OUR CHANGING PLANET




The U.S. Global Change Research Program for Fiscal Year 2016

A Supplement to the President's Budget

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"[C]limate change does not occur in isolation. Rather, it is superimposed on other stresses, which combine to create new challenges."

—The Third National Climate Assessment, 2014

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

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Since 1989, the U.S. Global Change Research Program (USGCRP) has submitted annual reports to Congress called *Our Changing Planet*. The reports describe the status of USGCRP research activities, provide progress updates, and document recent accomplishments. This FY 2016 edition of Our Changing Planet provides a summary of programmatic achievements, recent progress, future priorities, and budgetary information. It thereby meets the requirements set forth in the U.S. Global Change Research Act of 1990 (Section 102, P. L. 101–606) to provide an annual report on Federal global change research priorities and programs. It does not express any regulatory policies of the United States or any of its agencies, or make any findings that could serve as predicates for regulatory action.

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May 2015

Members of the Congress:

On behalf of the National Science and Technology Council, I am pleased to transmit *Our Changing Planet: The U.S. Global Change Research Program for Fiscal Year 2016*. USGCRP coordinates and integrates scientific research across 13 Federal agencies whose missions include understanding changes in the global environment and their implications for society. In accordance with the Global Change Research Act (GCRA) of 1990, the enclosed report summarizes USGCRP's recent progress and achievements, future priorities, and associated budget information.

This latest edition of *Our Changing Planet* includes an overview of the USGCRP research enterprise and recent highlights that demonstrate how the Program is fulfilling its 2012–2021 Strategic Plan. The report also spotlights progress in interagency research priority areas that intersect with President Obama's Climate Action Plan, such as climate predictions, drought and other hydrologic extremes, and actionable science. The highlights in this Our Changing Planet report represent the broad spectrum of USGCRP activities that extend from Earth system observations, modeling, and fundamental research through synthesis and assessment, decision support, education, and public engagement. This approach fully addresses the GCRA mandate to *"understand, assess, predict, and respond to human-induced and natural processes of global change."*

Our Changing Planet FY 2016 summarizes USGCRP's significant advancements toward achieving its scientific goals, delivering on its Congressional mandate, supporting the President's Climate Action Plan, and building a knowledge base that effectively informs human responses to global change. I appreciate the close cooperation of the participating agencies and look forward to working with members of the Congress to implement the continuation of this essential national program.

Sincerely,

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

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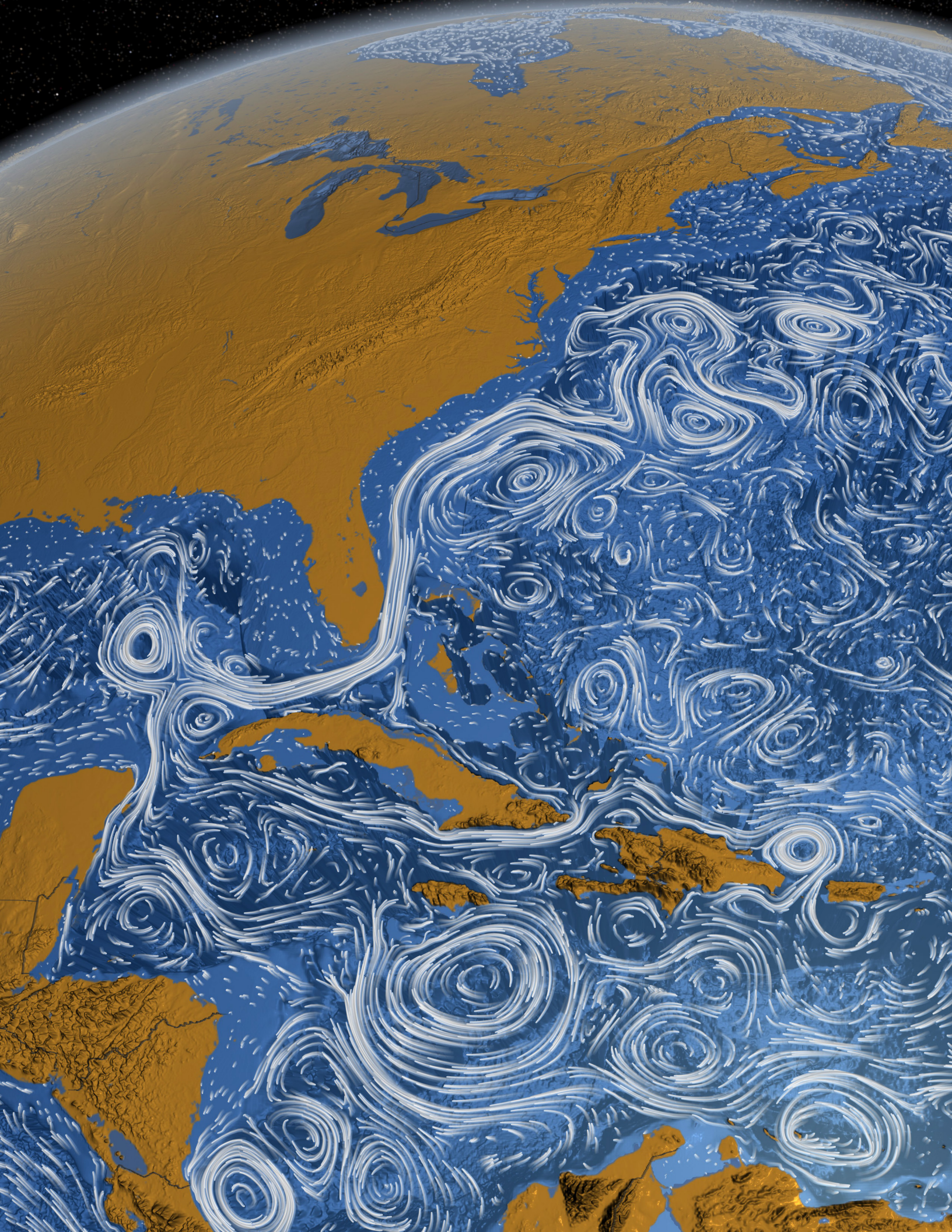


