OUR CHANGING PLANET

THE U.S. GLOBAL CHANGE RESEARCH PROGRAM FOR FISCAL YEAR 2012

A Report by the U.S. Global Change Research Program
and the Subcommittee on Global Change Research

A Supplement to the President's Budget
for Fiscal Year 2012

OUR CHANGING PLANET - THE U.S. GLOBAL CHANGE RESEARCH PROGRAM FY 2012

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EXECUTIVE OFFICE OF THE PRESIDENT
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WASHINGTON, D.C. 20502

February 15, 2012

Members of Congress:

I am pleased to transmit a copy of Our Changing Planet: The U.S. Global Change Research Program for Fiscal Year 2012. This report summarizes programmatic achievements, priorities, and budgetary information for the U.S. Global Change Research Program (USGCRP) established under the Global Change Research Act (GCRA, P. L. 101-606) of 1990. The USGCRP coordinates and integrates scientific research on climate and global change and is supported by thirteen participating departments and agencies of the U.S. Government.

As described in the new edition of Our Changing Planet, the USGCRP will build upon its foundational elements while placing greater emphasis on several areas identified in its updated decadal Strategic Plan, which is expected to be released in spring of 2012. Areas of greater emphasis include: advancing the scientific knowledge of the integrated human and Earth system; providing the scientific basis to inform and enable timely decisions on adaptation and mitigation; building sustained assessment capacity that improves the Nation's ability to understand, anticipate, and respond to global change impacts and vulnerabilities; and increasing public understanding of global change through improved communications and educational activities.

The USGCRP is committed to building a knowledge base that informs human responses to global change through coordinated and integrated federal programs of research, education, communication, and decision support. I appreciate the close cooperation of the participating agencies, and I look forward to working with the Congress in the continued development and implementation of this essential national program.

Sincerely,

John P. Holdren
Assistant to the President for Science and Technology
Director, Office of Science and Technology Policy

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I PURPOSE OF THIS REPORT

Since 1990, the United States Global Change Research Program (USGCRP) has developed and submitted an annual report, *Our Changing Planet*, to Congress describing the current state of the USGCRP and ongoing Federal research activities focused on global change. This Fiscal Year (FY) 2012 edition summarizes the Program's achievements, progress made, future priorities, and budgetary information. It thereby responds to the requirements of the U.S. Global Change Research Act of 1990 (GCRA; Section 102, P.L. 101-606) for an annual report on "Federal global change research priorities, policies, and programs."

II OVERVIEW OF THE USGCRP

BACKGROUND

U.S. global change research over the past several decades has contributed substantially to an improved understanding of the interactions of natural and human-induced changes in the global environment and their effects on society. To continue assisting the government and society as a whole with understanding, projecting, and responding to global change, the agencies of the Federal government deploy a wide range of powerful science and technology resources.

To integrate and coordinate these resources throughout the Federal government, the USGCRP was launched through a presidential initiative in 1989. A year later, the USGCRP was codified by Congress in the Global Change Research Act (GCRA) of 1990 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.*" (See <www.gcrio.org/gcact1990.html>) The USGCRP brings together, in a single interagency program, research activities that are distributed across thirteen United States government agencies and departments (see Figure 1). Success in developing, translating, and delivering the scientific information necessary for decisionmaking relies on coordinating the programmatic and budgetary decisions of the agencies and departments that make up the USGCRP.

PROGRAM GOVERNANCE

The USGCRP is coordinated through the Subcommittee for Global Change Research (SGCR), which falls under the National Science and Technology Council (NSTC) (see Figure 2), and is overseen by the White House Office of Science and Technology Policy (OSTP).

- 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
- United States Agency for International Development

Figure 1: USGCRP Member Agencies Structure

The SGCR is comprised of representatives from each of the 13 participating agencies and departments, which act as principal leads. It is led by a chair from one of the participating agencies, and coordinates USGCRP programs in the participating departments and agencies. In order to align the program's governance with its strategic needs, vice-chairs have been identified for Strategic Planning and Process Research, Integrated Observations, Integrated Modeling, and Adaptation Science. The USGCRP is directed by an Executive Director from the OSTP and is supported by the USGCRP National Coordination Office (NCO), which supports the day-to-day coordination activities, including USGCRP program area planning and integration of activities implemented through various Interagency Working Groups (IWGs).

The OSTP and the Office of Management and Budget (OMB) work closely with the SGCR to establish research priorities and funding plans to ensure that the program is aligned with our National priorities, reflects agency planning, and meets the requirements of the GCRA, P.L. 101-606.

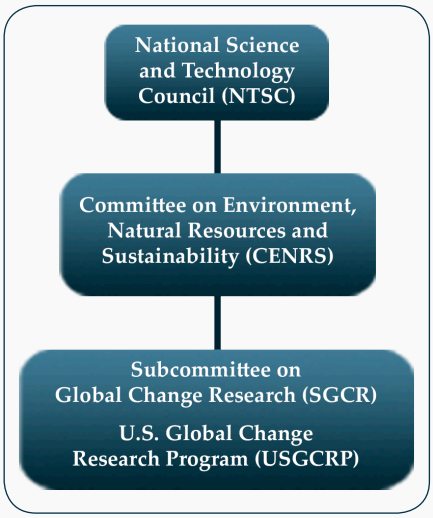

Figure 2: USGCRP Governance

III STRATEGIC AND ORGANIZATIONAL REALIGNMENT

HISTORICAL STRATEGIC ALIGNMENT OF PROGRAM ELEMENTS

The GCRA mandates the USGCRP to develop a decadal strategic plan. The last Strategic Plan was published in 2003 and organized the USGCRP around seven main program elements and a number of crosscutting activities to coordinate scientific research and the flow of information through interdisciplinary interagency working groups (IWGs). As reported in the past several annual reports to Congress (FYs 2003–2010), these working groups were aligned with and intended to meet the 2003 plan goals and objectives. In the last Our Changing Planet (OCP) report (FY 2011), the USGCRP took the initial steps to review historical program elements and priorities and identified a new set of interim strategic program elements (see Figure 3). These have served as the foundation for realizing the new vision of the program, ranging from fundamental research for advancing the understanding of global change to decision support and informing responses to global change.

1. Integrated Observations
2. Fundamental Research
3. Adaptation Science
4. End-to-end Modeling
5. National Climate Assessment
6. Climate Services
7. Communications and Education
8. Societal Areas of Interest (e.g., Climate Change and Human Health)
9. International Research and Cooperation

Figure 3: FY 2011 Interim Program Elements

The USGCRP continues to maintain its traditional strengths by supporting and coordinating a variety of research activities to gain more detailed predictive understanding of climate variability and change over multiple time scales. However, as mandated in Section 101 of the GCRA, the USGCRP purpose is to "assist the Nation and the world to understand, assess, predict, and respond to human-induced and natural processes of global change." In order to adequately comply with the mandate to assist in responding to global change, the program is currently undergoing a strategic and organizational realignment to:

- Further enhance these traditional fundamental science strengths;
- Meet the evolving societal needs for climate and global change information; and
- Predict as-yet undetected impacts.

The program will strengthen and leverage existing agency or department programs that enable science capabilities needed to meet the requirements of the GCRA and societal needs. This new integrated focus of the program will facilitate use of scientific information to reduce impacts of climate-related events and promote economic opportunities across the United States and the globe.

NATIONAL RESEARCH COUNCIL AND EXTERNAL ADVICE FOR REFORMING THE USGCRP

As required by the GCRA, the USGCRP receives periodic guidance from the National Research Council (NRC) of the National Academies and other external sources. Recent NRC reports concluded that the program provides the scientific foundation required to address the urgent needs of society in responding to global change, but that the USGCRP should be broader in scope and should strive to play a more proactive role in informing decision making. The United States needs a comprehensive and integrated global change science enterprise that not only contributes to our fundamental understanding of global change but also informs decision making necessary for effective responses to global change.

Some of the most important reports that were used to inform the USGCRP strategic and organizational realignment include:

- NRC 2005. Analysis of Global Change Assessments: Lessons Learned;
- NRC 2007. Evaluating Progress of the U.S. Climate Change Science Program: Methods and Preliminary Results;
- NRC 2009. Restructuring Federal Climate Research to Meet the Challenges of Climate Change;
- NRC 2009. Informing Decisions in a Changing Climate;
- USGCRP 2009. Global Climate Change Impacts in the United States;
- Doherty et al. 2009. Lessons Learned from IPCC Fourth Assessment Report (AR4): Scientific Developments Needed to Understand, Predict, and Respond to Climate Change;
- USGCRP/IPCC Working Group II Technical Support Unit 2009 Workshop. Enhancing U.S. Contributions to WGII of the IPCC Fifth Assessment Report (AR5);
- USGCRP 2010. National Adaptation Summit Report;
- NRC 2010. America's Climate Choices. Advancing the Science of Climate Change;
- NRC 2010. America's Climate Choices. Limiting the Magnitude of Climate Change;
- NRC 2010. America's Climate Choices. Adapting to the Impacts of Climate Change;
- NRC 2010. America's Climate Choices. Informing an Effective Response to Climate Change; and
- NRC 2011. America's Climate Choices. Final Report.

In response to these and other reports, the USGCRP is being restructured to enable a better understanding and more effective response to global and climate change impacts and societal needs, in accord with the GCRA's mandate to understand, assess, predict, and respond to human-induced and natural processes of global change. Increased emphasis is being placed on bridging the gaps between estimating how climate may change and preparing for the impacts these changes may have on society (including ecosystem services, water and energy resources, natural resource utilization, human health, and societal well being), as well as on an improved understanding of the vulnerability of the Earth and human systems. The goal of the restructuring is to better inform decision making.

IV NEW USGCRP STRATEGIC PLAN, ORGANIZATIONAL FRAMEWORK, AND RELATED ACHIEVEMENTS

STRATEGIC VISION AND MISSION

Developed by a team of scientists, educators, and policymakers across the USGCRP Federal agencies and departments, the strategic plan is motivated by the USGCRP's new guiding vision and develops an integrated set of strategic priorities that, together, will assure the realization of the USGCRP's new 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."*

NEW STRATEGIC PLAN

Over fiscal year 2011, the USGCRP developed a new decadal Strategic Plan, set to be finalized in winter 2012. The plan links scientific discovery to societal needs, thereby contributing to a government-wide "end-to-end" strategy for understanding and addressing global change. USGCRP's role is to provide the science that informs decisions. The plan articulates the program's research goals, provides a framework for informing decisions and assessing progress, and outlines shared capabilities to support interagency activities. The USGCRP's set of strategic goals and objectives provides a strong research foundation for understanding global change, and a basis for enhanced partnerships with other parts of the government, academia, and the private sector. It will shape the direction of the program from 2012 to 2021, ensuring that the interim strategic program elements as described in the last report to Congress (OCP FY 2011) are fully integrated throughout the four new strategic goals as described below. The individual execution of and integration across the various program elements will provide the foundation to help meet the strategic goals and the overall USGCRP vision and mission.

NEW DRAFT STRATEGIC GOALS

The new strategic approach will provide an expanded framework for global change science. *Please note: the goals described below are in draft form, were released for public comment in fall 2011, and are subject to change in the final Strategic Plan.*

GOAL 1. ADVANCE SCIENCE

Advance scientific knowledge of the integrated natural and human components of the Earth system. This goal most closely aligns with the traditional emphasis of the USGCRP. It identifies the research, including integrated observations and modeling, necessary to better understand the behavior and interaction of the natural and human components of the Earth system and their response to global change. The program will increasingly emphasize integrating physical, biological, and social science research, and developing reliable knowledge of the causes and consequences of global change at regional and global scales to help assist and inform adaptation and mitigation decisions. The 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. The USGCRP member and cooperating agencies will emphasize the use of scientific knowledge in support of adaptation and mitigation decisionmaking, translating and providing research results (from Goal 1) into information, formats, and results that are policy relevant, usable, and accessible to decisionmakers, and facilitate meaningful engagements and partnerships between scientists and decisionmakers. The program and its member agencies will provide global change information, tools, and services needed to make decisions.

GOAL 3. SUSTAINED ASSESSMENTS

Build sustained assessment capacity that improves the United States' ability to understand, anticipate, and respond to global change impacts and vulnerabilities. The USGCRP will conduct and participate in national and international assessments to evaluate past, current, and likely future scenarios of global change and their impacts, as well as how effectively science is being used to support and inform the United States' response to change. The USGCRP will integrate emerging scientific understanding of the Earth system into assessments and identify critical gaps and limitations in scientific understanding. It will also build a standing capacity to conduct national assessments and support those at regional levels. The USGCRP 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 state-of-the-art information on global change, the 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 personal and professional lives. These efforts will also help build climate and global change literacy among the diverse audiences. Global and climate change education also supports scientific workforce development.

IMPLEMENTATION PLANNING

The USGCRP has developed a set of implementing guidelines that will be used in implementing the new Strategic Plan that also provide approaches for updating the plan as progress is evaluated. To achieve its strategic vision and goals, the USGCRP will need access to the resources of agencies and departments that have not historically been engaged with the USGCRP. The guiding principles are as follows:

- Ensure the continuing strength of the scientific foundation of the USGCRP (observations, modeling, and process research);
- Use the scientific foundations to support all four goals;
- Develop flexible plans for phasing in new activities and priorities that are consistent with the budget and build upon member agencies' strengths;
- Develop a portfolio of essential foundational and new activities that:
  - *Promote scientific progress that results in direct societal benefit;*
  - *Have strong interdependencies among the USGCRP agencies that are facilitated through the USGCRP leadership and coordination;*
  - *Build the capacity within the 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 decisionmaking; and*
  - *Enable discoveries through transformational research that can lead to breakthroughs in how the United States documents, predicts, understands, and responds to global change.*
- Build connections among 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 United States' responses to global change;
- Focus on international partnerships that advance science and enhance science assessment and response activities in the United States and globally; and
- Regularly re-evaluate interagency priorities and the balance between research and service goals.

ANNUAL PRIORITIZATION

As stated in the USGCRP's legislative mandate (GCRA Section 105), "*the committee shall each year provide general guidance to each Federal agency or department participating in the Program with respect to the preparation of requests for appropriations for activities related to the Program.*" In preparation for the annual USGCRP budget crosscut, the USGCRP agencies participate in an interagency process that involves coordination and alignment of agency efforts across the draft strategic plan goals (for FY 2013, using the draft strategic plan) while prioritizing Federal investments for global change research and supporting programmatic activities. As part of this activity, the agencies, together with OSTP and OMB, will annually revisit the budget crosscut to ensure that it reflects each agency's investment in USGCRP activities.

V ACCOMPLISHMENTS AND FUTURE DIRECTIONS

The USGCRP made several key accomplishments in FY 2011, including:

- Drafting a new decadal strategic plan and beginning a process to realign program goals with the new plan;
- Launching the development of the 2013 National Climate Assessment (NCA);
- Monitoring global land surface winds and inland lake surface temperatures;
- Developing integrated Earth system model capabilities;
- Leading an initiative on sea level response to ice sheet evolution;
- Advancing research on climate warming and weather extremes;
- Providing science for water resource decisionmaking and management;
- Understanding vulnerabilities of fish habitats, climate, and land use changes;
- Researching the economic implications of climate change and adaptation in the agricultural sector;
- Understanding the interactions between air quality and climate change, identifying opportunities to advance the field of co-benefits
- Advancing climate change education and literacy; and
- Understanding the linkage between biodiversity and infectious diseases.

In addition, in FY2011, the USGCRP advanced its core programmatic and cross-cutting scientific areas in alignment with the draft goals and objectives of its new decadal Strategic Plan. The following descriptions of the program areas and cross-cutting areas include an overview of the area, recent accomplishments, both interagency and agency-specific illustrations of these accomplishments, and future activities.

PROCESS RESEARCH

OVERVIEW

Process Research: *Research on global and climate change, including on interactions between the Earth and human system.*

Fundamental research into the basic workings of the Earth system, directed toward understanding the nature, magnitude, and pace of climate and global change, provides the foundation for all aspects of the USGCRP. Fundamental process research integrates across observations, modeling, and laboratory and field experiments. Observations of all components of the Earth system (atmosphere, ocean, cryosphere, biosphere, lithosphere, human society) provide the basis for documenting its present state and its evolution through time and for understanding and predicting its future evolution. An understanding of Earth processes combined with a sufficiently comprehensive set of observations and modeling capabilities, jointly provide a rigorous basis for connecting cause and effect, and for understanding the sources of historical and future global, regional, and local change. Similarly, models provide quantitative methods to test this understanding of the Earth system gained through observation and experiments, and serve as tools for formulating hypotheses about its future evolution. Used together, observations, process research, and modeling provide a means to understand the Earth system and its components (including their

spatial and temporal variability), and to construct and test hypotheses about present and potential future Earth system changes.

