007).

Stressor: A chemical or biological agent, environmental condition, external stimulus or event that causes stress to an organism or system.

Subcommittee on Global Change Research (SGCR): The steering committee of the *U.S. Global Change Research Program* (USGCRP) under the *Committee on Environment, Natural Resources, and Sustainability*, overseen by the Executive Office of the President. SGCR is composed of representatives from each of the member agencies of the USGCRP.

Sustainability: Balancing the needs of present and future generations while substantially reducing poverty and conserving the planet's life support systems.

Sustainable development: Development that meets the needs of the present without compromising the ability of future generations to meet their own needs (Brundtland Commission (IPCC, 2007).

Synoptic timescale: On the order of 10 days.

System: Integration of interrelated, interacting, or interdependent components into a complex whole.

Technology: A piece of equipment or a technique for performing a particular activity.

Terabytes (TB): A multiple of the unit byte for digital information. One terabyte is equivalent to 10^{12} bytes.

Teleconnection: A connection between *climate* variations over widely separated parts of the world (IPCC, 2007).

Timescale: Characteristic time for a process to be expressed.

Tipping point: A critical *threshold* at which a tiny perturbation can qualitatively alter the state or development of a system (Lenton, 2008, Proceedings of the National Academy of Sciences).

Three-dimensional ocean heat content: The heat stored in the volume of the world's ocean.

Threshold: A point in a system after which any change that is described as *abrupt* is one where the change in the response is much larger than the change in the forcing. The changes at the threshold are therefore abrupt relative to the changes that occur before or after the threshold and can lead to a transition to a new state (IPCC, 2007, WGI)

Uncertainty: An expression of the degree to which a value (e.g., the future state of the *climate system*) is unknown (IPCC, 2007).

United States Global Change Research Program (USGCRP): An interagency program that coordinates and integrates federal research on changes in the global environment and their implications for society. USGCRP began as a presidential initiative in 1989 and was mandated by Congress in the Global Change Research Act of 1990 (P.L. 101-606), which called for "*a comprehensive and integrated United States research program which will assist the Nation and the world to understand, assess, predict, and respond to human-induced and natural processes of global change*." Thirteen departments and agencies participate in the USGCRP, which was known as the U.S. Climate Change Science Program from 2002 through 2008. The program is steered by the *Subcommittee on Global Change Research* under the *Committee on Environment and Natural Resources*, overseen by the Executive Office of the President, and facilitated by a National Coordination Office.

U.S. Group on Earth Observations: An interagency group established in 2005 under the White House *Office of Science and Technology Policy*'s *Committee on Environment, Natural Resources, and Sustainability* to lead federal efforts to achieve a national Integrated Earth Observation System. Through USGEO, the United States further supports cooperative, international efforts to build the *Global Earth Observation System of Systems* (GEOSS).

Vulnerability: The degree to which a system is susceptible to, or unable to cope with, adverse effects of *climate* and *global change*, including *climate variability* and *extremes*, as well as climate change in conjunction with other stressors (expanded from IPCC, 2007),
Weather: The specific condition of the atmosphere at a particular place and time. It is measured in terms of parameters such as wind, temperature, humidity, atmospheric pressure, cloudiness, and precipitation.

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