1 INTRODUCTION

2014 was the hottest year on record worldwide, with record-breaking global average temperatures for the months of May, June, August, September, and October. Although it was only the 34th warmest year on record within the contiguous United States, it marked the 18th year in a row in which U.S. temperatures exceeded the 20th century average. California, Nevada, Arizona, and Alaska experienced their highest annual temperatures ever recorded. Eight U.S. weather and climate disasters exceeded $1 billion each in 2014 alone.{1}

Looking beyond this single year, long-term observations show that the United States and the world are getting warmer, global sea level is rising, oceans are becoming more acidic, and some types of extreme weather and climate events are becoming more frequent and more severe. Temperatures are projected to rise another 2°F to 4°F in most areas of the United States over the next few decades, with far-reaching implications for urban and rural areas, food security and water supply, natural resources and human health, and sectors such as energy and transportation.{2} According to the Third National Climate Assessment:

> The observed warming and other climatic changes are triggering wide-ranging impacts in every region of our country and throughout our economy. Some of these changes can be beneficial over the short run…. But many more are detrimental, largely because our society and its infrastructure were designed for the climate that we have had, not the rapidly changing climate we now have and can expect in the future.{3}

Recognition of the seriousness of this issue is growing. The Department of Defense has identified climate change as a national security "threat multiplier".{4} For the second time in a row, the U.S. Government Accountability Office has included climate change on its biennial list of significant financial risks to the Federal Government.{5} Business leaders have come together to quantify the economic risks posed by the impacts of climate change.{6} According to NASA, even the U.S. space program stands to be affected by power failures associated with heat waves and erosion at coastal launch sites that will accelerate with sea level rise and increased storm intensity.{7}

It is clear that the Nation needs reliable scientific information about how the climate is changing, how those changes interact with other global dynamics, and how we can adapt and respond effectively. The U.S. Global Change Research Program (USGCRP) is at the center of the Federal Government's efforts to fulfill this critical need.

Created by President Ronald Reagan in 1989 and codified by Congress in the Global Change Research Act (GCRA) of 1990,{8} USGCRP has been a leader for 25 years in advancing Earth system science and expanding the knowledge base needed to respond to a continually changing world. USGCRP agencies conduct state-of-the-art research to understand the interactive processes that influence the Earth system, which encompasses the atmosphere, oceans, land, ice, ecosystems, and people. Though climate change is a central theme of this research, the Program has a broader mandate that includes related dimensions

of global change. This broader view is essential because the environmental challenges facing society rarely involve climate change in isolation. Rather, regional- and local-scale stressors like changes in land use and land cover, pollution, and limited natural or economic resources can interact with climate change to produce compounded impacts requiring comprehensive solutions.

USGCRP fulfills the mandate of the GCRA, executes the National Global Change Research Plan 2012–2021[9] (hereafter, the 2012–2021 Strategic Plan), and contributes to the research and decision-support goals of the President's Climate Action Plan[10] by coordinating the Federal Government's sustained annual investment in global change science. In addition to facilitating major advances in the knowledge of Earth's climate and environment, this investment supports an actionable understanding of society's vulnerabilities to the impacts of global change.

The Program's extensive body of work is carried out by the research arms of 13 Federal agencies (*Box 1*; see also *Section 6.2*), each contributing its distinct expertise while working together in a unified framework under the direction of the Subcommittee on Global Change Research (SGCR; see *Section 6.1*). Through the SGCR, USGCRP collaborates with other sub-groups of the Committee on Environment, Natural Resources, and Sustainability, such as those that focus on Earth observations, ocean science, and Arctic research.

In addition to the formal research contributions from its 13 agencies, USGCRP cooperates with and leverages expertise from other areas of the Federal Government that have a vested interest in understanding the effects of climate and related global change. This collaborative approach is facilitated by interagency working groups (IWGs; see *Section 6.1*). IWGs provide a connective network for coordinating research efficiently across the Federal Government, and they enable multidirectional interchanges between agencies studying global change and agencies responding to its impacts.

This report provides an overview of the USGCRP enterprise (*Box 2; Section 2*), with examples of recent progress in delivering on the goals of 2012–2021 Strategic Plan (*Section 2*) and in meeting research priorities that intersect with the Climate Action Plan (*Section 3*). It also provides an outlook on research priorities for Fiscal Year (FY) 2016 (*Section 4*), and supporting budgetary information (*Section 5*).