Advances in knowledge of the processes underlying the behavior of Earth system components, and their interactions and feedbacks, have led to a growing appreciation for their complexity and interconnectedness, of the significant role that human activities play in climate change, and of the importance of dimensions of global change, such as land use and land cover change and changes in the carbon, nitrogen, and water cycles, that act both as drivers of and co-stressors with climate change. This fundamental research has shown that climate change is occurring, that these changes can be attributed to human activities, and that climate change poses significant risks for both human and natural systems. This research has illuminated a broad spectrum of changes in the climate in addition to global warming, such as increases in the frequency of intense rainfall, decreases in snow cover and sea ice, more frequent and intense heat waves, rising sea levels, and widespread ocean acidification. Individually and collectively, these changes pose risks for freshwater resources, the coastal environment, ecosystems, agriculture, fisheries, human health, and national security, among others.

Building on its strong history of success, the USGCRP must increasingly focus on expanding the knowledge base required to help society respond to these changes at global, regional, and local scales. As society responds to the risks and opportunities brought on by global change, decisionmakers will require scientific information to inform their actions. It is important that the scientific community continue to conduct research that will improve understanding of the causes and consequences of climate and global change, and improve our understanding of the options available to limit the magnitude of global change, adapt to impacts, and capitalize on the opportunities that may arise. In addition, the scientific community should strive to be as comprehensive, integrated, and flexible as possible to meet the evolving scientific needs of society.

EXAMPLES OF RECENT ACCOMPLISHMENTS IN PROCESS RESEARCH

UNDERSTANDING THE COMPLEX ECOSYSTEM DYNAMICS OF THE BERING SEA

Understanding of the complex ecosystem dynamics of the Bering Sea has been advanced significantly through funding from a partnership of the National Science Foundation's (NSF) Bering Ecosystem Study (BEST) and the North Pacific Research Board's Bering Sea Integrated Ecosystem Research Program (BSIERP). The five-year BEST-BSIERP "Bering Sea Project" has engaged more than 100 scientists in the observation and modeling of the Bering ecosystem during this time of rapid environmental change. Now in its fourth year, the Bering Sea Project will release its first special issue, which includes findings about certain key fisheries species that are temperature-limited and therefore trapped between a warming southern Bering Sea and a cold pool to the north in the Bering Strait. These and other emerging results, made possible through collaborations with the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Fish and Wildlife Service (USFWS) scientists, provide a picture of a sea in transition (see Figure 4). Shifts in the productivity of these northern fishing grounds and seabird and marine mammal habitat have impacts that extend far beyond the regional economy, subsistence lifeways, and biodiversity.

Figure 4: Scientists in the Field for the Bering Sea Project. *Deployment of a Bongo net system from the stern of the U.S. Coast Guard Cutter Healy to sample zooplankton in the upper water column in the Bering Sea, an area that supports a large biomass of top predators. Zooplankton moderate phytoplankton blooms in the Bering Sea and are a critical food source for many fish populations. important in commercial and subsistence fisheries.*

UNDERSTANDING ICE SHEET CONTRIBUTION TO GLOBAL SEA LEVEL RISE

IceBridge is a National Aeronautics and Space Administration (NASA) airborne mission to continue the record of ice altimetry begun by the Ice, Cloud, and Land Elevation Satellite (ICESat) until the launch of ICESat 2 in 2016. The mission's goal is to improve our understanding of the contribution of the polar ice sheets to global sea level rise, and understand changes in global ice cover in response to climate change. IceBridge uses NASA and

other aircraft to map the thickness and other characteristics of the ice sheets, including the sea ice, Greenland, Antarctica and the major glacial systems of Alaska and Canada. The mission has interagency partnerships with NOAA, the Office of Naval Research (ONR), and the U.S. Army Corp of Engineers (USACE). The interagency work includes participation in mission planning and coordination of IceBridge flights with fieldwork programs of these agencies.

IMPROVING UNDERSTANDING OF THE DYNAMICS OF THE MADDEN-JULIAN OSCILLATION

The Madden-Julian Oscillation (MJO) is a large-scale weather pattern that forms in the Indian Ocean and propagates slowly eastward into the equatorial Pacific Ocean. The MJO influences the monsoon rains of South Asia, Southeast Asia, Australia, and the Maritime Continent, and thus impacts floods, droughts, and severe weather over a large and densely populated region of the world. The MJO also affects weather over the United States, including the frequency of hurricane formation over the Gulf of Mexico. A new observational program called the Dynamics of the Madden-Julian Oscillation (DYNAMO) is underway to study the initiation of the MJO. DYNAMO's goal is to collect data that can help to improve understanding of the MJO, to improve the representation of tropical convection and its organization in weather and climate models, and to improve predictions of the MJO and its impacts from operational forecast centers. Thus, the campaign is intended to improve weather prediction, short-term climate forecasts, and the ability of climate models to simulate both present-day climate and climate change.

NSF, NOAA, ONR, and the Department of Energy (DOE) support DYNAMO in collaboration with over a dozen international partners. Assets deployed to the field by U.S. agencies include the National Center for Atmospheric Research (NCAR) S-Pol radar facility and the DOE Atmospheric Radiation Measurement (ARM) Mobile Facility version 2 (AMF2), both deployed to Addu Atoll in the Maldives; the NOAA P-3 aircraft, deployed on Diego Garcia; and the research vessel Roger Revelle, which is stationed about 10 degrees east of Addu Atoll. DOE will also investigate the MJO as it migrates into the Pacific Ocean at its ARM Tropical Western Pacific site on Manus Island.

FUTURE ACTIVITIES FOR PROCESS RESEARCH

Research will be conducted under the auspices of the USGCRP to continue deepening our understanding of individual Earth system components and processes and address the many critical research gaps that remain. Efforts will focus on advancing knowledge in areas such as the interplay between climate change and other dimensions of global change, the interactions between different components of the Earth system and the different spatial and temporal scales that characterize Earth system processes (e.g., global to regional to local), and complex, nonlinear behaviors that emerge from component and scale interactions in the Earth system (e.g., extremes, triggers, thresholds, and cascading impacts).

In addition, several United States federal agencies have planned for a major integrated field campaign studying atmospheric convection and its contributions to atmospheric chemistry and physics, in both the United States and Southeast Asia, to take place in 2012. In particular, NASA and NSF have agreed to coordinate planned campaigns in a way that leverages the investment of both; the NASA-led campaign involves extensive participation of principal investigators from NOAA, Department of Defense (DOD), and DOE laboratories.

Vertical transport and injection of material emitted into the planetary boundary layer up into the upper troposphere and stratosphere is important because the atmospheric lifetime of some of these materials will significantly increase. For example, small airborne particles can affect the Earth system's energy budget by scattering or absorbing light over a longer time period. Further, reactive gases and airborne particles can also alter the chemistry of the upper atmosphere. Southeast Asia is a region where large natural and human-produced emissions appear to be transported to the upper atmosphere in the seasonal monsoon circulation and by marine convection. NASA, NSF, and the Naval Research Laboratory (NRL) are planning an airborne science campaign in Southeast Asia during August and September 2012. During the Southeast Asia Composition, Cloud Climate Coupling Regional Study (SEAC4RS), NASA's ER-2 and DC-8 and NSF's Gulfsteam V will be deployed to Thailand, enabling access to the vicinity of the Northern Bay of Bengal and the South China Sea. The satellite, airborne, and ground-based data collected during SEAC4RS will help quantify vertical transport, gain better understanding of chemical transformations during vertical transport, and characterize feedbacks atmospheric constituents have on processes important for weather and climate.

Specific future research topics might include:

- Climate variability and its relationship to climate change;
- Climate system forcing, feedbacks, and sensitivity;
- Thresholds, abrupt changes, and other climate surprises;
- Effects of climate and global change and impacts of enhanced carbon dioxide (CO2) on ecosystems, ecosystem services, and biodiversity; and
- Detailed description of the effects of climate change on essential human activities, such as agriculture, forestry, or electricity production.

INTEGRATED OBSERVATIONS

OVERVIEW

Integrated Observations: ***Environmental observing and monitoring capabilities and related measurements that support the understanding of global and climate change and related impacts.***

Physical, chemical, ecological, and socio-economical observations are vital to our ability to monitor and understand global change, as well as to plan for, predict, and respond to the changing climate, and to protect our citizens and infrastructure. Today, millions of individual observations are collected every day, allowing us to document Earth system variability at a variety of spatial and temporal scales, and examine Earth system processes. These observations serve as the basis for modeling atmospheric composition, ecosystem and human health, weather patterns, agricultural production, and hundreds of other characteristics of our planet. Ongoing efforts to maintain and improve our observing systems will be required to continue to improve our understanding of global change, and to develop the ability to assess and protect natural resources, physical infrastructure, and communities.

Long-term, stable, and high-accuracy records for observations (from satellites, *in-situ* facilities, and other observing systems) are essential for defining the current state of the Earth's system, discovering the magnitude and sources of past trends, and providing the scientific basis for predictions of future variability and change. Other kinds of observations routinely collected on a regional basis but not collected uniformly or consistently worldwide, such as health and agricultural statistics, are critical indicators of global and climate change effects, and help gain a better understanding of the interactions among climate, human, and environmental systems. The shortage of reliable and consistent data on these interactions limits our ability to understand how humans affect climate (and vice versa) and the design of effective management- and policy-based responses to global change.

Through several mechanisms, including the USGCRP, participating Federal agencies already play an important role in coordinating interagency partnerships central to the management of civilian satellite programs, which, among other things, are critical to our Nation's weather forecasting capability. Unfortunately, deployments of new satellites, including the replacements for existing systems, are not keeping pace with the failure of older systems. Half of the current national and international Earth observing satellites are past their intended operational lives, most without an assurance of replacement. The long-term continuity of many high-quality research- and space-based observations implemented in the United States from the late 1990s through the 2000s is in jeopardy, as well as operationally oriented observations that the United States has implemented over several decades.

In addition to global observations made from space, surface-based measurements (including those taken from the ocean) provide critical data on parameters at fine spatial and temporal scales as well as in places and conditions not measurable from space. For example, stream gauge measurements not only inform short-term water resource management decisions, but also monitor effects of global change on hydrological systems. Ground-based measurements also validate and calibrate measurements made by satellites. The observational infrastructure for *in situ* measurements is aging, and the demand for monitoring programs continues to grow.

Development of an integrated and sustained global and climate change observing system stands as a large and urgent challenge. The design, deployment, and maintenance of a comprehensive and integrated observing/monitoring system can support the most critical aspects of understanding and responding to climate and global change. One part of the challenge is that the required observing system must deliver multidecadal data records with the accuracy and precision needed to distinguish long-term climate and global changes from natural short-

term variability and other environmental influences. This requires the commitment to an ongoing investment in observations, data processing, and distribution.

OVERVIEW OF RECENT ACCOMPLISHMENTS IN INTERGRATED OBSERVATIONS

A draft decadal Integrated Climate Observations Plan was developed by USGCRP's Integrated Observations Working Group to address Federal observations related to investments in global change research and monitoring for the period 2013 to 2023. The plan addresses observations needed to:

- Improve understanding of the climate system and its interaction with other Earth systems;
- Build the next generation of robust climate models for forecasting future climate; and
- Support and inform the Intergovernmental Panel on Climate Change (IPCC) assessment, the NCA, and adaptation and mitigation efforts.

The plan, which is an essential element of the National Earth Observations Strategy, describes objectives for maintaining, improving, and integrating the Federal climate observing needs of the United States. In addition to planning, the USGCRP agencies have taken steps, individually and collectively, to enhance our observational capability for the global Earth system. The SAC-D/Aquarius satellite, a joint U.S.-Argentinean mission to measure sea surface salinity, was launched in June 2011 and has already demonstrated the ability to provide observations that will help to characterize global variability in salinity and inform model calculations of ocean dynamics and the global water cycle. The Suomi National Polar-orbiting Partnership (NPP), formerly known as the National Polar-orbiting Operational Environmental Satellite System Preparatory Project, was launched to continue many of the imaging, sounding, and ozone observations initiated by NASA in the 2000s and to provide on-orbit tests of the next-generation of operational satellite instruments for the Joint Polar Satellite System, the United States' next generation polar-orbiting operational meteorological satellite system. The USGCRP agencies have also coordinated in the initiation and planning of process-oriented field research.

EXAMPLES OF RECENT ACCOMPLISHMENTS IN INTEGRATED OBSERVATIONS

MODERN ERA RETROSPECTIVE ANALYSIS FOR RESEARCH AND APPLICATIONS (MERRA)

One way the challenge of integrating observations is being addressed is through the development of reanalyzed meteorological data sets. A reanalysis utilizes a data assimilation system to optimally combine observations with a climate system model. The NASA Modern Era Retrospective Analysis for Research and Applications (MERRA) was undertaken to place observations from multiple platforms, including *in situ* and remotely-sensed data, in a climate context. The reanalysis combines up to four million observations during one six-hour analysis cycle to produce an integrated meteorological analysis extending from 1979 to the present. The reanalysis allows the integrated study of numerous climate-relevant atmospheric processes, such as the hydrologic cycle, polar climates, and climate extremes. A special collection of 17 journal articles related to the MERRA reanalysis was recently published in the Journal of Climate, describing the reanalysis methodology and presenting a number of scientific applications.

DEFINING ESSENTIAL CLIMATE VARIABLES OF ATMOSPHERE, OCEANS & LAND MEASUREMENTS

The Global Terrestrial Observing System, Global Climate Observing System, World Meteorological Organization (WMO), and Committee on Earth Observation Satellites support consistent global observations and measurements for climate monitoring. To accomplish this goal, "essential climate variables" of atmosphere, oceans, and land measurements were defined that are technically and economically feasible for systematic observation and that are needed to meet the United Nations Framework Convention on Climate Change (UNFCCC) and requirements of the IPCC.

Several of the 14 land climate variables referred to as Terrestrial Essential Climate Variables (ECV) can only be measured by *in situ* observation, while others are suitable for measurement by remote-sensing technologies. The four Landsat-derived ECV priorities include:

- **Land Cover:** This is clearly the highest priority for ECV production as land cover is an essential indicator for almost all environmental investigations – from local to global scales. The challenge associated with this ECV is the development of a specification that can lead to land cover characteristics products with sufficient consistency and accuracy to allow the detection of land changes over time.

- **Fire Disturbance:** This can include active fire location, burned area definition, and fire radiated energy estimation. Landsat is most suited for mapping burned areas.
- **Lake Variables:** The lake ECV definitions emphasize lake level. However, surface water extent is also identified and production of relatively consistent water area time series measures (including lake areas) is feasible using Landsat.
- **Leaf Area Index:** Leaf Area Index (LAI) is a quantitative measure of the amount of live green leaf material present in the canopy per unit ground surface and is important for assessing the state and evolution of the Earth's vegetation. NASA Ames researchers are now developing capabilities to derive LAI from Landsat data and the U.S. Geological Survey (USGS) can serve as a partner in their activity and distribute the LAI ECV as part of the overall Landsat ECV collection.

6 MILLION LANDSAT DATA SETS SERVED TO USERS

Landsat data offers the longest continuous record of satellite observations of the Earth's land surface at scales by which to detect, characterize, and monitor natural and human-induced changes on the landscape. The full USGS archive holds over three million scenes obtained continuously from July 1972 to today by a series of six Landsat satellites. Since 2008, when the images became available free of charge and downloadable from the Internet, there has been a burst of innovative science applications of Landsat data. Landsat scenes are crucial inputs for regional, national and international assessments of climate and land use change. Since October 1, 2008, the scientific and educational users of Landsat increased by 170% (see Figure 5). As of October 2011 over six million data sets had been downloaded. Scientists, educators, and resource managers from virtually every country in the world have used the no-cost download option.

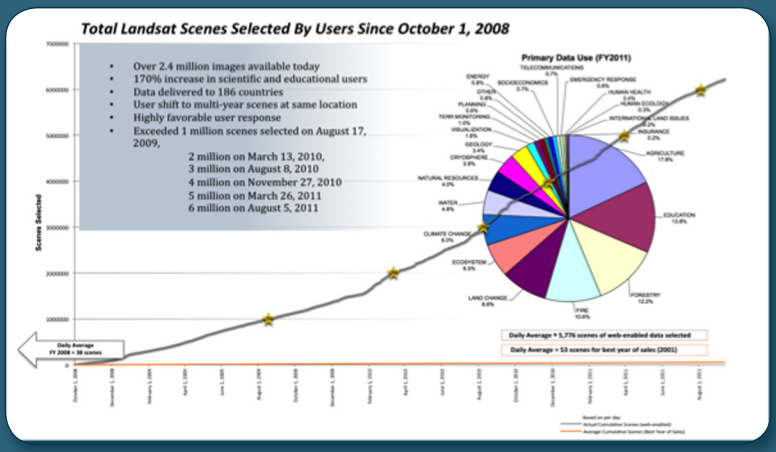

Figure 5: Landsat Web-Enabled Imagery

In 2008, the USGS completed an extensive conversion from an inefficient, on-demand data ordering and processing system to a fully automated access and distribution mechanism. The previous range of options for processing semi-custom digital Landsat products for paying customers was replaced by free Internet access to the entire Landsat archive of over 3 million scenes from around the globe. Users can now select an area of interest and easily download standardized image files. Shortly after this conversion, demand for Landsat data surged from around 20,000 scenes sold per year to over 2 million downloaded for free per year.