The activities highlighted in this report are only a small fraction of USGCRP's portfolio, which extends from research through decision support, assessment, education, and communication. USGCRP's ability to produce the results described herein is made possible by long-term investments in observations, research, modeling, and data stewardship. These long-term

Box 1. USGCRP Agencies

These 13 agencies work together to empower the Nation with global change science.

- 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

investments lay the necessary groundwork for scientific breakthroughs and provide critical support for the U.S. scientific community, enabling research that can inform effective decisions by governments, communities, and businesses. From understanding global sustainability to building climate resilience at the community level, the activities highlighted in this report reflect the fruition of foundational research investments needed to understand and respond to a dynamic planet.

Box 2. USGCRP At A Glance

USGCRP is a confederation of the global change research arms of 13 Federal agencies. It was established by Presidential Initiative in 1989 and mandated by Congress in the Global Change Research Act of 1990 to "assist the Nation and the world to understand, assess, predict, and respond to human-induced and natural processes of global change."

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.

Strategic Goals: USGCRP's 2012–2021 Strategic Plan maintains a clear emphasis on advancing global change science; it also calls for a strengthened focus on ensuring that USGCRP science informs real-world decisions and actions. USGCRP's four strategic goals, around which *Section 2* of this report is organized, are as follows:

Advance Science - Advance scientific knowledge of the integrated natural and human components of the Earth system to understand climate and global change.

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

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

Communicate and Educate - Advance communication and education to broaden public understanding of global change and develop the scientific workforce of the future.

Background information about the 2012–2021 Strategic Plan is available on USGCRP's website.
To learn more about USGCRP, see *Section 6.1*.

2 FEDERAL INVESTMENTS IN GLOBAL CHANGE RESEARCH

The many dimensions and dynamic nature of global change create moving targets for science and response strategies alike. USGCRP's 2012–2021 Strategic Plan serves as a roadmap for navigating this challenge, charting the course for a deeper scientific understanding and better decision-support tools to enable effective responses. With help from collaborators inside and outside the Federal Government, USGCRP agencies are making significant progress toward fulfilling the 2012–2021 Strategic Plan through a long-term focus on its four pillars: advancing science (*Section 2.1*), informing decisions (*Section 2.2*), conducting sustained assessments (*Section 2.3*), and communicating with and educating a range of audiences (*Section 2.4*). The first of these goals provides the scientific foundation for the other three, which in turn continually shape future research priorities.

2.1. Advancing Science

Understanding global change is critical to America's welfare. Fundamental use-inspired research, made possible by cutting-edge tools for collecting and analyzing data, can provide the knowledge that governments, businesses, and communities need as they address the climate-related changes that pose growing risks to life, property, natural resources, and the economy.[2]

USGCRP research advances understanding of the interacting physical, chemical, biological, and societal components of the Earth system; the vulnerability and resilience of its natural and human dimensions; and the means by which scientific knowledge can effectively inform responses to global change. Such research depends on sustained programmatic investments in multidisciplinary observations (*Box 3*), process studies, and modeling. These foundational components of scientific inquiry require their own expertise, infrastructure, and planning horizons, but they ultimately work together to produce a more comprehensive and integrated understanding of global change.

For instance, observations collected via satellites, weather stations, and ocean platforms enable scientists to monitor the state of the global climate (*Highlight 1*), while modeling and analysis examine the causes of observed extreme weather and climate events (*Highlight 2*). Long-term, field-based measurements of environmental variables feed into research efforts on a variety of scales and subjects. A few examples include analyses of Earth's carbon budget (*Highlight 3*), models of ecosystem–atmosphere interactions (*Highlight 4*), indices of seasonal change (*Highlight 5*), and studies of how microorganisms mediate carbon storage (*Highlight 6*). Observations not only provide the input and baseline conditions that drive many Earth system models; they also serve as important real-world checks to evaluate model output (*Highlight 7*).

In addition to conducting and supporting these integrated research activities, USGCRP is working to improve and synergize the Nation's global change research capabilities—for instance, contributing to the evaluation of U.S. Earth observing systems (*Highlight 8*), supporting cooperation across the U.S. modeling community (*Highlight 9*), and enhancing national and international collaboration to advance carbon cycle science (*Highlight 10*). Moreover, USGCRP is increasing the utility of its research through a stronger relationship with the social

sciences, as called for in the 2012–2021 Strategic Plan. Members of a USGCRP task force recently published a commentary paper[11] that offers a framework for understanding how social science research can help to operationalize the global change knowledge base. On the basis of this framework, the paper identifies specific bridging activities to improve the integration of social sciences, including participatory decision-making processes, the connection of knowledge networks, common data standards, and the development of information systems. These guiding principles and activities can foster continuous dialogue between scientists and stakeholders, guide new research priorities, and help transform global change research into action.

Box 3. Observations to Support Global Change Research

USGCRP science—including fundamental research, modeling, assessments, and science for decision support—depends upon sustained investments in observations of Earth's atmosphere, oceans, ice, land, and ecosystems. USGCRP's portfolio of Earth observations includes satellite, airborne, ground-based, and ocean-based missions, platforms, and networks—all of which provide measurements that are necessary for understanding and responding to global change. To illustrate the breadth and depth of this foundational element of the Program, the table below lists observational efforts that launched or wrapped in 2014 and 2015, as well as those slated to begin later this year (see also *Highlights 4* and *33* for additional examples).