Thousands of Landsat images are downloaded every day from a USGS archive holding nearly four decades of Landsat satellite data. Government, commercial, industrial, civilian, military, and educational communities throughout the United States and worldwide rely upon Landsat for a wide range of applications in areas such as global change research, agriculture, forestry, geology, resource management, geography, mapping, water quality, and oceanography.

The Landsat satellite series has provided imagery of the Earth's surface for nearly 40 years, providing the most consistent, reliable documentation of global land surface change ever assembled. No other current or planned remote sensing system, public or private, fills the role Landsat continues to play in global change research or in civil and commercial applications.[1]

[1] Learn more about Landsat data at <http://earthexplorer.usgs.gov/>.

CREATING A BENCHMARK MAP OF FOREST CARBON STOCKS IN TROPICAL REGIONS ACROSS THREE CONTINENTS

A NASA-led research team developed a "benchmark" map of biomass carbon stocks over 2.5 billion hectares of forests on three continents, encompassing all tropical forests, for the early 2000s (see Figure 6).[2] They mapped the total carbon stock in live biomass (above- and belowground) using a combination of data from 4079 *in situ* inventory plots and satellite Lidar samples of forest structure to estimate carbon storage, plus optical and microwave imagery (1 km resolution) to extrapolate over the landscape. The total biomass carbon stock of forests in the study region is estimated to be 247 gigatons of carbon (Gt C), with 193 Gt C stored aboveground and 54 Gt C stored belowground in roots. Forests in Latin America, sub-Saharan Africa, and Southeast Asia accounted for 49%, 25%, and 26% of the total stock, respectively.

The benchmark map illustrates regional patterns and provides methodologically comparable estimates of carbon stocks for 75 developing countries where previous assessments were either poor or incomplete. When combined with spatially explicit information on deforestation, improved estimates of emissions from tropical deforestation and degradation will be possible, both improving our understanding of the global carbon cycle and assisting in monitoring climate change mitigation efforts.

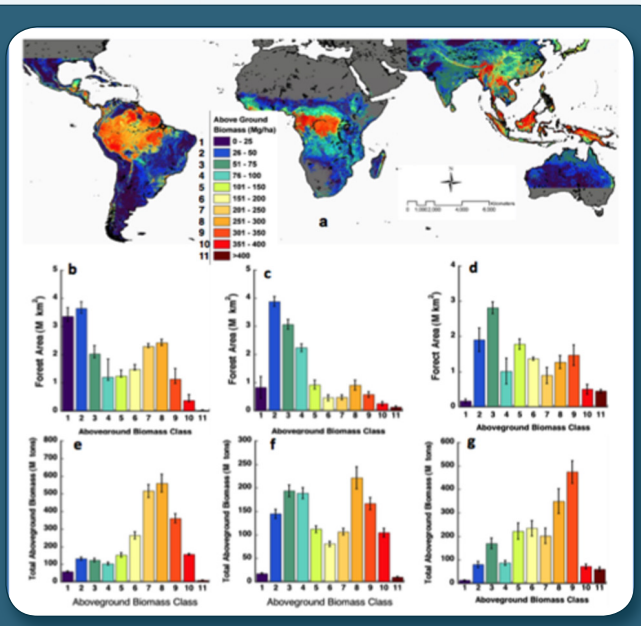

Figure 6: Distribution of Forest Aboveground Biomass
a. Forest aboveground biomass (ABG) is mapped at 1-km spatial resolution. The study region was bounded at 30° North latitude and 40°South latitude to cover forests of Latin America and sub-Saharan Africa, and from 60° to 155° East and West longitude. The map was colored based on 25 – 50 Mg/ha AGB classes to better show the overall spatial patterns of forest biomass in tropical regions. Histogram distributions of forest area (at 10% tree cover) for each biomass class were calculated by summing the pixels over Latin America in b. Africa in c. and Asia in d. Similarly, total AGB for each class was computed by summing the values in each region with distributions provided for Latin America in e. Africa in f. and Asia in g. [Mg = Million metric tons]. (circa 2000)

MONITORING LAKE SURFACE TEMPERATURES

The temperatures of lakes and other inland water bodies are excellent indicators of climate change. Previously, *in situ* temperature data have been used to measure the impact of climate change on lakes. These data are generally accurate; however the data are restricted to a few sites and continuous, long-term *in situ* observations are rare. Satellite thermal infrared data have been used to measure lake surface temperature, but there were major geographical limitations. To provide a more global scope, two NASA scientists used 25 years of thermal infrared satellite data at 104 inland water bodies worldwide in order to determine possible trends in nighttime surface water temperatures (see Figure 7). This study used seasonally averaged (July–September and January–March) nighttime data from the series of Advanced Very High Resolution Radiometers and the series of Along-Track Scanning Radiometers obtained between 1985 and 2009. Satellite-based trends were found to closely match those derived from buoy data obtained from the National Data Buoy Center, as validated over the American Great Lakes.

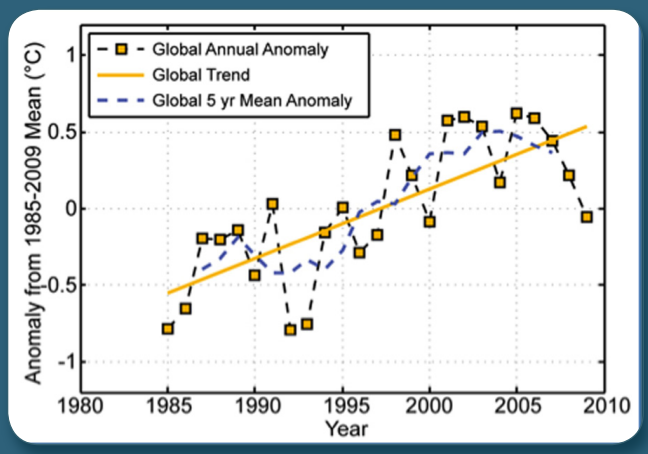

Figure 7: Global Average Nighttime Lake Surface Temperatures
Global average nighttime lake surface temperatures show year-to-year variability, including a decrease during the last two years, yet over the full period for which data are available, the temperatures increased on average by 0.045°C per year.

[2] Saatchi, S.S., N. L. Harris, S. Brown, M. Lefsky, E. Mitchard, W. Salas, B. Zutta, W. Buermann, S. Lewis, S. Hagen, S. Petrova, L. White, M. Silman, and A. Morel, 2011: Benchmark map of forest carbon stocks in tropical regions across three continents. *Proceedings of the National Academy of Sciences*, 108,9899-9904.

Using a merged data set consisting of data from two sensors improves the agreement considerably.

MONITORING GLOBAL LAND SURFACE WINDS

Wind speed and direction have been observed on an hourly or synoptic basis at many thousands of stations around the world; however, it wasn't until this year that a team of scientists from the United States, France, Australia, and the United Kingdom were able to accurately assess wind speed anomalies and trends. The main scientific challenge was careful attention to the homogeneity of station time series. That limited the assessment of wind speed anomalies and trends anomalies for 2010 to less than 10% of the stations shown in Figure 8.

As shown in Figure 9, observed wind speed over much of the global land areas tends to be decreasing. However, model reanalysis of air pressure and other data, produces wind fields that show little or no change in wind speed over time. The difference is believed to be at least partly due to increases in surface roughness associated with growth of vegetation. These land surface changes are currently not fully represented in model data reanalysis systems. Roughness changes near wind observing sites may not impact higher elevation sites that are important for wind energy.

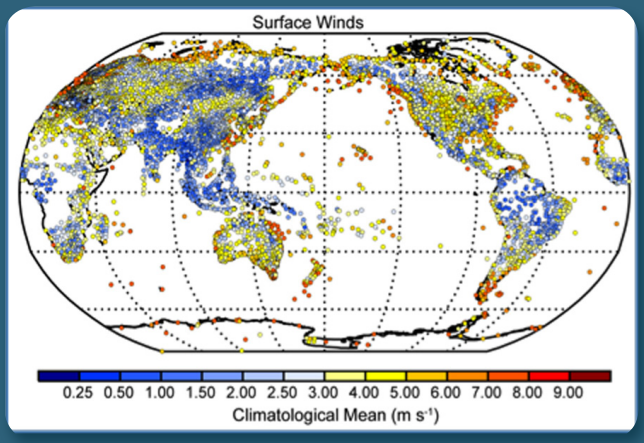

Figure 8: Observed Average Wind Speed in 2010
Observed average wind speed at almost 11,853 stations with at least five years of observations between 1979 and 2010.

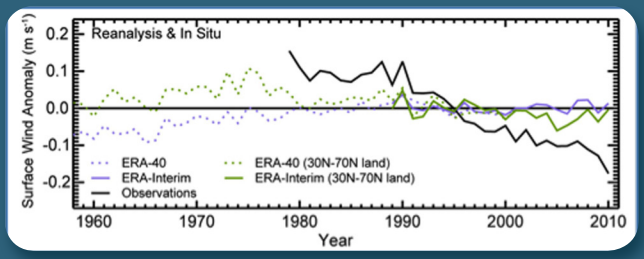

Figure 9: Global Average Wind Speeds Over Land
Global average observed wind speeds over land show a decrease over time while model data reanalysis systems indicate no trend.

FUTURE ACTIVITIES FOR INTEGRATED OBSERVATIONS

In the new strategic framework, the core objective for integrated observations is to advance capabilities to observe the physical, chemical, biological, and socioeconomic components of the Earth system over multiple spatial and temporal scales, to gain fundamental scientific understanding and monitor important variations and trends, as well as to provide a rigorous basis for Earth system modeling (including initialization, evaluation, and process representation). The USGCRP and its member agencies will build on existing observational capabilities and achievements to:

- Sustain and strengthen the capacity to observe and analyze 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, regional, and local adaptation and mitigation efforts; and
- Integrate observations and modeling to advance both scientific understanding and decision support.

In collaboration with the U.S. Group on Earth Observation (USGEO), a USGCRP interagency working group is responsible for carrying out the coordination activities of climate and global change observations.

INTEGRATED MODELING

OVERVIEW

Integrated Modeling: *Predictive (and retrospective) modeling and projections of global and climate change and related impacts.*

Cost-effective adaptation and mitigation efforts require understanding climate change and its impact on living systems (human and ecological) and physical infrastructure. USGCRP agencies develop, use, and increasingly integrate three classes of models to improve this understanding: Earth System Models (ESM); Integrated Assessment Models (IAM); and Impact, Adaptation, and Vulnerability (IAV) models. Of these, ESMs have the most comprehensive representations of physical and biological systems and their interactions, and hence are essential tools for exploring Earth system complexities predicting the behavior of the climate system, and interpreting observed changes in climate and weather.

Despite their increasing sophistication, scope, and fidelity, these models need additional development in a number of important areas. Key challenges include improving the ability to predict climate at finer spatial (e.g., regional and local) scales, improving representation of climate and weather extremes (e.g., droughts and hurricanes), and extending the time horizon of predictive forecasts out to the decadal time scale relevant for many types of decisions. New and enhanced models are expected to make important contributions toward advancing our fundamental understanding of climate change, as well as informing future policymaking, planning, and decision support for sectors such as energy, natural resources, food, and water, and national security.

Used in conjunction with climate and ESMs, so-called IAV models are designed for assessments of potential climate change impacts, critical vulnerabilities, and effective adaptation strategies in sectors such as agriculture, coastal systems, energy, transportation, health, forestry, fisheries, ecosystem services, and more. Improvements in IAV science and modeling will lead directly to a more thorough understanding of these critical dimensions of assessment and decision support. The requirements imposed by these assessments and decisionmaking needs in turn will drive future improvements in climate and ESMs, for example, in the areas of greater spatial resolution, improved representation of extremes, and more thorough estimation of intermodal consensus and uncertainties. These IAV models will also assist in the development of more informative and comprehensive scenarios of drivers of future climate forcing, socioeconomic vulnerability, and adaptive capacity.

Finally, integrated assessment models (IAMs) combine the drivers and consequences of climate change within a consistent modeling framework. At the center of IAMs are representations of present and possible future human activities (e.g., changes in emissions, land, or water uses, etc.) and their potential influence on the Earth system. Compared to ESMs, IAMs have less sophisticated representations of physical and biological systems but much more complete representations of human systems. IAMs address the two-way coupling between changes in the natural climate system and human activities, including those undertaken to mitigate climate change, to adapt to climate change, or as consequences of changes in climate or other aspects of the Earth system. Understanding these consequences, with particular attention to options for mitigation and adaptation at regional and local scales, requires the development of next-generation models, including improved representation of natural and human systems and the interactions between them, while simultaneously maintaining the modest computational demands of current IAMs. Meeting these new challenges and delivering timely and relevant projections and scenarios to decisionmakers will require a coordinated effort that builds upon our Nation's substantial research and modeling infrastructure. Besides improvements in each class of model, we need better integration among IAMs, ESM, and IAV models.

OVERVIEW OF RECENT ACCOMPLISHMENTS FOR INTEGRATED MODELING

Under the auspices of the USGCRP, the climate and global change modeling community has taken advantage of rapidly advancing computing resources to work toward a number of goals. To provide regional-scale information for planning purposes, the resolution at which models are being run has continued to increase as ESMs aim to provide information at scales that are relevant to local decisionmakers. New numerical methods, grids, physics, and parameterizations have been introduced to meet the challenges of running these models at unprecedentedly fine resolutions.

In addition, the scope of processes represented in such models, particularly in the area of biogeochemistry, has increased. A first generation of ESMs now capture representations of carbon and nitrogen cycles and dynamic vegetation, thereby allowing feedbacks involving these processes to be represented. In addition, the simulation

of cloud and aerosol processes has become more sophisticated, enabling improved modeling of aerosol effects on clouds and climate, as well as climate system feedbacks.

Until recently, ESMs have not included dynamical ice sheet models for the large Greenland and Antarctic ice sheets and have therefore been unable to provide projections of future sea level rise in climate change scenarios. Ice sheet model components have recently been added to some ESMs to provide a fully interactive and dynamic model of ice sheet melting and its contribution to sea level rise. Early efforts have had relatively simple dynamical components but next generation models will better represent the full dynamics of ice sheet flow and also have better treatments of the ocean/ice shelf interface, calving and basal hydrology and lubrication. These next generation models will provide improved estimates of the rate of sea level rise due to climate change.

The IAM community has advanced the representation and prediction of the interactions of the natural and human components of the Earth system. The community has made advances in the integration of land use with the modeled economics and has made great strides in bringing fine-scale representations of water and hydrology into the models. In addition, new work is linking IAMs and ESMs to explicitly capture human-environment interactions in the coupled models for a deeper understanding of the Earth system.

One of the critical needs for improved integration across models is interoperability. Model interoperability has been facilitated by the ongoing support by several USGCRP agencies of the Earth System Modeling Framework (ESMF), a software infrastructure designed to increase ease of use, portability, and reuse of components in ESMs. The recently released version 5.2.0r of the ESMF software package constitutes a significant improvement over previous versions. It allows for backward compatibility with earlier versions, improved regridding options, metadata handling, and numerous other improvements.

Another critical element of integration is connecting the hierarchy of models with the needs of end users in decision support applications through improvements in the usability of the model outputs and products. For example, in an effort to improve the skill of seasonal-timescale weather forecasts, NASA, NOAA, and NSF have collaborated with other research institutions on the National Multi-Model Ensemble (NMME). Initial results indicate that the NMME approach of combining results from multiple models generally yields better-forecast skill than can be obtained from any single model. Similarly, to help meet some of the immediate needs of decisionmakers, impacts researchers, and others users, several USGRCP agencies (Department of the Interior (DOI), DOE, and NOAA), in collaboration with the U.S. Army Corps of Engineers (USACE), academia, and the private sector, developed and recently expanded a data portal housing and distributing a large ensemble of downscaled climate and hydrology simulations for the coterminous United States.

EXAMPLES OF RECENT ACCOMPLISHMENTS IN INTEGRATED MODELING

FIFTH COUPLED MODEL INTERCOMPARISON PROJECT (CMIP5) FOR STATE OF THE ART CLIMATE AND EARTH SYSTEM MODELS

In preparation for the Fifth IPCC Assessment Report (AR5), modeling centers around the world have been designing and performing new, high-resolution runs of their state-of-the-art climate and Earth system models. NASA, NOAA, DOE, and NSF fund the modeling efforts in the United States. Multiple, independent versions of the climate models are run for a wide array of future scenarios and experiments to ensure the robustness of model operation and results. The resulting model outputs contribute to the fifth Coupled Model Intercomparison Project (CMIP5), a major international effort under the auspices of World Climate Research Programme (WCRP).