Mission or Campaign	Description
Global Precipitation Measurement (GPM)	GPM is an international satellite mission to provide next-generation observations of rain and snow worldwide every three hours. Launched in February 2014 by NASA and the Japanese Aerospace Exploration Agency (JAXA), the GPM mission will advance knowledge of Earth's water and energy cycles and improve the forecasting of extreme events such as hurricanes and floods.
Orbiting Carbon Observatory 2 (OCO-2)	OCO-2, launched by NASA in July 2014, measures carbon dioxide from space with the precision, resolution, and coverage needed to provide a global picture of human and natural sources and sinks. These measurements are being combined with data from ground stations, aircraft, and other satellites to help answer key questions about the global carbon cycle and how it interacts with climate change.
Arctic Radiation IceBridge Sea and Ice Experiment (ARISE)	The ARISE field campaign was held over the Arctic in summer 2014 to study the interaction of sea ice retreat and clouds and their effects on Arctic climate. ARISE is NASA's first Arctic airborne campaign designed to take simultaneous measurements of ice, clouds, and the levels of incoming and outgoing radiation, the balance of which determines the degree of climate warming.
Ship-Aircraft Bio-Optical Research (SABOR)	SABOR, a NASA-coordinated ship and aircraft campaign, took place off the U.S. Atlantic coast in summer 2014. It will advance space-based capabilities for monitoring microscopic plankton that form the base of the marine food chain.
Deriving Information on Surface Conditions from Column and Vertically Resolved Observations Relevant to Air Quality (DISCOVER-AQ)	DISCOVER-AQ is a five-year, NASA-led airborne and ground-based mission to improve the use of satellites in monitoring air quality, with a focus on U.S. areas for which air quality is typically poor. NASA concluded the final field campaign in 2014 over Colorado in collaboration with EPA, DOC's National Oceanic and Atmospheric Administration (NOAA), the Colorado Department of Public Health and Environment, and the NSF-funded Front Range Air Pollution and Photochemistry Experiment (FRAPPÉ).
Biogenic Aerosols – Effects on Clouds and Climate (BAECC)	DOE and Finnish scientists collaborated on the 2014 BAECC field campaign, measuring biogenic aerosols emitted from a pine forest in Finland to determine their effects on clouds, precipitation, and climate.
Hurricane and Severe Storm Sentinel (HS3)	The NASA-sponsored HS3 airborne campaign used two Global Hawk uninhabited aircraft systems (UAS) to investigate the processes that underlie hurricane formation and intensity change in the Atlantic Ocean basin. Field measurements were collected during the hurricane seasons of 2012–2014.

Box 3 (continued on next page)

Box 3 (continued)

Deep Argo	NOAA implements the U.S. component of the international Argo program, a global array of free-drifting floats collecting measurements in the upper 2,000 meters of the ocean. In June 2014, the United States, Australia, and New Zealand conducted a research cruise in the southwest Pacific to test a new generation of sensors and two prototype Deep Argo floats that can measure conditions in the deep ocean (down to 6,000 meters)—an area that is important to Earth's energy budget but little explored.
RapidScat	NASA's RapidScat instrument launched to the International Space Station (ISS) in late 2014. It measures the speed and direction of ocean surface winds, helping to improve weather forecasts and contributing to hurricane monitoring.
Cloud-Aerosol Transport System (CATS)	NASA's CATS instrument, launched to the ISS in January 2015, measures the three-dimensional structure of aerosols and clouds to improve air quality model forecasts and support research on the effects of cloud–aerosol interactions on climate.
Soil Moisture Active Passive (SMAP)	Launched in January 2015, NASA's SMAP satellite mission will collect worldwide measurements of soil moisture and the freeze/thaw status of the soil. These measurements will be used to study links between Earth's water, energy, and carbon cycles; quantify carbon fluxes in boreal landscapes; improve weather and crop yield forecasts; and enhance flood prediction and drought monitoring capabilities.
Deep Space Climate Observatory (DSCOVR)	The DSCOVR satellite mission, launched in February 2015, will monitor solar winds and other space weather phenomena that can affect power grids and communication systems. The mission—led by NOAA in partnership with NASA and the U.S. Air Force—will also support research on climate and the energy cycle by measuring the radiation that Earth emits and reflects, and by imaging the Earth's surface and atmosphere.
CalWater2/ARM Cloud Aerosol Precipitation Experiment (ACAPEX)	The CalWater2/ACAPEX field campaign, which occurred January—March 2015, is a collaboration between NOAA, DOE, and NASA. It collected measurements to improve understanding and modeling of processes associated with atmospheric rivers and aerosol-cloud interactions that influence precipitation variability and extremes in the western United States.
Evaluation of Routine Measurements using UAS (ERASMUS)	DOE's ERASMUS campaign, taking place in spring 2015 at the DOE Oliktok Point Atmospheric Radiation Measurement (ARM) site, will use UAS to collect a detailed set of atmospheric measurements geared toward a better understanding of Arctic moisture, aerosol, and radiation budgets.
Airborne Tropical Tropopause Experiment (ATTREX)	ATTREX is a multi-year, NASA-sponsored airborne campaign using the Global Hawk UAS to study tropical cirrus formation and the exchange of water and other substances between the troposphere (the layer of the atmosphere closest to Earth) and the stratosphere (the layer above). 2015 is the last of four deployment years.
Hyperspectral Infrared Imager (HyspIRI) Airborne Campaign	HyspIRI, taking place from 2013 to 2015 over California, uses remote sensing instruments aboard the ER-2 aircraft to characterize spectral variations across strong ecological gradients. The goal is to provide precursor data for a potential future NASA satellite mission.
Shale Oil and Natural Gas Nexus (SONGNEX) – Four Corners	In spring 2015, NOAA and NASA are collaborating on a SONGNEX aircraft campaign to quantify methane emissions associated with fossil fuel extraction and other sources in the Four Corners region of the western United States.
Plains Elevated Convection At Night (PECAN)	PECAN is a multi-agency (NSF, DOE, NOAA, NASA) ground-based and aircraft campaign, taking place over the U.S. Southern Great Plains in summer 2015. It aims to advance understanding of the nocturnal, warm-season precipitation that constitutes much of this region's rainfall.
Jason-3	In 2015, NOAA, NASA, and European partners will launch Jason-3, the fourth in a series of joint satellite missions measuring the height of the ocean surface. These measurements provide critical information about ocean circulation and global and regional changes in sea level.