Scenarios and emissions profiles used to drive the CMIP5 models were developed as a result of international and interagency cooperation. The DOE and the U.S. Environmental Protection Agency (EPA) supported the U.S. contribution to this effort, which projected socioeconomic trends, energy pathways, land use, and biogeochemical emissions and their implications for greenhouse gas concentrations at appropriate spatial scales. CMIP5 output will be used to inform 21st-century climate projections for the IPCC AR5. The climate model output also will be used extensively in research projects over the next 5 to 10 years to further our understanding of the Earth system. The Program for Climate Model Diagnosis and Intercomparison (PCMDI), funded by DOE, plays a vital role in CMIP5 by coordinating model data across groups, providing leadership for the Earth System Grid Federation (for distributed data access), and ensuring international access to the CMIP5 model data through the PCMDI gateway. Over the last two years, NASA's Jet Propulsion Laboratory

(JPL) and DOE's PCMDI have worked jointly to provide a number of satellite data sets specifically tailored for CMIP model evalutation, with the initial target being CMIP5.[3]

DECADAL AND REGIONAL CLIMATE PREDICTION USING EARTH SYSTEM MODELS

NSF, DOE, and the U.S. Department of Agriculture (USDA) successfully completed a joint funding competition, Decadal and Regional Climate Prediction using Earth System Models (EaSM). Projects funded are expected to generate state-of-the-art coupled models (see Figure 10) that will lead to improved understanding of impacts at regional levels as well as facilitate development of effective adaptation strategies on decadal time scales. Both the regional spatial scale and the earlier time frame are direct responses to the needs of decisionmakers, who have repeatedly requested information at the scale at which management decisions are made. The agencies jointly supported forty-two projects in the first round of the EaSM solicitation; several projects are collaborative across multiple institutions. Key requirements for EaSM projects included: (1) understanding climate variability and change and the associated regional impacts at decadal time scales; (2) interdisciplinary approaches to address the impacts of climate change; and (3) interagency cooperation in tackling climate change issues of mutual interest to agencies.

The EaSM projects will address challenges associated with the development of next-generation EMSs that include coupled and interactive representations of ecosystems, agricultural lands and forests, urban environments, Earth's biogeochemistry, atmospheric chemistry, ocean and atmospheric currents, water cycle, land and sea ice, and human activities. Some of the project topics are: the effect of changing atmospheric chemistry on Asia's climate; how climate factors are used in international negotiations for Earth's resources; human vulnerability in urban environments in a changing climate; agricultural planning in South America for the coming decades; and improving decadal prediction of the Arctic climate using a high-resolution Regional Arctic System Model.

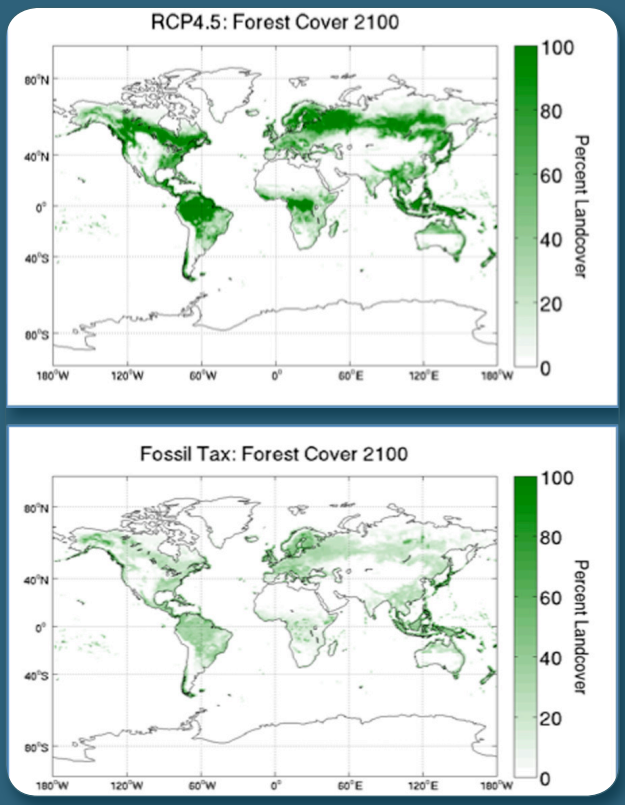

Figure 10: Testing Early Results from "Experiment 0" of an Integrated Earth Systems Model

Preliminary studies illustrate the significance of potential carbon management strategies when land is considered within an Integrated Earth System Model. In the case where only fossil fuel carbon is valued (above of two forest cover images), a shift toward deforestation occurs in comparison with the IPCC Representative Concentration Pathway (RCP) case.

[3] *Key requirements associated with this activity have been: 1) only satellite retrievals that have compatibility with model output variables are selected so that comparisons/evaluations are meaningful; 2) satellite data sets are formatted in a manner analogous to the model output so that they can be seamlessly integrated into the Earth System Grid (ESG) alongside the model output; and 3) a standardized form of technical documentation for each satellite variable is provided to describe the satellite quantity, its retrieval methodology, sampling characteristics, validation results, and strengths and caveats relative to model evaluation. Based on this initial activity, supported by NASA and DOE, about 20 satellite data sets have been identified. The relatively small number and specific selections derive in part from the requirement 1) above, the limited time and funding available for the initial activity, and based on guidance from PCMDI in general and from an early joint NASA/PCMDI workshop on priorities and viabilities for specific quantities.*

DEVELOPMENT OF AN INTEGRATED EARTH SYSTEM MODEL (iESM) FOR CLIMATE RESEARCH AND INSIGHTS

Understanding the climate system and its human components is a grand scientific challenge and a priority for the USGCRP. Addressing this challenge, DOE has constructed the first Integrated Earth System Model (iESM), connecting the Community Earth System Model (CESM) with the Global Change Assessment Model (GCAM), the former an ESM, the latter an IAM. Both CESM and GCAM enjoy significant interagency support, CESM through a major collaboration between DOE and the NSF, and GCAM through co-funding by DOE and EPA of model development at the Joint Global Change Research Institute. The iESM is a multi-laboratory research effort involving the Pacific Northwest National Laboratory, Oak Ridge National Laboratory, and the Lawrence Berkeley National Laboratory, representing a new class of ESMs. iESM enables specific types of in-depth research not enabled by either of the two foundational models with initial progress marked by successful one-way coupling for data exchange. As reflected in Figure 11, significant new insights have already emerged that transform our understanding of socioeconomics, land use, emissions, biogeochemical cycles, and the potential implications for the climate system. Next phases will address two-way couplings and, ultimately, dynamic feedbacks. Recent, significant advances in both the CESM and GCAM have enabled progress in iESM. CESM has benefitted from deployment of a new, more agile architecture permitting more flexible operational capabilities while incorporating a new sea ice model, land ice model, detailed atmospheric chemistry model, radiation package, aerosol sub-model, as well as new cloud schemes and improvements to the global ocean sub-model. GCAM now includes significant advances in representing hydrology, land use, energy technologies, and processes at finer spatial and temporal scales.[4]

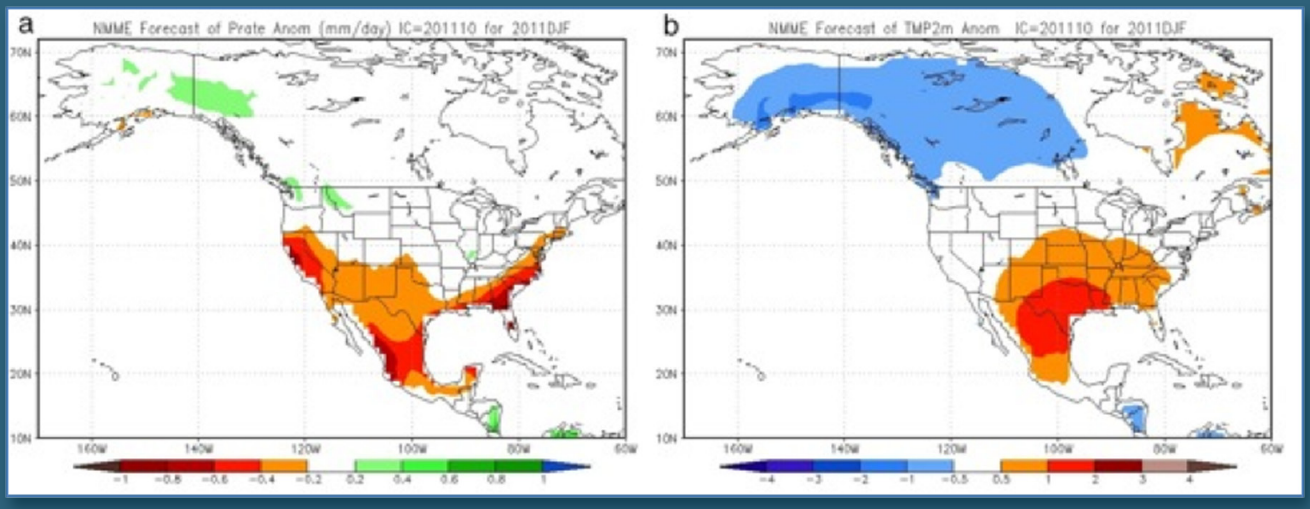

Figure 11: National Multi-Model Ensemble Predictions of Winter 2011 – 2012 Precipitation and Near-Surface Temperature Anomalies
NMME predictions of winter 2011-2012 precipitation (a) and near-surface temperature (b) anomalies. Predictions for December, January, and February (DJF) were initialized in October 2011. Probabilistic information will also accompany these deterministic forecasts, as the system is developed and tested. Precipitation anomalies are given in terms of millimeters per day, while temperature anomalies are given in terms of degrees Celsius. The figures present results from an ensemble of seven models that are developed and run by U.S. agencies and research laboratories, including NASA, NOAA, and NCAR (DOE/NSF). (Figure is courtesy of the National Centers for Environmental Prediction).

[4] Edmonds, J.A., Collins, W.D., Thornton, P.E., 2011: *Project Spotlight: Development and Early Results from an Integrated Earth System Model*, DOE Climate and Earth System Modeling Principal Investigators Meeting, Washington, D.C.

NATIONAL MULTI-MODEL ENSEMBLE (NMME) TO IMPROVE SEASONAL CLIMATE PREDICTION

NOAA, in partnership with NASA, DOE, NSF, and other research institutions has initiated a research effort to improve seasonal climate prediction skill based on multiple U.S. climate models. Such a research effort follows the National Academy of Science's 2010 report[5] recommendation for experimentation with multi-model ensembles as a way to improve upon current predictive capabilities, as research has shown that multi-model systems have prediction skill that is generally superior to that of any single-model system. The current initiative, named the National Multi-Model Ensemble (NMME), in its initial phase, is producing real-time multi-model seasonal climate predictions based on readily available models and a basic experimental design (see Figure 11 above). Future NMME plans, spearheaded by NOAA, include a more comprehensive research investigation regarding the optimal design and added value of this multi-model predictive system.

ADVANCING CLIMATE MODELING SYSTEMS TO SIMULATE AND PREDICT CLIMATE VARIABILITY AND CHANGE

NOAA has fostered major advances in its climate modeling systems and capability to simulate and predict climate variability and change. In March 2011, the NOAA National Center for Environmental Prediction released a new version of its Climate Forecast System (CFSv2), a model that underlies NOAA's operational intra-seasonal to seasonal forecasts. This updated model includes major advances in data assimilation techniques (which govern the use of observations to set the initial conditions for the model forecasts) and modeling. Improvements in the CFSv2 include CO2 concentrations that are now allowed to vary with time; ocean, atmosphere, and land systems that are each initialized using a consistent data set; and a substantial increase in the resolution at which the model is run. An extensive set of seasonal and sub-seasonal hindcasts were performed with this system and are being distributed to the scientific community for research and user-driven climate applications. Real time forecasts from CFSv2 can be viewed on the Climate Prediction Center website.[6]

NOAA's Geophysical Fluid Dynamics Laboratory (GFDL) has made great advances in its research efforts to develop cutting-edge high-resolution climate models for use in predicting and projecting climate variability and change, and ESMs incorporating complex Earth system processes (see Figure 12). Key to this successful development was an interagency agreement with DOE, which provided NOAA laboratories access to a 980 teraflop computing system named Gaea, hosted at DOE's Oak Ridge National Laboratory, ranked amongst the world's 20 most powerful computing systems. Areas of focus included the development of a unified prediction system that provides regional scale information on intra-seasonal out to centennial time scales. These new and improved modeling systems enable greater understanding of climate change – ecosystems impacts and feedbacks, and research on hurricane prediction, tropical storm activity, and climate change over North America and elsewhere.

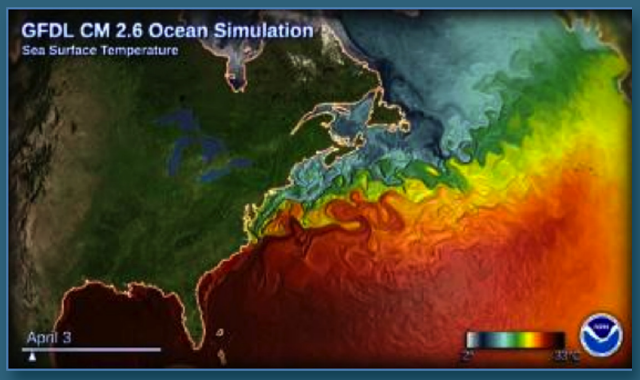

Figure 12: Geophysical Fluid Dynamics Laboratory High-Resolution Ocean Simulation
High-resolution ocean simulation running inside the coupled GFDL CM 2.6 model. Higher resolution in the ocean allows for the simulation of mesoscale and smaller eddies and structure in the ocean circulation.

LEADING AN INITIATIVE ON SEA LEVEL RESPONSE TO ICE SHEET EVOLUTION (SEARISE)

NASA leads the Sea Level Response to Ice Sheet Evolution (SeaRISE) initiative, an international collaboration designed to inform the IPCC of the potential contribution of ice sheets to sea level rise over the next 200 years. It focuses on refining models of ice sheet evolution, with existing observations, and by adding processes to simulate ice streams, interactions with oceans, internal water transport, and basal interactions. Models used to estimate sea level rise for the 2007 IPCC report did not include such detailed processes. In light of recent observations,

[5] National Academy of Sciences, 2010: *Assessment of Intraseasonal to Interannual Climate Prediction and Predictability*, <dels.nas.edu/Report/Assessment-Intraseasonal-Interannual-Climate/12878>.
[6] Access realtime forecasts from CFSv2 from the Climate Prediction Center at <origin.cpc.ncep.noaa.gov/products/people/wwang/cfsv2fcst/>.

they are believed to play critical roles in removing ice from the ice sheets and in controlling the dynamic stability of key regions in the Arctic and Antarctic.

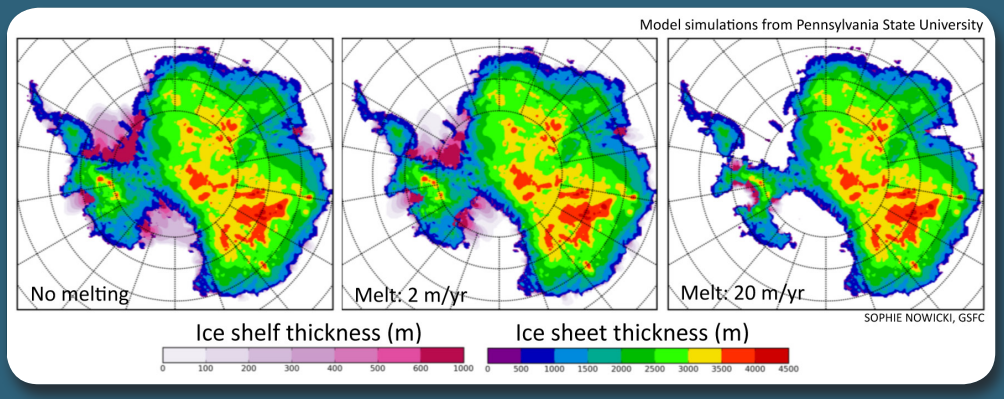

Figure 13: Examples of the Antarctic Response to Different Hypothetical Melt Rates

In December 2010, researchers agreed to develop experiments focused on assessing the impact of the Earth's climate, its oceans, and rates of basal sliding on the future evolution of the Greenland and Antarctic ice sheets. Examples of the Antarctic response to different hypothetical melt rates are shown in Figure 13. Considerable effort has gone into standardizing the data sets used by all models, and into developing control runs to minimize unrealistic aspects of any single model. The results of these experiments were presented at a NASA workshop in September 2011, and will inform the IPCC's AR5. Over the past year, participants in the SeaRISE initiative have closely collaborated with the science team for NASA's Operation IceBridge to select flight lines in key areas to improve the quality and accuracy of ice sheet models. In particular, the collection of bedrock topography data with airborne ground-penetrating radar has improved simulations of ice velocity, increased the accuracy of ice volume estimates, and strengthened predictions of future ice sheet evolution.

GLOBAL CHANGE AND AIR QUALITY

A number of projects are investigating how a changing climate, changing emissions, and changing land use patterns will affect air quality. This has been a particular topic of research in EPA's Office of Research and Development, while NSF and NASA have also focused on this area. One recent project, led by researchers funded by NSF, NASA, and EPA, examined how the continued proliferation of kudzu (*Pueraria montana*) would affect air quality across the southern United States.[7] Because of kudzu's high capacity for nitrogen fixing, kudzu invasions can lead to substantial increases in emissions of nitrogen oxides (NO_x) from soil. In the extreme case in which kudzu covers all nonagricultural, nonurban soils in the Southeast, soil emissions of NO_x were calculated to increase by 28%, leading to a sizable increase in the number of summertime ozone episodes.

Another recent project funded by EPA related measured concentrations of particulate matter and its chemical components to measurements of various meteorological phenomena.[8] This work improved on previous similar work by taking into account the natural co-variances among meteorological phenomena, while previous modeling sensitivity studies have often perturbed one variable at a time. This work suggested that particulate matter concentrations are strongly positively correlated with temperature, driven mainly by changes in sulfate and organic carbon aerosols.

This positive relationship was driven largely by temperature's correlation with stagnation and other meteorological conditions. This work suggested that, when thinking about the impacts of climate change on air quality, it is important to consider synoptic-scale (~1000 km) phenomena, such as stagnation, not just individual meteorological variables. This could represent an important shift in thinking about this aspect of climate change impacts.

[7] Hickman, J.E., S. Wu, L.J. Mickley, and M.T. Lerdau, 2010: Kudzu (*Pueraria montana*) invasion doubles emissions of nitric oxide and increases ozone pollution. *Proceedings of the National Academy of Sciences*, 107, 10115-10119.

[8] Tai, A.P.K., L.J. Mickley, and D.J. Jacob, 2010: Correlations between fine particulate matter (PM2.5) and meteorological variables in the United States: Implications for the sensitivity of PM2.5 to climate change. *Atmospheric Environment*, 44, 3976-3984.

DEVELOPMENT AND APPLICATION OF AN INTEGRATED ECOSYSTEM MODEL FOR ALASKA

Ongoing climate change throughout Alaska has the potential to affect terrestrial ecosystems and the services that they provide to the people of Alaska and the Nation. These services include the provisioning of food and fiber, the contributions of ecosystems to recreation, cultural, and spiritual activities of people in Alaska, and the role Alaska ecosystems play in regulating the climate system.

Assessments of the effects of climate change on ecosystem services have in part been hindered by the lack of tools capable of forecasting how landscape structure and function might change in response to climate change. Such tools need to consider how ecological processes play out in both space and time. Landscapes may change substantially because of shifting composition of species dominance (e.g., an increase of shrubs in tundra) and species migration (e.g., treeline advance). These shifts in landscape structure and function may be caused by changes in disturbance regimes (e.g., fire, insects, wind throw), permafrost integrity, and hydrology across the landscape.

A study was initiated in 2010 by the DOI Alaska Climate Science Center to develop and apply an ecosystem model for Alaska that is capable of forecasting how landscape structure and function might change in response to interactions among disturbance regimes, permafrost integrity, hydrology, vegetation succession, and vegetation migration. This tool will provide scenarios of changes in landscape structure and function that could be used by resource-specific impact models to assess the effects of climate change on specific natural resources.[9]

Figure 14: Climate Warming and Weather Extremes Studies Highlighted in Nature Magazine
The Nature cover featuring the results of two studies highlights the significant effects of anthropogenic activities on observed trends in temperature and mean precipitation. The studies are among the first to formally identify the human fingerprint on extreme precipitation.

CLIMATE WARMING AND WEATHER EXTREMES

The prospect of more extreme temperature and precipitation as climate warms is of increasing concern to society, and an area of focused research for several USGCRP agencies. New research[10] found that many areas of the globe are likely to move into an unprecedented extreme heat regime over the next four decades should greenhouse gas concentrations continue to increase. The study (see Figure 14) includes analyses of a large suite of global climate model experiments and observational data from around the globe and reveals that global warming is already resulting in a novel heat regime in which the coolest summer of the new climate envelope is hotter than the hottest summer of the old climate envelope. Tropical areas exhibit the most immediate emergence of unprecedented heat, with many tropical areas exhibiting a 50% likelihood of permanently moving into a novel seasonal heat regime in the next two decades. In addition, many areas of the United States, Europe, and China will experience similar extreme temperature conditions.

Two other groups sponsored jointly by DOE and NOAA through their support of the International Detection Attribution Group now present evidence that anthropogenic greenhouse gases have significantly increased the probability of heavy precipitation and local flood risk. One study[11] compared observations and simulations of rainfall between 1951 and 1999 in North America, Europe and northern Asia, and finds a statistically significant effect of increased greenhouse gases on the incidence of extreme precipitation events over much of the Northern Hemisphere land area. A second study[12] examined a flooding event in England and Wales in autumn 2000,

[9] Learn more about Development and Application of an Integrated Ecosystem Model for Alaska Project at <http://www.iab.uaf.edu/research/research.php?project_id=222>.
[10] Diffenbaugh, N.S. and M. Scherer, 2011: Observational and model evidence for global emergence of unprecedented heat in the 20th and 21st centuries, *Climatic Change*, 107, 615-624.
[11] Min, S.-K., X. Zhang, F.W. Zwiers, and G.C. Hegerl, 2011: Human contribution to more intense precipitation extremes. *Nature*, 470, 378-381.
[12] Pall, P., T. Aina, D.A. Stone, P.A. Stott, T. Nozawa, A.G.J. Hilberts, D. Lohmann, and M.R. Allen, 2011: Anthropogenic greenhouse gas contribution to flood risk in England and Wales in autumn 2000. *Nature*, 470, 382-385.

which damaged nearly 10,000 properties across that region. The study used several thousand seasonal-forecast-resolution climate model simulations of autumn 2000 weather, both under realistic conditions, and as they would have been for pre-industrial climate conditions. Twentieth century anthropogenic greenhouse gas emissions were shown to increase the risk of floods occurring in England and Wales in autumn 2000.

FUTURE ACTIVITIES FOR INTEGRATED MODELING

In the new strategic framework, the core objective for integrated modeling is to develop and improve advanced models that integrate across the physical, chemical, ecological, and socioeconomical components of the Earth system, including the feedbacks among and between them, in order to more comprehensively represent and more realistically predict global change processes. To achieve this objective, and more broadly to help execute its new Strategic Plan, the USGCRP recently established an Interagency Working Group on Integrative Modeling (IGIM). As three- to five-year priorities for the USGRCP are refined in the near future, the IGIM has identified specific goals for climate system modeling, such as:

- High-resolution EMSs allowing improved representation of regional variability and change, feedbacks, and climate and weather extremes;
- Advanced validation and verification frameworks to challenge and enhance model development with process science and measurements;
- Enhanced prediction skill at intra-seasonal to decadal timescales;
- Comprehensive suite of IAV models to transform our quantitative understanding of the consequences of climate change;
- Next generation IAMs for national and regional decision support that consider the complex interactions of human and natural systems and the influence of mitigation and adaptation options;
- Flexible, interoperable, and accessible modeling frameworks that facilitate linkages among and within the modeling paradigms and underlying communities;
- Uncertainty characterization methodologies both to advance the science of models and to provide stakeholders with an understanding of the value of climate projections; and
- Translation of climate projections to spatially and temporally user-relevant resolutions and into local value-added information for decisionmakers, including downscaling of model bias information.

These modeling activities will place new demands on all USGCRP activities, for example development of new and improved observational data sets for model evaluation, and development and implementation of better methods for identifying and meeting the needs of stakeholders and decisionmakers for climate-related information. Broader integration and interactions among the agencies, facilitated by the USGCRP, will be essential.

ADAPTATION SCIENCE

OVERVIEW

Adaptation Science: ***Integrated scientific research that directly contributes to enabling adjustments in natural or human systems to a new or changing environment and that exploits beneficial opportunities or helps moderate negative effects.***

As documented in the latest NCA report, Global Climate Change Impacts in the United States, and the NRC's report series on America's Climate Choices, communities, states, and regions across the Nation are already experiencing a range of climatic changes, including more frequent and extreme precipitation events, longer wildfire seasons, reduced snowpack, more extreme heat events, increasing ocean temperatures, and rising sea levels.[13] These changes pose significant social, economic, and environmental risks to the United States and the global community as they affect livelihoods, infrastructure, ecosystems, food production, energy supply, national security, and the cultural heritage of populations and communities.

Certain communities and ecological systems are particularly vulnerable to these impacts, leading to changes in public investments in roads and other infrastructure, responses by public health institutions, private investments in agriculture and facilities, and adjustments to insurance and other risk management approaches, among many

[13] USGCRP, 2009: *Global Climate Change Impacts in the United States*, <www.globalchange.gov/publications/reports> and National Research Council, 2011: *America's Climate Choices*, The National Academies Press, Washington, DC, <www.nap.edu/catalog.php?record_id=12781>.

others. The climate risks are well enough known to justify some actions now that ensure a safer, more resilient, and prosperous future. This is particularly true in the case of investments in long-lived physical infrastructure. As climate changes, responses and standards that public and private institutions have historically relied upon to inform their decisions may no longer be effective.

There currently exists limited knowledge about the ability of communities, regions, and sectors to adapt to a changing climate. To address this shortfall, research on climate change impacts and adaptive capacity must include complex human dimensions, such as economics, management, governance, behavior, and equity. Interdisciplinary research on adaptation that takes into account the interconnectedness of the Earth system and the complex nature of the social, political, and economic environment in which adaptation decisions must be made would be central to this effort. Research to develop expanded understanding of how climate change is altering natural, social and economic environments is critical to enabling better-informed decisions at levels from household to corporate to national and international levels.

In 2009, the Obama Administration convened the Interagency Climate Change Adaptation Task Force[14] (ICCATF), co-chaired by the CEQ, OSTP, and NOAA, along with representatives from more than 20 Federal agencies. Following the establishment of the ICCATF, President Obama signed Executive Order 13514, "*Federal Leadership in Environmental, Energy, and Economic Performance*[15]," in October 2009, directing the ICCATF to recommend how the Federal Government can strengthen policies and programs to better prepare the Nation to adapt to the impacts of climate change. The ICCATF activities initially included multiple Workgroups, including Adaptation Science, which was initiated in fall 2009 under CEQ. In summer 2010, the Adaptation Science Workgroup was transferred to USGCRP as a new program in order to improve the Federal Government's capacity to provide science in support of adaptation decisions at all scales.

The mission of the Adaptation Science program element at the USGCRP is to ensure that the Federal government's science enterprise informs adaptation decisions at a range of scales for a diversity of users. Successful adaptation to climate change will require sustained, ongoing dialogue, mutual information exchange, and feedback between scientists, decisionmakers, and information users throughout the research and implementation processes. Science in support of adaptation requires collaborative studies bridging scientific disciplines (e.g., physical, biological, social, and economic sciences) and the integration of observations, monitoring, research, and modeling Adaptation science includes foundational research on decisionmaking processes in the face of risk, uncertainty, conflict, and complexity.

Effective adaptation also depends on improved fundamental knowledge of climate science, impacts, and processes, and the needs of stakeholders can inform research priorities in these areas. Science in support of adaptation is most beneficial when translated and communicated through user-friendly formats that the adaptation practitioner community can access. The USGCRP promotes partnerships and enables sustained dialogue and interaction among stakeholders that are working with local, state, tribal, and regional entities, nonprofit organizations, private industry, and academia on climate and global change adaptation efforts. This sustained dialogue allows for engagement with information uses in an effort to understand and address their needs.

OVERVIEW OF RECENT ACCOMPLISHMENTS IN ADAPTATION SCIENCE

The USGCRP Adaptation Science efforts are coordinated through an interagency Adaptation Science Workgroup comprised of USGCRP agency representatives. The Adaptation Science Workgroup over the past year has been primarily devoted to advancing a new framework for planning, coordinating, and deploying science in support of adaptation that effectively leverages existing activities across the Federal enterprise, particularly those that already engage decisionmakers outside of the Federal government.

Over the past year, the Workgroup has made progress on identifying and classifying by function existing Federal science efforts that inform and support adaptation. Progress also has been made on prioritizing activities that address science gaps important to adaptation decisions and policies. Finally, progress has been made scoping the science translation and communication capacity in relation to adaptation science, as well as identifying

[14] Learn more about the Council on Environmental Quality (CEQ) Interagency Climate Change Adaptation Task Force at <http://www.whitehouse.gov/administration/eop/ceq/initiatives/adaptation>.

[15] White House, 2009: *Executive Order 13514: Federal Leadership in Environmental, Energy, and Economic Performance*, <http://www.whitehouse.gov/assets/documents/2009fedleader_eo_rel.pdf>.

effective pathways for integration of science into decisionmaking.

Drawing lessons learned from user-feedback sessions with cities, states, regions, natural resource managers, planners, scientists, and Federal agencies, the Adaptation Science Workgroup is developing a framework for a "map" of Federal science capabilities, drafting a handbook on effective techniques for translating technical science jargon into usable information for decisionmakers, and prioritizing future interagency science activities in support of adaptation.

The Adaptation Science Workgroup has also actively participated in the ICCATF, through development of recommendations to the Progress Report submitted to the President, and support of activities that help to implement the various recommendations that were laid out in the report. In addition, the Adaptation Science program has been engaging with the ongoing NCA effort, including contributions to the 2013 report chapter on Adaptation and helping to build capacity and resources to support the sustained assessment process.

EXAMPLES OF RECENT ACCOMPLISHMENTS IN ADAPTATION SCIENCE

SCIENCE FOR WATER RESOURCE DECISIONMAKING 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 adequate amounts of fresh, clean water to growing populations. This 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) by providing scientific underpinnings, including new observing and modeling capabilities and products. 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 decisionmakers who manage scarce natural resources, particularly in the face of the large uncertainties about the pace and magnitude of future climate change.

As early as August 2010, the NOAA Climate Prediction Center predicted that La Niña conditions would increase the potential for drought formation across the southern United States in the following year. In 2011 a drought of strong intensity and vast geographical extent developed in the southern tier of the United States. To respond to these severe ongoing conditions, NOAA and a host of other Federal and state agencies, and universities convened two regional drought outlook forums. The first forum was in Albany, Georgia, and covered the Southeast United States with special emphasis on the Apalachicola-Chattahoochee-Flint River Basin. The second forum was held in Austin, Texas, and focused on the Southern Plains states.

The forums provided detailed assessments of current drought conditions and impacts to date, comparisons with past drought events, and predictions for the next year. The forums also developed mechanisms to communicate the information to water managers, planners, and others concerned with drought through news media, webinars, and newsletters. Representatives from institutions representing water resources, ecosystem resources, agriculture and livestock, forestry and wildfire management, state and Federal agencies, and the media were in attendance. Other forum partners included the NOAA Regional Climate Service Director for the Southern Region, the NOAA-supported Southern Climate Impacts Planning Program (SCIPP) and the Southeast Climate Consortium (SECC) Regional Integrated Sciences and Assessments (RISA) programs, the National Drought Mitigation Center (NDMC), Southeast River Forecast Center, state climatologist offices, and the regional climate centers.

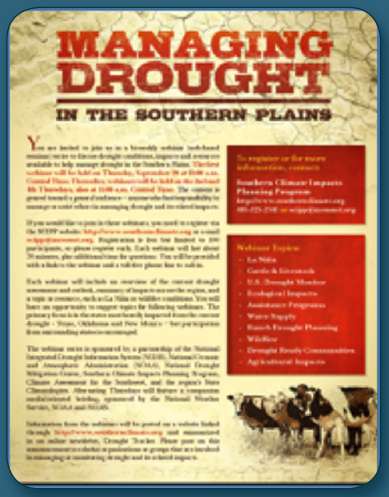

Figure 15: Flyer for the Southern Plains Drought Outlook webinar series

Since the initial drought outlook forums, NIDIS has established an ongoing webinar series (see Figure 15) in the two regions to keep stakeholders updated on current and expected conditions. These efforts are being led by the SCIPP and SECC RISAs and include participation from multiple state climatologist offices, USGS, USACE, NOAA's National Weather Service, NDMC, and the Apalachicola National Estuarine Research Reserve among others.

ASSESSING THE IMPACTS OF CLIMATE CHANGE ON FRESHWATER RESOURCES

The ICCATF, co-chaired by OSTP, CEQ, and NOAA has identified management of freshwater resources as a key challenge posed by a changing climate. The decision to make adaptation of freshwater resources a priority was based on analysis of major impacts of a changing climate on freshwater resources by the USGCRP. These impacts include warmer waters, less snowfall, changes in rainfall amounts, more intense rainfall and storm events, and rising sea levels. Several major reports were released during 2011 addressing the expected impacts of climate change on freshwater resources and outlining needed adaptation actions.