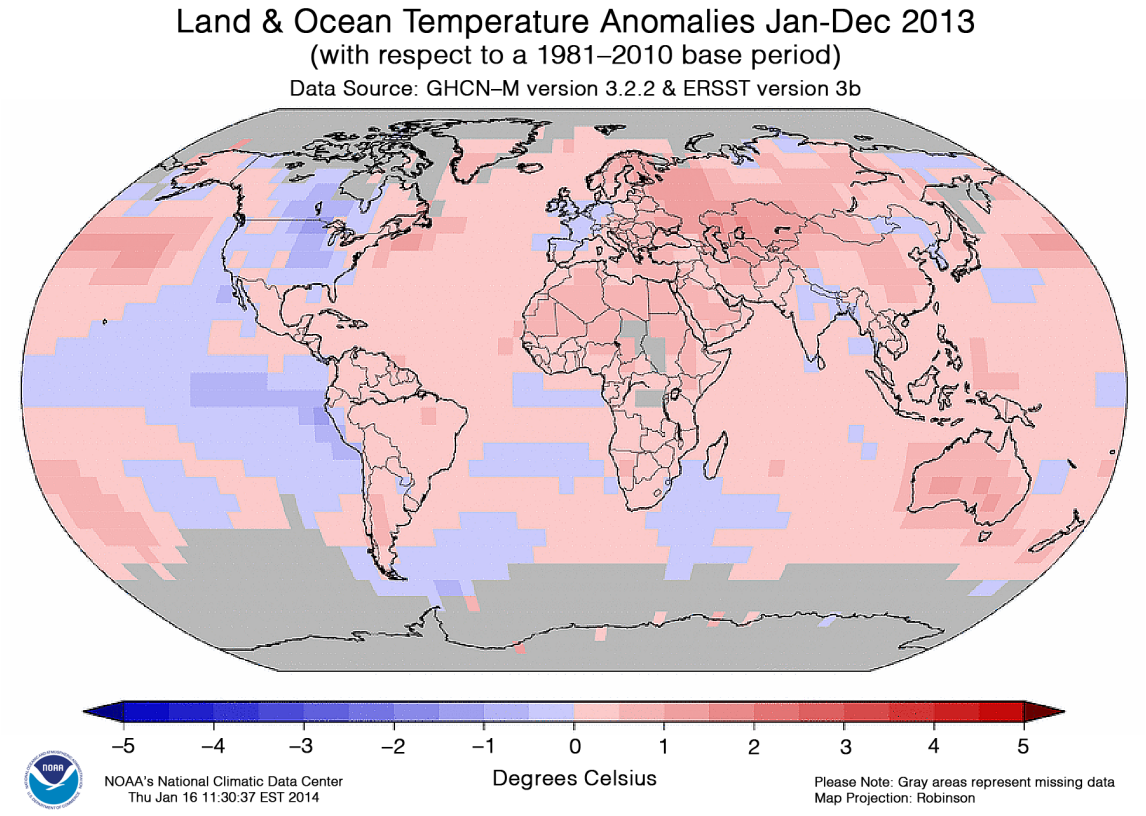
RECENT HIGHLIGHTS

Highlight 1. Monitoring the State of the Global Climate

In 2013, the vast majority of worldwide climate indicators—including greenhouse gas concentrations, sea levels, and global temperatures, among others—continued to reflect evidence of a warming planet. That was the conclusion of the State of the Climate in 2013,[12] a report published in July 2014 by the *Bulletin of the American Meteorological Society (BAMS)*. Scientists from NOAA's National Climatic Data Center (NCDC) served as the lead editors of the report, which was authored by 425 scientists (including researchers from NASA and other divisions of NOAA) from 57 countries around the world.

The report, which is issued annually, details unusual and extreme weather events and uses dozens of internationally recognized indicators to track changes in the global climate system. Each indicator is based on thousands of measurements from multiple independent datasets, consolidated with the help of a diverse array of international scientists. The report provides a valuable reference not only for scientists, but also for the increasing number of decision makers who consider climate conditions and trends in their work. NOAA has issued a preliminary version of the State of the Climate report for 2014,[1] and the full report is expected later this year. ♦

This map shows largely warmer temperatures (shades of red) in 2013 relative to average temperatures between 1981 and 2010. (Source: NOAA NCDC)



Highlight 2. Explaining Extreme Events from a Climate Perspective

Extreme events such as heavy rains, severe storms, drought, and heat waves can have devastating effects on infrastructure, the economy, and vulnerable segments of the population. A growing field of climate science seeks to understand the drivers behind extreme events and how they connect to broader climate trends. Building on efforts to monitor the global climate (see *Highlight 1*), a recent report[13] published in *BAMS* integrates findings from 20 different research groups to assess the respective roles of human-caused climate change and natural climate variability in 16 extreme events. NOAA scientists served as three of the four lead editors on the report, working with authors from NOAA, NASA, DOI's U.S. Geological Survey (USGS), DOE's Oak Ridge and Lawrence Berkeley National Laboratories, U.S. academic institutions, and research entities in 13 other countries.

Five of the 20 research groups studied the record heat in Australia, and all five found that human-caused climate change increased the likelihood and severity of such an event. But for some of the other 2013 events, the evidence was more mixed. For instance, the report did not find conclusive evidence for the impact of human-caused climate change on the ongoing drought in California. However, it did find that human activity increased the likelihood of unusual atmospheric pressure patterns associated with drought. In another example, the report found that while human-caused warming increased the moisture content of the air over Colorado, it did not increase—and in fact apparently decreased—the likelihood of the extreme rainfall that caused widespread flooding in Boulder.

Flooding from heavy rains damaged Boulder, Colorado, in September 2013—one of several extreme events examined in the collaborative report. (Source: S. Zumwalt, FEMA)

Understanding the relative influence of human and natural factors in extreme events can help governments and communities make informed decisions about minimizing and responding to the effects of climate change. In particular, being able to anticipate increases in specific types of extreme weather within a given region can motivate actions to reduce risk. ♦

Highlight 3. Tracking Earth's Carbon Budget with Global Observations

The international Global Carbon Project released its annual Global Carbon Budget in September 2014, shining a spotlight on rising carbon dioxide emissions and their significance for international efforts to reduce climate change. The 2014 Budget comprises analyses of emissions data for 2013, projections through the end of 2014, and implications for future climate and energy choices. The emissions data are available to explore interactively through the Global Carbon Atlas, worldwide and by country. According to the Budget, global carbon dioxide emissions from fossil fuel use and cement production grew to a record high of 36 billion tons in 2013, while emissions from deforestation were relatively low at 3.3 billion tons. [14]

The Global Carbon Budget relies on observational data from many sources, with significant contributions from USGCRP agencies including NOAA, DOE, and NSF. For the first time, the 2014 Budget used data collected by autonomous instruments on "ships of opportunity" and moorings that measure carbon dioxide at the ocean surface. The 2014 Budget estimates that oceans absorbed 29% of all human emissions of carbon dioxide in 2013, representing a nearly three-fold increase in carbon storage by the oceans over the last 50 years. Although this increased carbon storage helps to mitigate the climatic effects of human emissions, it also results in more acidic ocean waters, threatening shellfish and other ecologically and economically important marine animals. NOAA's investment in improved observations and technology helped reduce uncertainty in the ocean carbon storage measurements by more than 50%. [15]

In addition to providing data, multiple USGCRP agencies supported U.S. contributions to the 2014 Budget analyses. USGCRP contributes to the Global Carbon Project through annual funding for the international programs that partner with Future Earth (see related *Highlight 40*). USGCRP's U.S. Carbon Cycle Science Program Office is an affiliated office of the Global Carbon Project. ♦

Technicians work on a NOAA buoy equipped with carbon dioxide sensors. Autonomous sensors like these have improved estimations of how much carbon is stored annually by the oceans. (Source: NOAA)

Highlight 4. Natural and Human Emissions in the Tropical Canopy

In addition to being hotbeds of biodiversity, tropical forests are important to Earth's water, energy, and carbon cycles—but they are increasingly impacted by climate change and human activities. Atmospheric chemistry in the once-pristine Amazon Basin, for example, is rapidly changing with deforestation, biomass burning, and pollution related to development in the region.

Like other forests, tropical forests naturally generate and emit volatile organic compounds that can react with other elements to form aerosols, or fine particles suspended in the atmosphere. A multi-year observational campaign was recently deployed in the Amazon Basin to study interactions between tropical ecosystems, aerosols, clouds, and precipitation under clean conditions, as well as how such interactions are influenced by pollutant outflow from the tropical megacity of Manaus, Brazil. The observational campaign, which is jointly sponsored by DOE, NSF, and two Brazilian organizations, used ground-based and aircraft platforms to gather extensive environmental observations. A Fourier transform spectrometer deployed for the experiment will serve a double purpose as an important Southern Hemisphere validation point for measurements from NASA's OCO-2 satellite.