- The ICCATF released the *National Action Plan: Priorities for Managing Freshwater Resources in a Changing Climate*.[16] The Action Plan includes a national goal and six recommendations to aid freshwater resource managers in understanding and reducing the risks that climate change poses for the Nation's freshwater resources. It is designed to help freshwater resource managers assure adequate water supplies, safeguard water quality and aquatic ecosystems, and protect human life, health and property.
- An interagency team developed a report to the Congress, in response to section 9506 of the Omnibus Public Lands Act, titled "*Strengthening the Scientific Understanding of Climate Change Impacts on Freshwater Resources of the United States*."[17] This report provides careful consideration of the strengths and weaknesses of the existing data and information systems that are important to current and future understanding of these impacts and specific suggestions for appropriate next steps to address data gaps and improve information availability.
- The Bureau of Reclamation within the DOI published a report[18] to Congress, in response to section 9503 of the Omnibus Public Lands Act, assessing climate change risks in the Western United States and how these risks could impact water operations, hydropower, flood control, and fish and wildlife. The report represents the first consistent and coordinated assessment of risks to future water supplies across eight major Reclamation river basins, including the Colorado, Rio Grande and Missouri river basins.

MANAGING FISH HABITAT IN A RAPIDLY CHANGING CLIMATE

To protect and enhance aquatic habitats nationwide, resource managers need to know what habitats are most vulnerable in our rapidly changing climate. Scientists and resource managers from ten government agencies and academic institutions in eight states are working together to project anticipated changes to the Nation's aquatic habitats from altered climate and land use. One tool used to assess habitat vulnerability is downscaled mathematical models of decadal-scale global climate, or general circulation models (GCMs). In this project,[19] Managing the Nation's Fish Habitat at Multiple Spatial Scales in a Rapidly Changing Climate (see Figure 16), researchers are coupling atmosphere–ocean GCM downscaling techniques with models that simulate land use change and urban growth to identify effects on fish habitats at national, regional, and local scales. The projected changes to fish habitat will be used

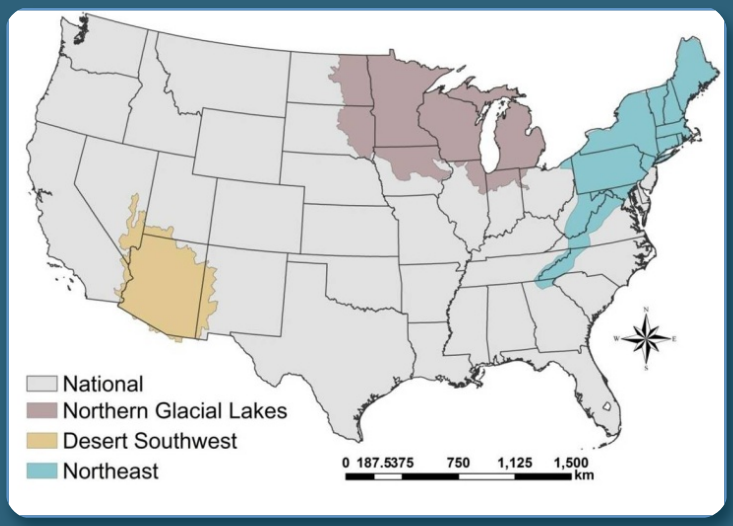

Figure 16: Map Illustrating the Initial Assessment Regions for the Project
Map showing initial assessment regions for the "Managing the Nation's Fish Habitat at Multiple Spatial Scales in a Rapidly Changing Climate" project, which uses downscaled climate and land use models composed of variables that influence fish habitat health, such as surface temperature and agricultural inputs. The map was created by Jodi Whittier at the University of Missouri.

[16] Learn more about the National Action Plan at <http://www.whitehouse.gov/sites/default/files/microsites/ceq/2011_national_action_plan.pdf>.
[17] Federal Interagency Panel on Climate Change and Water Data and Information, 2011: *Report to Congress—Strengthening the scientific understanding of climate change impacts on freshwater resources of the United States*, 49 p, <http://www.doi.gov/news/pressreleases/loader.cfm?csModule=security/getfile&pageid=260567>.
[18] Reclamation, SECURE Water Act Section 9503(c) – *Reclamation Climate Change and Water, Report to Congress*, 2011, <http://www.usbr.gov/climate/SECURE/docs/SECUREWaterReport.pdf>.
[19] Learn more about the progress of this far-reaching study at <http://fishhabclimate.org/>.

to determine how certain fish distributions and population-level metrics, such as growth, may change.

The results from this project will provide management agencies with the information they need to assess risks and help guide how they will manage fish habitat and communities in a changing climate. Among the project results are regionally specific metrics to assess vulnerability of the habitats of, for example, economically important smallmouth bass in the Northern Glacial Lakes region or eastern brook trout in the Northeast United States. Map-based tools will be generated that can be used as part of a decision support system for natural resource managers to assess present risks and plan for potential risks to local resources. Collaborative relationships have been established with local and regional habitat management groups, such as the Eastern Brook Trout Joint Venture and the Desert Fish Habitat Partnership. A climate change symposium hosted by the project team at the National American Fisheries Society Annual Meeting in 2011 connected fisheries professionals with fisheries-relevant climate knowledge and initial project results.

CLIMATE MODELING TO SUPPORT MANAGEMENT DECISIONS FOR NATIVE FISH SPECIES

There is a widely recognized need for climate information at spatial and temporal resolutions that are relevant to landscape and wildlife management decisions. Native fish populations of Yellowstone and Lahontan Cutthroat, Gila and Bull trout in the western United States are at risk for irreversible loss of remaining habitat due to degradation of water quality and spread of invasive species. The potential loss stems from both human activities (e.g., habitat fragmentation) and climate change (e.g., water temperature, wildfire). Ongoing, collaborative research at the USGS is bringing together fish biologists, climatologists, hydrologists, and decision support scientists from Federal and state agencies and non-governmental organizations to evaluate existing and potential threats to native fish populations and to translate those findings into sound decision support strategies for resource managers.

USGS researchers are producing long (e.g., multi-decadal to multi-century) simulations of past, present and future regional climate at a grid spacing of 50 km over North America and at a grid spacing of 15 km over Western and Eastern North America. The model output represents an early attempt to achieve coordinated, high-resolution downscaling with wide geographic and temporal coverage. A wide range of researchers and managers are using the model output over North America, including those working in the USFWS, National Forests, Bureau of Land Management ecoregions, National Parks, and multi-stakeholder Landscape Conservation Cooperatives. These results are used to help manage the Nation's fish habitats under a range of future climate scenarios and are providing a visualization approach to project future distributions of North American species and ecosystems.

WORKING WITH NATIONAL ESTUARY PROGRAMS IN SUPPORT OF ADAPTATION PLANNING

Estuaries are highly vulnerable to climate-related changes in water temperature, precipitation, wind-driven waves, and sea level rise. Impacts such as increased inundation of coastal wetlands, changes in water availability and quality, and altered patterns of sedimentation and erosion are increasingly interacting with other human stressors such as extractive water use and land use changes. A novel methodology has been developed to help National Estuary Programs assess the vulnerability of their natural resources to climate change. The method involves application of formal expert elicitation techniques to develop a systematic exercise for "rapid" assessment of ecosystem vulnerabilities in a two-day workshop setting.

The method was piloted in the Massachusetts Bay and San Francisco Bay estuaries. Interdisciplinary teams of local experts developed "influence diagrams" showing the relationships among key process variables, and then characterized the direction and magnitude of each relationship under current conditions and under scenarios of future climate change. The combined judgments indicate which relationships may show, under future climate change: (1) increasing relative impact on the overall process; (2) increasing sensitivity; and (3) abrupt threshold changes. Based on the amount of expert agreement on each relationship, it is possible to identify "top pathways" of interest for management. Relating top pathways and associated adaptation options to existing management activities is a path forward for action. Using this type of information to "mainstream" climate change adaptation into ongoing, iterative planning processes will increase the ability of managers to identify win-win options, weigh multiple tradeoffs, and prepare for long-term changes.

ECONOMIC IMPLICATIONS OF CLIMATE CHANGE AND ADAPTATION IN THE AGRICULTURAL SECTOR

The Economic Implications of Climate Change and Adaptation in the Agricultural Sector (USDA- Economic Research Service) research will examine how farmers' and ranchers' responses to a changing climate – including

changes in yields, extreme events, and pest invasions – will affect domestic crop and livestock production patterns, productivity growth, input use, crop rotations, economic returns, and environmental outcomes. This line of inquiry focuses on farmers, and domestic and international market responses to a new climate regime. It will also assess the economic implications of policy options for addressing climate-related increases in risk and costs. In addition, the U.S. Forest Service (USFS) technology transfer activities provide information, tools, and management strategies for climate change adaptation and mitigation, many of which are accessible via a web portal hosted by the USFS.

RESEARCH AND MANAGEMENT APPROACHES TO THE IMPACTS OF CLIMATE CHANGE ON LIVING SYSTEMS

NASA, USGS, U.S. National Park Service (NPS), USFWS, and Smithsonian Institution (SI) jointly solicited basic research and applications proposals to address the responses of species and ecosystems to a changing climate. The solicitation, *Climate and Biological Response: Research and Applications*, resulted in 17 funded projects lasting from one to four years. The research projects will explore climate impacts on: (1) the distribution and/or abundance of species, populations, or functional groups of species; and (2) the sustainability of ecosystems over time and/or ecosystem connectivity across landscapes or seascapes. Applications projects will develop new methods and improve existing tools for resource managers, which project the impact of changing climate on populations, species, communities, and ecosystems of management concern. Projects range geographically from regional to global, cover both terrestrial and aquatic systems, and involve organismal groups scaling from phytoplankton to whales.

Projects also include an assortment of ecosystem types and biomes, such as the mangrove-salt marsh ecotone in coastal Florida and the temperate forests of the northwestern U.S. The interagency approach to this program ensures that all funded projects include remote sensing imagery of a host of environmental parameters, *in situ* measures of organisms and ecosystems, and ecological models to help bridge the gaps in spatial scale inherent in these different types of observations.

FUTURE ACTIVITIES IN ADAPTATION SCIENCE

Focused research on thresholds, tipping points, and extremes and their influence on adaptation decisions is a critical emphasis for immediate attention by the Adaptation Science Workgroup. Building resilience requires a more complete understanding of the adaptive capacity of human and natural systems to risks, impacts, and vulnerabilities that emanate from rapid as well as gradual changes, and from climate and weather extremes. The ability to anticipate and plan for thresholds and extremes improves adaptation choices, can minimize future impacts, and assures that information value is maximized. Designing research, services, and tools that provide early warning and clarify the limits of adaptation is critically important in cost-effective adaptation actions and institutional responses. Improved knowledge of research, services, and tools that support adaptation decisionmaking will likely influence the research agenda to provide information that:

- Advances the understanding and identification of social and ecological tipping points and thresholds to help define options and limits to adaptation;
- Integrates social, behavioral, and economic sciences (e.g., decisionmaking under uncertainty, assessing adaptation trade-offs, costs of action versus inaction) to improve the communication of options and the use of information in responding to rapid changes and extreme events; and
- Determines the effects of multiple interacting stressors on coupled human and natural systems and how these affect resilience as extremes create system thresholds and as tipping points define the limits of resilience.

The Adaptation Science Workgroup will use its growing knowledge of adaptation processes to advance foundational science that contributes to adaptation effectiveness. Through its diverse and disciplined processes of: (1) creating an inventory of capabilities; (2) evaluating the adaptation actions; and (3) coordinating and translating agency science, tools, and information, the Workgroup is creating a framework for more clearly responding to the needs of adaptation decisionmakers and identifying scientific research opportunities that support adaptation. The group is also identifying ingredients for success and innovation by leveraging the value of science capacity through collaborative science management frameworks and researching adaptive management approaches as a tool in adaptation decisionmaking.

ASSESSMENT

OVERVIEW

Assessment: *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.*

One of the USGCRP's four strategic goals is to build sustained assessment capacity that improves our Nation's ability to understand, anticipate, and respond to global change impacts and vulnerabilities. Investigators funded through the USGCRP consistently play leadership roles in international assessments such as those of the IPCC and the WMO/United Nations Environment Programme (UNEP). Data and model results from USGCRP-funded research are central to these assessments. In addition to its contributions to international assessments, the USGCRP has a statutory requirement under the GCRA of 1990 (Section 106, Scientific Assessment) to produce a quadrennial science assessment on global change and its impacts on the United States.

The Act further requires an assessment that:

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

The NCA will respond fully to the mandate of the GCRA by establishing a continuing, inclusive process that produces authoritative data and reports over time. The report that will be produced in 2013 will set the stage for more comprehensive assessments in the future. The NCA will evaluate climate impacts, including both variability and trends, in a global change context (considering social, economic, and ecological implications). Climate-related vulnerabilities and response strategies will be documented through ongoing efforts to assess how communities and our Nation as a whole can create environmentally sound and sustainable development paths. This can only be achieved by including Federal efforts outside of the USGCRP as well as those of state and local governments, regional entities, the private sector, and nonprofit organizations.

Like previous U.S. assessments, this assessment will evaluate the current state of scientific knowledge regarding climate impacts and trends. Unlike previous U.S. climate assessment efforts, the assessment process will be a continuing effort rather than a periodic report-writing activity; include a discussion of the Nation's efforts in adaptation and mitigation; involve long-term partnerships with nongovernmental entities; build capacity for assessments in regions and sectors; include new methods for documenting climate-related risks and opportunities; and provide web-based information that supports decisionmaking processes within and among regions and sectors of the United States. The 2013 NCA and future assessments will:

- Analyze past and future trends in global change within regions and sectors, considering a full range of possible outcomes, and report on the current and anticipated effects on a number of specific sectors, including those required by the GCRA;
- Provide Congress, the President, and Executive Agencies with sound scientific information they can use to develop policies and strategies to respond to climate change and variability;
- Develop, from a variety of sources, sound, integrated, and relevant scientific information about climate change, to support the public and private sectors at local, state, and regional levels as they develop policies and strategies for climate change response;
- Guide the establishment of a permanent, broad-based, and inclusive assessment capacity, which will evaluate the current state of scientific knowledge of climate science, climate impacts and trends and will develop and deploy information that supports decisionmaking processes within regions and sectors of the United States;
- Build or leverage existing data, observations, model output, and indicator network/systems to obtain

information on the status and trends of global change impacts and vulnerabilities, including the capacity of the Nation to respond and adapt to such changes;
- Ensure ongoing evaluation of assessment processes and products, using specific criteria for determining success, and incorporate the findings into an adaptive response for systemic improvement;
- Develop and maintain a web-based assessment information storage, access, and retrieval system that facilitates easy access to actionable information for those that need it and provides up-to-date information on a continuous basis; and
- Foster effective communication on climate-related issues with a variety of audiences.

OVERVIEW OF RECENT ACCOMPLISHMENTS IN ASSESSMENTS

An Interagency National Climate Assessment (INCA) working group was established under the Committee on Environment, Natural Resources and Sustainability (CENRS). Representatives from up to 18 Federal agencies have met biweekly since spring 2010 to support and implement the NCA. Among other achievements, the INCA working group and NCA staff organized 14 methodological workshops for the NCA between February 2010 and April 2011 and 20 regional and sectoral assessment workshops prior to the end of 2011.

The NOAA-sponsored National Climate Assessment Development and Advisory Committee (NCADAC) was appointed in 2011. The 60-member committee (which includes ex officio members from the USGCRP agencies) and 12-member Executive Secretariat have held several meetings and formed active ad hoc working groups. This Federal Advisory Committee Act committee will produce the next NCA report in 2013 and provide advice on building and sustaining assessments. A strategic plan, report outline, and timeline have been approved by the NCADAC, along with plans for various workstreams. There are 30 individual teams now working to develop material for the 2013 report and to support the ongoing Assessment process.

A public Request for Information was published in the Federal Register in July 2011. This unprecedented effort to include the public (including academia, NGOs, and other private and public sector entities) in the Assessment process resulted in over 100 teams and individuals responding with expressions of interest to provide technical inputs and assessment capacity by March 2012. USGCRP agencies are leading technical input teams for each of the sectors, regions, and crosscutting topics. These technical inputs will form a foundation for the 2013 NCA report.

Many of the Federal agencies are important contributors of expertise, data records, models, and model-produced data sets for global climate and related environmental assessment activities, such as the IPCC and the WMO/UNEP Ozone Assessment Reports. These assessments, and others, provide important information on climate change and are used by policymakers, especially with the recent increased interest in climate vulnerability, impacts, and adaptation.

Agencies are expanding their contributions of data and assessment capacity to the NCA – both its products (reports, indicators, and information systems) and its process. For example, NASA committed significant FY 2011 funding to direct support of NCA Coordinating Office activities, and to its centers in support of research and synthesis of data for specific assessment products, and to enhance community capability to sustain assessment activities into the future. These investments make NASA's expertise and capabilities available to the NCA and support integration of NASA's data and modeling assets into NCA broadly, including scenario creation and assessment products implemented by other agencies.

Additionally, NOAA deployed its eleven RISA teams to support the NCA in a number of roles, including helping to build regional networks, to work on regional report chapters, to select and monitor indicators, and to define the ongoing assessment process, as well as hosting workshops. NOAA is also hosting a technical support unit (TSU) to provide core scientific, technical and staff support for the NCA. Significant effort in the TSU is being placed on making observed and model data available to all NCA authors and to support a web-based system for scientific collaboration and for deployment of the NCA information as part of the global change information system (GCIS – see below for additional information). In FY 2011, components of many other agencies, such as DOI's Climate Science Centers and Landscape Conservation Cooperatives, USDA networks such as the SNOTEL and SCAN (soil climate analysis network) of the Natural Resources Conservation Service (NRCS), and the regional offices of EPA, have all actively engaged with the NCA to provide their facilities, expertise and staff. These agency involvements in the NCA are forging critical new linkages to improve Federal provision of climate knowledge and services, and to foster adaptation to a changing climate.

FUTURE ACTIVITIES IN ASSESSMENTS

Over the next year, the NCA will investigate options for expanding its network of external partners to help develop information that focuses specifically on adaptation, mitigation, and global change information and services, while also expanding the data documentation and archiving system that will ensure transparency of findings. An important priority for the USGCRP is to implement a national indicators strategy and focus on publication and web deployment of the 2013 assessment report.

Future efforts include promoting a better national and regional understanding of current and future types and magnitudes of risks by building national priorities and processes for vulnerability assessments, and new economic and non-economic evaluations of opportunities and options for response that are available for decisionmakers. All of these activities will promote improved resilience of communities and infrastructure.

While the GCIS is a fundamental component of the sustained NCA process, and a critical feature of the engagement and outreach strategy, it must also be supplemented with a coherent set of engagement, communications and outreach activities to draw attention to the new assessment products and major new breakthroughs in understanding (see Communications and Education section). In order to showcase the value of the ongoing assessment process, the NCA will feature several new assessment products and reports that demonstrate the ongoing commitment of the agencies and assessment partners to regional and sectoral updates between the quadrennial major assessment efforts. Timely issue-focused assessments and web deployment of constantly updated information are critical for decisionmakers to understand risks and opportunities.

GLOBAL CHANGE INFORMATION

OVERVIEW

Global Change Information:
Coordination of the production, translation, and delivery of global and climate change data, information, and products in a timely and responsive manner.

At present, our Nation lacks the capability to provide the full range of global change information that is needed to effectively inform society. While many of those unmet information needs could be met by combining the products of many agencies and organizations, there is currently no single point of access for authoritative, credible, and useful information about such important topics as sea level rise, temperature and precipitation, costs of preventing adverse human health outcomes, ensuring a reliable water supply, managing changes in ecosystems, and the social implications of population migration and competition for resources. Over the past 20 years, a considerable amount of global change data has been generated. However, the data need to be translated into information that is useful to decisionmakers.

Just as our Nation's global change research efforts require and benefit from interagency and academic partnerships, so too will the development and communication of global change information. As recommended by the NRC, a framework is needed to coordinate Federal efforts to provide global change information and services to meet the global change information needs of policy and decisionmakers concerned with global and climate change impacts, mitigation, and adaptation at Federal, state, and local levels (see Figure 19). This will allow for information to be translated for decisionmakers in the United States and the world to assist in understanding, anticipating, and responding to climate variability and global change.

Local Planners
Changes in extreme events, such as floods and droughts, heat waves and freezes

Farmers and Ranchers
Changes in season length and temperature, not just for their own farms but also for those of their local and distant competitors; new combinations of threats from pests and weeds

Coastal Zone Managers
Changes in sea level, storminess, and estuarine temperatures

Water Resource Managers
Changes in snowpack and runoff and changes in the frequency and intensity of floods and droughts

Community Health Planners
Changes in locations of heat and cold waves and heavy precipitation events tied to disease outbreaks

Industry
Changes in extremes that might affect shipping and other business issues

Figure 19: Examples of Climate Data, Information, and Products Needed by Public and Private Sector Decisionmakers

To be successful, the production, translation, and delivery of global change data, information, and products will require multiple Federal agency partnerships, comprehensive *in situ* and space-based observing assets, comprehensive modeling capabilities, data management and information-generation capabilities and shared standards, and effective, efficient means of delivering relevant information to end users.

OVERVIEW OF RECENT ACCOMPLISHMENTS IN GLOBAL CHANGE INFORMATION

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 information that is easily accessible, as well as a demand for timely scientific information about global change and its impacts. An authoritative, integrated information resource is needed that helps people make informed decisions that incorporate climate and global change information into their daily decision processes. The USGCRP has been leading an interagency initiative to build a new GCIS that would provide timely and relevant data and information to stakeholders and the public. This system will support many objectives across the Federal government including: (1) a need for more timely access to information; (2) the capacity to provide data, information, and products to a much broader set of audiences; (3) continued transparency of data and results: (4) the ability to update information in real time; and (5) the informational needs of the NCA.

FUTURE ACTIVITIES IN GLOBAL CHANGE INFORMATION

As stated above, the GCIS will be essential for the success of the NCA, including documentation of sources, easy retrieval of information, and improved potential for decision support because of more rapid deployment of data. Direct links to data and information used in the NCA will be an essential component of the GCIS as well as providing easy access to synthesized summary information generated from the NCA. The GCIS will evolve into broader applications in support of the USGCRP agencies and multiple Federal and non-federal stakeholders and support more timely access to information, provide products to a much broader set of audiences, and update information in real time.

COMMUNICATION AND EDUCATION

OVERVIEW

Communications and Education: ***Activities specifically designed for outreach, education, and engagement regarding global and climate change and its impacts.***

From our communities to our businesses to our government agencies, climate and global change pose increasing challenges to decisionmakers and the public. In order to tackle these challenges, the public must understand and apply knowledge of this often-complex topic to their decisions and actions. Recent surveys and assessments on the state of public climate literacy indicate that new approaches to communication and education are needed in order to develop a citizenry more informed about climate and global change science. In turn, the research community needs to find new ways to listen to the public and business interests in order to define research priorities that are timely and responsive to the most pressing needs.

With this in mind, the USGCRP is expanding not only its research portfolio but also its efforts to make the results of that research accessible to the public through innovative communication and education practices. It will focus on fostering greater public understanding of the science through the dissemination of relevant, timely, and credible climate and global change information, and also on gaining greater understanding of the public's science and information needs through engagement and dialog. This will be accomplished by integrating communication and education (including outreach and engagement) into its core program activities. The result will be the emergence of cutting-edge tools, such as social media, technological applications, and curriculum approaches, to complement the cutting-edge research conducted by the USGCRP.

The USGCRP is in an ideal position to lead the United States in global change communication, education, and engagement efforts. The USGCRP has at its disposal many of the most talented communicators, educators, and outreach specialists within the Federal government and is enhancing its network of social scientists whose research will inform decisionmaking and communication strategies. The USGCRP will coordinate the development of multi-agency programs, facilitate multi-agency communication forums, and leverage the unique technical and human skills of each agency in order to develop new and support existing innovative tools for bringing climate science to the global community.

OVERVIEW OF RECENT ACCOMPLISHMENTS IN COMMUNICATION AND EDUCATION

The USGCRP played a supporting role in the Department of State-led U.S. Center in Cancun during the UNFCCC Conference of the Parties (COP-16) from November 29 to December 10, 2010. Specifically, NOAA, NASA, DOE, and the Department of State (DOS) collaborated to produce a series of interactive presentations featuring the innovative new TouchTable technology. By weaving together compelling visuals and information from all across the Federal government – including maps and visualizations produced using satellite remote-sensing data, computer simulations, and aircraft- and surface-based sensors – communications experts were able to show and tell inspiring stories about the United States' leadership roles in climate science and services, both nationally and internationally. Presentation themes included our current understanding of the state of the climate, how we leverage that science to inform adaptation and mitigation choices, international partnerships for climate services, and how Earth-observing satellites are revolutionizing our view of our world.

The USGCRP's interagency Communication, Education and Engagement Team and the Climate Change and Human Health Group (CCHHG) contributed to a set of key messages that were delivered to OSTP regarding climate change and human health that helped to inform future communication and education efforts, raising awareness of Federal activities and progress made on climate change and human health research, impacts, and applications. Through collaboration among NASA, NOAA, NSF, and DOS, the Global Learning and Observations to Benefit the Environment (GLOBE) Program launched its Student Climate Research Campaign (SCRC) in September 2011. Linking studies of the conceptual foundations of climate science, intensive observing periods, and research investigations, SCRC aims to engage students in measuring, investigating, and understanding the relation between the climate system and the environmental conditions in their local communities and around the world. Students will use GLOBE scientific measurement protocols and other Earth environmental data sets in schools to take climate-related measurements and investigate research questions about climate.

AN EXAMPLE OF RECENT ACCOMPLISHMENTS IN COMMUNICATION AND EDUCATION

ADVANCING CLIMATE CHANGE EDUCATION AND LITERACY

NASA, NOAA, and NSF have been working together, through the USGCRP and complementary programs, to support projects focused on global climate literacy and education in formal and informal learning environments, and have fostered collaborations among awardees that create a strong national network for effectively presenting climate science to diverse audiences. With the goals of leveraging existing resources, developing common evaluation metrics, minimizing duplication, and facilitating communication among members of this emergent community of scientists and educators, the 2nd annual NASA, NOAA, NSF Climate Change Education Principal Investigators Meeting was held this year (see Figure 17). Over 200 representatives from more than 120 different projects participated in a range of activities and conversations that addressed effective climate science communication and successful project management. The meeting provided opportunities for attendees to meet each other and showcase their projects in poster sessions as well as to exchange ideas and best practices through a series of topical panels and breakout sessions. Cross-agency discussions enabled by the meeting are yielding new collaborations and synergies that are expected to produce a more cohesive Federally funded portfolio of projects, with greater overall impact. A significant outcome of the conference was agreement on the need for a community database of learning resources and other educational resources that are being developed through the individual projects, indexed by audience type and resource type. Plans are currently under consideration for creating such a database that would be accessible via the USGCRP web site.

Figure 17: Participants work collaboratively at the 2nd annual NASA, NOAA, NSF Climate Change Education Principal Investigators Meeting.

FUTURE ACTIVITIES IN COMMUNICATION AND EDUCATION

The 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 through integrating communication, education, and engagement into the program's core activities.

The USGCRP strategy for communication, education, and engagement efforts identified in the new Strategic Plan for 2012 to 2021 will build on the strengths of the participating agencies to expand the reach of information beyond single agencies, and to ensure that feedback and input from public engagement is shared broadly within the Federal global change science community. As a trusted provider of accurate information on global change, the 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. The program will also help build global change literacy among the general public.

Over the next two to three years and in tandem with the NCA and the GCIS effort, interpretive information will be developed to help make the findings of the NCA easily accessible and understandable. A "layered" approach will be taken to develop and publish climate and global change content in the GCIS to serve users who wish to skim for easily digestible information (Wikipedia-style briefs) as well as users who want more context and interpretation (in-depth articles with data visualizations), with the ability for users to trace information and data sets back to their original sources. Emphasis will be placed on the climate-related risks, opportunities, and uncertainties investigated in the NCA. Editorial review policy and procedures will be established to ensure that all content published is peer-reviewed by subject experts via a process that is documented and transparent.

Beyond supporting the NCA, the Communication and Education component of the 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. The USGCRP strategy for communication, education, and engagement efforts 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.

SCIENTIFIC-SOCIETAL AREAS OF INTEREST: THE CLIMATE CHANGE AND HUMAN HEALTH EXAMPLE

OVERVIEW

The NRC and others have recommended that the USGCRP should be restructured around crosscutting, integrated, societally relevant themes to ensure that the research it supports is most useful to our Nation. The NRC report, *Restructuring Federal Climate Research to Meet the Challenges of Climate Change*, called these "scientific-societal issues" while the America's Climate Choices report, *Advancing the Science of Climate Change*, referred to "areas of interest to decisionmakers." By structuring the program around such topics, the research agenda will better reflect the overarching USGCRP mission "to build a knowledge base that informs human responses to climate and global change." Examples of scientific-societal themes from the NRC reports include sea level rise and the coastal environment; freshwater resources; ecosystems, ecosystem services, and biodiversity; agriculture and fisheries; cities and the built environment; transportation systems; energy systems; national and human security; extreme weather and disasters; and human health. The strategic planning and implementation processes are guiding the USGCRP on how to address societally relevant themes, what areas most reflect the priorities of the program, and how to best integrate them into the research agenda.

In response to the recommendations to restructure the USGCRP around crosscutting scientific-societal themes, a pilot effort on climate change and human health was launched in December 2009. Climate change poses unique challenges to human health, including heat waves and severe storms, ailments caused or exacerbated by air pollution and air-borne allergens, and many climate-sensitive infections. Whether or not increased health risks due to climate change are realized will depend largely on societal responses and underlying vulnerability. The

probability of exacerbated health risks due to climate change points to a need to maintain a strong public health infrastructure to help limit future impacts.[20]

OVERVIEW OF RECENT ACCOMPLISHMENTS IN CLIMATE CHANGE AND HUMAN HEALTH

As a part of the climate change and human health pilot effort, the interagency cross-cutting group on climate change and human health (CCHHG) has actively incorporated and leveraged interagency efforts on climate change and health, with specific projects and activities focused on stakeholder engagement and communications, data integration, adaptation, and contributions to the NCA. Through presentations and listening sessions at professional conferences and other key events, the distribution of flash drives with electronic resources and tools, and, as noted earlier, contributions to a set of key messages that were delivered to OSTP regarding climate change and human health, the CCHHG has raised awareness of Federal activities and progress made on climate change and human health research, impacts, and applications.

The CCHHG is in the process of developing an assessment tool to collect metadata on existing climate and health-related datasets that will then be repackaged into a web-based, interactive catalog to allow users better access, provide opportunities for integration, and identify critical gaps in relevant datasets for research and decision support tools. The CCHHG has also actively participated in the ICCATF, including developing recommendations to the Presidential Report, and supporting activities that help to implement the various recommendations that were laid out in the report.

Another key area of focus for the CCHHG has been engaging with the ongoing NCA effort, including identifying possible contributions to the 2013 assessment and helping to build capacity and resources to support the sustained assessment process. Because the group was established as a pilot activity, the CCHHG also spent significant time this year conducting and analyzing a self-assessment, which allowed the CCHHG leadership to make any necessary changes to improve the organization and focus of the IWG's efforts for the future. This unique role also laid the foundation for the group to actively participate in the USGCRP strategic planning process over this past year.

EXAMPLES OF RECENT ACCOMPLISHMENTS IN CLIMATE CHANGE AND HUMAN HEALTH

ESTABLISHING A TRANS-NATIONAL INSTITUTE OF HUMAN HEALTH WORKING GROUP ON CLIMATE CHANGE AND HEALTH

The Trans-National Institute of Health (NIH) Working Group on Climate Change and Health is a cooperative effort involving representatives from 15 of the 27 NIH Institutes and Centers. Soon after it was formed, the Working Group conducted an in-depth analysis of the NIH research grant portfolio, identified key gaps, and established the need for better capacity to predict health effects from changes in weather and climate. This portfolio analysis informed a subsequent competitive funding opportunity under the American Recovery and Reinvestment Act of 2009, whose grantees[21] participated in a subsequent workshop on research needs. Building on the workshop results, the Working Group developed the first dedicated multi-year funding opportunity in climate change and health at NIH, in which 11 Institutes and Centers participated. The first nine grants made under this program were announced in October 2011.[22] A manuscript describing the portfolio analysis and implications for climate change and health research at NIH was submitted for peer-reviewed publication in 2011.

UNDERSTANDING THE LINKAGE BETWEEN BIODIVERSITY AND INFECTIOUS DISEASES

Plant and animal extinctions may be detrimental to human health. This is the conclusion of research exploring the link between biodiversity and infectious diseases. The project was supported under the NSF-NIH Ecology of Infectious Diseases (EID) Program, with support from the EPA.

[20] USGCRP, 2009: Global Climate Change Impacts in the United States, <www.globalchange.gov/publications/reports>.
[21] National Institutes of Health. ARRA Investments in Human Health Impacts of Climate Change, <report.nih.gov/recovery/investmentreports/ViewARRAInvRpt.aspx?csid=143>.
[22] National Institutes of Environmental Health Sciences, 2011: NIH Launches Research program to Explore Health Effects from Climate Change, <www.niehs.nih.gov/news/newsroom/releases/2011/october06/index.cfm>.

The researchers found that species loss in ecosystems such as forests and fields results in increases in pathogens (disease-causing organisms). They also showed that the species most likely to disappear as biodiversity declines are often those that buffer infectious disease transmission. Those that remain tend to be the ones that magnify the transmission of infectious diseases like West Nile virus, Lyme disease, and hantavirus.