A surprising early result from the campaign is that organic aerosols appear to partially shift between liquid and solid phases with the extent of the pollution, potentially affecting both cloud formation and atmospheric chemistry. Longer-term expected results include better models of fast-reacting atmospheric chemistry within the tropical forest canopy; deeper knowledge and improved modeling of interactions between biogenic emissions, human-generated pollutants, and meteorological factors; and a better understanding of how these interactions affect cloud and precipitation lifecycles. ♦

The observational campaign in the Amazon Basin measures key environmental variables, including light and temperature, that drive biogenic emissions of volatile organic compounds from the canopy. (Source: NASA/JPL-Caltech)

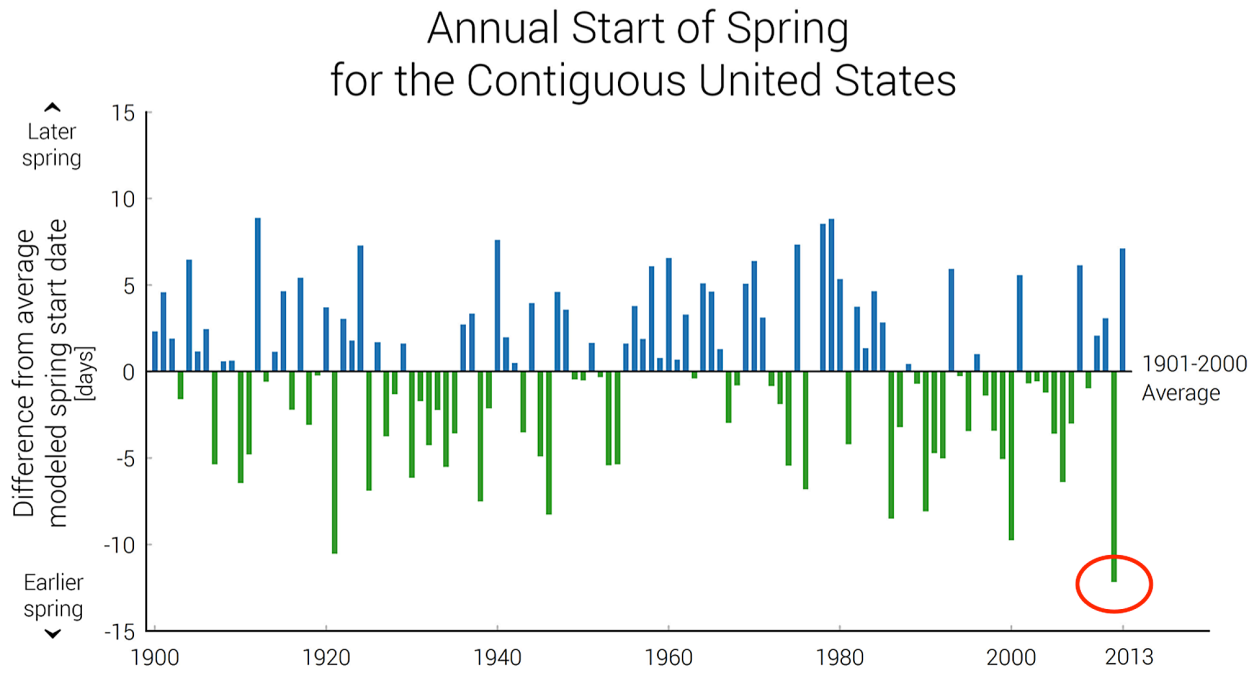
Highlight 5. The Record-Setting Early Spring of 2012

In 2012, spring came earlier for the contiguous United States than in any year since 1900, according to recent research[16] by a team of scientists with the USA National Phenology Network (USA-NPN). This research used the USA-NPN suite of "spring indices"—or algorithms based on the accumulated warmth needed to initiate growth in temperature-sensitive plants, which are validated by nationwide historical observations of lilac and honeysuckle growth. USA-NPN is sponsored by multiple Federal entities affiliated with USGCRP—including NSF, NASA, NOAA, DOE's Oak Ridge National Laboratory, and DOI's National Park Service (NPS), U.S. Fish and Wildlife Service (FWS), and USGS—in addition to academic and non-governmental organizations (NGOs).

Satellite measurements of vegetation "greenness" show that the cumulative effects of the unusually early 2012 spring were most pronounced across the Corn Belt, the western Great Lakes region, and the northeastern United States. The potential benefits of the early start to the growing season were reversed by late frosts in April, producing a so-called "false spring" that damaged fruit trees across the Upper Midwest and Great Lakes regions.