Expanding human populations are already increasing contact with novel pathogens through activities such as land clearing for agriculture and hunting for wildlife. Moreover, global biodiversity has declined at an unprecedented pace since the 1950s, with current extinction rates estimated at 100 to 1,000 times higher than in most past epochs, and projected to rise dramatically in the next 50 years. A better understanding of the role of environmental change in disease emergence and transmission is key to enabling both prediction and control of many infectious diseases in the future.[23]

FUTURE ACTIVITIES IN CLIMATE CHANGE & HUMAN HEALTH

The input from the self-evaluation and other lessons learned from the CCHHG pilot effort will be used to inform broader USGCRP programmatic planning efforts over the past year, and the group will continue to support the ongoing strategic planning and implementation planning efforts. In addition, the group plans to continue contributing to the ongoing NCA efforts through specific regionally based activities, as well as numerous other efforts in support of both the 2013 report and building overall capacity for the sustained assessment process. The CCHHG will host a workshop in October 2011 that will assist with the implementation of recommendations laid forth in the 2011 Interagency Climate Change Adaptation Task Force report,[24] and will continue to support those ongoing efforts as additional needs arise. The CCHHG has reaffirmed the establishment of priority work streams that will also carry out specific activities and deliverables to support the new USGCRP strategic goals, as well as further progress the Federal response to users' needs for scientific information related to climate change and human health.

USGCRP-SUPPORTED INTERNATIONAL ACTIVITIES

OVERVIEW

The USGCRP and the large community of U.S. scientists supported by or associated with it have a global reach. As required in the GCRA Sections 101, 102, 104 and Title II, USGCRP is dedicated to international coordination and participation in international global change activities. Activities in which the U.S. is involved include supporting global environmental change research programs, including those that operate under the aegis of the International Council for Science (ICSU) and the United Nations (UN) (such as the WMO and the Intergovernmental Oceanographic Commission); supporting international assessments; supporting regional global change research networks; playing an active role in informal organizations that are involved with the advancement of global environmental change research; and participating in and leading international efforts to provide coordination and cooperation in Earth observations. This support includes work with the DOS at a variety of levels, but particularly with respect to the IPCC and the UNFCCC.

RECENT ACCOMPLISHMENTS IN USGCRP-SUPPORTED INTERNATIONAL ACTIVITIES

The USGCRP provided support for the IPCC Working Group II Technical Support Unit, which also supports U.S. authors and contributors to all IPCC Working Groups. The USGCRP has coordinated author nominations as well as government and expert reviews for AR5, the *Special Report on Renewable Energy Sources and Climate Change Mitigation*, and the *Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation.*

The USGCRP provides continued support for the activities of the WCRP, the International Geosphere-Biosphere Programme (IGBP), the International Human Dimensions Program (IHDP), the DIVERSITAS Programme, and the SysTem for Analysis Research and Training, which operate under the aegis of ICSU and/or the UN and its subsidiary bodies. In particular, the USGCRP hosted and participated in the 2011 meeting of the IGBP's Scientific

[23] Keesing, F., et al., 2010: Impacts of biodiversity on emergence & transmission of infectious diseases. Nature, 468, 647-652.
[24] Council on Environmental Quality, 2011: *Federal Actions for a Climate Resilient Nation: Progress Report of the Interagency Climate Change Adaptation Task Force*, <www.whitehouse.gov/sites/default/files/microsites/ceq/2011_adaptation_progress_report.pdf>.

Steering Group and hosted a day-long symposium on IGBP science. USGCRP agencies were also among the largest sponsors of WCRP's Open Science Conference, held in October 2011, with over 1,900 participants from around the world participating. Support of these programs provides opportunities for U.S. investigators to work with their counterparts from other countries in a coordinated fashion. These activities enrich national activities on the same subjects, build capacity to conduct research and make observations of environmental change in less-developed countries, and foster advances in understanding of global environmental change in ways the investments of any single nation could not accomplish.

The USGCRP, through the active involvement of NSF, contributed to the activities of the Belmont Forum and the International Group of Funding Agencies for Global Change Research (IGFA) including redesign and hosting of the group's web sites and hosting the U.S. portion of the secretariat. Through its role in the Belmont Forum and IGFA, the USGCRP (via NSF) also played a role in the Alliance Transition Team, which is leading an 18-month process to design a 10-year Earth System Sustainability Initiative (ESSI) that is the result of the visioning process led by ICSU and the International Social Science Council (ISSC).

In December 2009, the Global Research Alliance on Agricultural Greenhouse Gases was launched in association with the UNFCCC conference in Copenhagen, Denmark, and now has more than 30 member countries from all regions of the world. The Alliance is designed to increase international cooperation and investment in research activities to help reduce the emissions of agricultural production systems and increase their potential for soil carbon sequestration. The Alliance promotes an active exchange of data, people and research to help improve the ways that agricultural greenhouse gas research is conducted and to enhance participating countries' scientific capability. Several agencies of the USDA coordinate the United States' participation in the Alliance, including the Agricultural Research Service, which leads the International Croplands Research Group. The USDA Foreign Agricultural Service sponsors the Global Research Alliance Fellowships, which to date have provided funding for 17 scientists from developing countries to come to the United States and work directly with U.S. researchers in government and academia on research priorities and goals of the Alliance.

USGCRP agencies participated in a range of other activities that help coordinate their activities with those of their international partners. In particular, such activities include those focused on observations (e.g., Group on Earth Observations, Committee on Earth Observing Satellites, Coordinating Group on Meteorological Satellites, the GCOS and its related panels such as the Ocean Observing Panel for Climate).

FUTURE USGCRP-SUPPORTED INTERNATIONAL ACTIVITIES

The USGCRP and its participating agencies will spend much of the next year reorganizing and developing a strategy, goals, and priorities for international programs, partnerships, and engagement that reflect the new scope and approach of the program as articulated in the Strategic Plan.

While this process is underway, the USGCRP will continue to support U.S. contributions to the IPCC technical support unit and to coordinate the U.S. scientific and Federal government community inputs toward the development of the IPCC AR5 and its associated special reports as well as other assessments. The USGCRP will also look to expand the breadth of agency participation in and continue to provide leadership for the International Group of Funding Agencies for Global Change Research and the Belmont Forum. As part of its involvement with the Belmont Forum and IGFA, the USGCRP has and will continue to play a role in the development of the ESSI with ICSU, the ISSC, and other Alliance partners. As part of the reorganization and strategy development action noted in the first paragraph, the USGCRP will address how to best direct its resources, both those funded collectively and by individual agencies, to deal with the evolving international picture.

The USGCRP and its participating agencies are involved in a variety of international outreach and communication efforts. These efforts include significant contributions to the development of the U.S. Center at UNFCCC COP-17 in Durban South Africa, significant presence at the WCRP Open Science Conference, and support for the upcoming Planet Under Pressure 2012.

VII RECENT AND NEAR-TERM EXPENDITURES

BUDGET HIGHLIGHTS

The FY 2012 budget request for USGCRP programs is $2.6 billion – an increase of approximately 6.3% over the FY 2011 enacted level. This increase reflects the needs discussed above and represents a commitment by the Administration to the USGCRP.

It is important to remember that the budget crosscut table represents those funds self-identified by the USGCRP agencies as their contributions to the USGCRP. The budget crosscut does not include the costs of many agency investments that are directly relevant, indeed necessary, to the ability of the USGCRP to address national objectives related to climate and global change (e.g., many of the observing networks and satellite systems so critical to documenting trends were originally carried out by their sponsoring agencies for current operational purposes, and those are not typically included in the budget crosscut).

In fiscal year 2011, the USGCRP participating agencies and departments contributed $1,995,642 to the IPCC in support of both the IPCC Technical Support Unit for Working Group II and travel support for U.S. scientists participating in all three of the IPCC Working Groups. In addition, the total U.S. Government contribution to the IPCC Trust Fund in FY 2011 was $2,682,845, of which $350,000 was for the Global Climate Observing System (GCOS), with the remaining $2,332,845 for IPCC programs.

BUDGET TABLE 1

U.S. GLOBAL CHANGE RESEARCH PROGRAM: FY 2010 – 2012 BUDGET BY AGENCY

Federal Agency	2010 Enacted (in millions)	2011 Enacted (in millions)	2012 Request (in millions)
Department of Agriculture (USDA)	121.00	116.00	125.00
Department of Commerce (DOC)	363.00	338.00	420.00
Department of Energy (DOE)	170.63	182.87	224.43
Department of Health and Human Services (HHS)	4.00	4.00	4.00
Department of State (DOS)	14.20	3.18	3.40
Department of the Interior (DOI)	63.00	64.00	73.00
Department of Transportation (DOT)	3.00	1.00	3.00
Environmental Protection Agency (EPA)	20.80	20.40	20.80
National Aeronautics and Space Administration (NASA)	1123.00	1431.00	1338.00
National Science Foundation (NSF)	319.55	321.31	425.11
Smithsonian Institution (SI)	7.00	7.30	8.00
[Agency for International Development (USAID)*]	28.00	25.00	28.00
TOTAL	**2237.18**	**2514.06**	**2672.74**

**USAID spending on international climate assistance does not add to the USGCRP total.*

VIII APPENDIX A: GLOSSARY AND ACRONYMS

DEFINITION OF KEY TERMS

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

Adaptive management: 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.

Aerosols: Fine solid or liquid particles suspended in a gas. Aerosols may be of either natural or anthropogenic origin.

Anthropogenic: Resulting from or produced by human beings.

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.

Belmont Forum: A collaborative mechanism among international organizations, such as the International Council for Science, and national funding agencies to identify global change research priorities that might benefit from better cooperation and how best to address these.

Biodiversity: The total diversity of all organisms and ecosystems at various spatial scales.

Biomass: The total mass of living organisms in a given area or volume.

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

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

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

Climate: The mean and variability of relevant measures of the atmosphere-ocean system over periods ranging from weeks to thousands or millions of years.

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.

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.

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 – including weather variations – in the future, for example, at seasonal, interannual, or long-term timescales.

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 scenarios 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.

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 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.

Climate variability: Variations in the mean state and other statistics (e.g., the occurrence of extremes, etc.) of the climate on all 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).

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.

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 (100 to 1000 km) models or data analyses.

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.

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: The conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life. Examples include provision of clean water, maintenance of liveable climates, pollination of crops and native vegetation, and fulfillment of people's cultural, spiritual, intellectual needs.

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

End-to-end: The nature of research needed to address the 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.

Extreme weather event: An event that is rare at a particular place and time of year. Definitions of "rare" vary, but an extreme weather event would normally be as rare as or rarer than the 10th or 90th percentile of the observed probability density of weather events.

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.

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

Geo-engineering: Deliberate large-scale manipulation of the planetary environment as a strategy to counteract anthropogenic climate change.

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

Global change information system (GCIS): 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; Section 102, P.L. 101-606): 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.

Greenhouse gas: 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.

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" e.g., agricultural system, political system, technological system, or economic system.

Human-natural system: Integrated systems in which human and natural components interact, such as the interaction between socioeconomic and biophysical processes in urban ecosystems.

***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 Environment Programme and the United Nations World Meteorological Organization.

IPCC AR4: The fourth in a series of assessment 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.

IPCC AR5: The fifth in a series of assessment reports by the Intergovernmental Panel on Climate Change, intended to assess the socio-economic aspects of climate change and implications for sustainable development, risk management, and the framing of a response through both adaptation and mitigation.

Land cover: The land surface covering, including areas of vegetation (forests, shrub lands, crops, deserts, lawns), bare soil, developed surfaces (paved land, buildings), and wet areas and bodies of water (watercourses, wetlands).

Landsat Program: The Landsat Program is a series of Earth-observing satellite missions jointly managed by NASA and the U.S. Geological Survey.

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.

Metadata: Information about meteorological and climatological data concerning how and when they were measured, their quality, known problems, and other characteristics.

Mitigation (climate change): An intervention to reduce the sources or enhance the sinks of greenhouse gases and other climate forcing agents. 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.

Monitoring: A scientifically designed system of continuing standardized measurements and observations and the evaluation thereof. Monitoring is specifically intended to continue over long time periods.

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 that 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): An arm of the National Academy of Sciences that forms committees to enlist 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 12881 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: 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 crustaceans.

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 consisting of three atoms of oxygen, readily reacting with many other substances.

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

Prediction: See climate prediction.

Projection: See climate projection.

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 radiation. A positive forcing warms the surface of the Earth and a negative forcing cools 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. In the climate context, remote sensing is commonly performed from satellites or aircraft.

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

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).

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. Sinks may be of natural or human origin.

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).

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.

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

Technology: An approach, including both the experimental technique and the instrumental and scientific infrastructure needed to implement it.

Tipping point: A critical threshold at which a tiny perturbation can qualitatively alter the state or development of a system.

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.

Uncertainty: An expression of the degree to which a value (e.g., the future state of the climate system) is unknown. Uncertainty in future climate arises from imperfect scientific understanding of the behavior of physical systems, and from inability to predict human behavior.

United Nations Framework Convention on Climate Change (UNFCCC): The United Nations Framework Convention on Climate Change is an international environmental treaty produced at the United Nations Conference on Environment and Development (UNCED) intended to stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.

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). Thirteen departments and agencies participate in the USGCRP. 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 (NCO).

U.S. Group on Earth Observations (USGEO): 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.

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.

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.

ACRONYMS

AGB – Above Ground Biomass
AR5 – IPCC Fifth Assessment Report
ARM – Atmospheric Radiation Measurement
BASINS CAT – BASINS Climate Assessment Tool
BEST – Bering Ecosystem Study
BSIERP – Bering Sea Integrated Ecosystem Research Program
CCHHG – Climate Change and Human Health Group
CENRS – Committee on Environment, Natural Resources, and Sustainability
CEQ – Council on Environmental Quality
CESM – Community Earth System Model
CFSv2 – Climate Forecast System
CMIP5 – Fifth Phase of the Coupled Model Intercomparison Project
CO2 – Carbon Dioxide
COP – Conference of the Parties
DOD – Department of Defense
DOE – Department of Energy
DOI – Department of the Interior
DYNAMO – Dynamics of the Madden-Julian Oscillation
EaSM – Decadal and Regional Climate Prediction using Earth System Models
ECV – Essential Climate Variables
EOP – Executive Office of the President
EPA – Environmental Protection Agency
ESG – Earth System Grid
ESM – Earth System Model
ESMF – Earth System Modeling Framework
ESSI – Earth System Sustainability Initiative
FY – Fiscal Year
GCAM – Global Change Assessment Model
GCIS – Global Change Information System
GCM – General Circulation Model
GCRA – Global Change Research Act
GFDL – Geophysical Fluid Dynamics Laboratory
GLOBE – Global Learning and Observations to Benefit the Environment
GPS – Global Positioning System
GRACE – Gravity Recovery and Climate Experiment
IAM – Integrated Assessment Model
ICCATF – Interagency Climate Change Adaptation Task Force
ICSU – International Council of Science
iESM – Integrated Earth System Model
IGBP – International Geosphere-Biosphere Programme
IGFA – International Group of Funding Agencies for Global Change Research
IGIM – Interagency Group on Integrative Modeling
INCA – Interagency National Climate Assessment Working Group
IPCC – Intergovernmental Panel on Climate Change

ISSC – International Social Science Council
IWG – Interagency Working Group
JPL – Jet Propulsion Laboratory
LAI – Leaf Area Index
MERRA – Modern Era Retrospective Analysis for Research and Applications
MJO – Madden-Julian Oscillation
NAS – National Academy of Sciences
NASA – National Aeronautics and Space Administration
NCA – National Climate Assessment
NCADAC – National Climate Assessment Development and Advisory Committee
NCAR – National Center for Atmospheric Research
NCO – National Coordination Office
NDMC – National Drought Mitigation Center
NIDIS – National Integrated Drought Information System
NIH – National Institutes of Health
NMME – National Multi-Model Ensemble
NOAA – National Oceanic and Atmospheric Administration
NRC – National Research Council
NSF – National Science Foundation
NSTC – National Science and Technology Council
OCP – Our Changing Planet
OMB – Office of Management and Budget
OSTP – Office of Science and Technology Policy
PCMDI – Program for Climate Model Diagnosis and Intercomparison
RISA – Regional Integrated Sciences and Assessments
RO – Radio Occultation
SCIPP – Southern Climate Impacts Planning Program
SCRC – Student Climate Research Campaign
SeaRISE – Sea-level Response to Ice Sheet Evolution
SECC – Southeast Climate Consortium
SGCR – Subcommittee for Global Change Research
STEM – Science, Technology, Engineering, and Mathematics
TSU – Technical Support Unit
UN – United Nations
UNEP – United Nations Environment Programme
UNFCCC – United Nations Framework Convention on Climate Change
USDA – U.S. Department of Agriculture
USFS – U.S. Forest Service
USGCRP – U.S. Global Change Research Program
USGEO – U.S. Group on Earth Observation
USGS – U.S. Geological Survey
WCRP – World Climate Research Programme
WEPPCAT – Water Erosion Prediction Project Climate Assessment Tool
WMO – World Meteorological Organization

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ADDITIONAL INFORMATION

This document describes the U.S. Global Change Research Program (USGCRP) for FY 2012. It provides a summary of the achievements of the program, an analysis of the progress made, and budgetary information. It thereby responds to the annual reporting requirements of the U.S. Global Change Research Act of 1990 (Section 102, P. L. 101-606). It does not express any regulatory policies of the United States or any of its agencies, or make any findings of fact that could serve as predicates for regulatory action. Agencies must comply with required statutory and regulatory processes before they could rely on any statements in this document or by the USGCRP as a basis for regulatory action.