USA-NPN's research demonstrates the need for sustained monitoring to identify emerging environmental changes that might be missed without a long-term data record. Other long-term datasets covering different geographical ranges—such as the Northern Hemisphere and the western United States—have documented advances in the start of spring in response to increased temperatures.[2] Coupled with satellite observations of vegetation growth, indicators like the spring indices will become increasingly important for determining how climate change may affect seasonal patterns, and for tracking related impacts on ecosystems, natural resources, and the agricultural sector. ♦

This graph shows the number of days by which the start of spring in each year differs from the average start of spring during the 20th century. The spring of 2012 (circled) set a record for earliest start. (Source: Adapted from the USGCRP indicators pilot, with data from USA-NPN and NOAA NCDC)



Highlight 6. Soil Carbon Storage: A Big Role For Microorganisms

The majority of terrestrial (land-based) carbon is stored in soil. With changes in climate and land use, understanding this key player in the carbon cycle is increasingly important. In October 2014, a group of scientists from 13 countries gathered in South Carolina for the Sixth International Workshop on Soil and Sedimentary Organic Matter Stabilization and Destabilization (SOM6). Participants engaged in focused discussions and shared results from research funded by USDA, NSF, DOE, USGS, and NOAA, among other sources. USDA's National Institute of Food and Agriculture was a major supporter of the workshop, allowing participation from many students and post-doctoral researchers who otherwise would not be able to attend.

Microbes living in the soil, which play an important part in carbon storage, are affected by farming practices.

An important thread that has surfaced within the research community involved in SOM6 is the understanding that carbon storage is mediated by microorganisms (microbes) living in the soil, which in turn can be influenced by land management practices and plant biodiversity. For example, USDA-funded research at Michigan State University's Kellogg Biological Station (an NSF Long-Term Ecological Research site) found that soil accumulated significantly more carbon under organic farming conditions than under conventional farming practices—even though organically farmed soils may be tilled more frequently and may receive less carbon from plant residues. This counterintuitive finding is attributed to the higher biomass, activity, and growth efficiency of microbes in organic sites, a difference associated with higher biodiversity among the plants being grown. Moreover, long-term datasets from grassland ecosystems showed that higher biodiversity resulted in more carbon reaching the microbial communities that live around plant roots, increasing both microbial activity and soil carbon storage. Altogether, this suggests that ecosystem properties favoring the abundance, diversity, and activity of microbial communities are important to maximizing carbon storage in soil. ♦

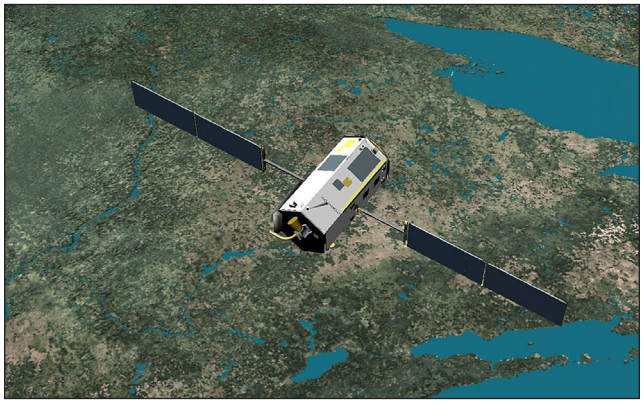
Highlight 7. Observations to Improve Climate Models

The 2012–2021 Strategic Plan emphasizes the need for synergy between Earth observations and Earth system modeling—two cornerstones of global change research. Obs4MIPs (or Observations for Model Intercomparison Projects) is an emerging activity that uses observations to better support the Coupled Model Intercomparison Project (CMIP), an international effort under the World Climate Research Program (WCRP) that coordinates experiments across climate modeling centers and delivers research for major assessments. Conceptualized at a 2010 meeting organized by NASA and DOE,[17] Obs4MIPs now bridges essential components of major observational and modeling programs.[18] NASA's Jet Propulsion Laboratory provides leadership in satellite observations, while the DOE-supported Program for Climate Model Diagnosis and Intercomparison at Lawrence Livermore National Laboratory (LLNL) contributes expertise in the technical aspects and observational needs of CMIP.

Obs4MIPs currently focuses on an important, achievable, and otherwise unaddressed objective: providing researchers with the observational data most needed for evaluating climate models, in a format that enables direct comparisons with CMIP model output. Specifically, each Obs4MIPs dataset is formatted according to the latest CMIP requirements and corresponds to a model output field in one or more CMIP experiments. This technical alignment of observational products with model output makes it possible to more effectively compare, evaluate, and ultimately improve climate models. With contributions from NOAA, the European Space Agency, and other new partners, along with guidance from the WCRP Data Advisory Council, Obs4MIPs is growing into a larger, more international enterprise. Efforts are now underway to coordinate the advancement of Obs4MIPs with the next phase of CMIP. ♦

Highlight 8. Evaluating U.S. Earth Observations

Civil Earth observations support key public services, long-term research, scientific discovery, and technological innovation. The Federal Government makes significant investments each year in civil Earth observations and data across multiple agencies, in addition to utilizing investments made by academia, industry, and state, local, and tribal governments. Planning and evaluation are critical to ensure that these investments lead to Earth observations that are streamlined, effective, and immediately useful.



NASA's Orbiting Carbon Observatory-2 satellite (above) was a landmark 2014 addition to the U.S. portfolio of Earth observing systems. (Source: NASA)

Building on the 2013 National Strategy for Civil Earth Observations,[19] the White House Office of Science and Technology Policy (OSTP) recently released the National Plan for Civil Earth Observations[20] with support from the interagency U.S. Group on Earth Observations (USGEO), which leverages expertise from USGCRP agencies. The Plan delivers a blueprint for maximizing the potential of Earth observations to help protect life and property, stimulate economic growth, maintain homeland security, and advance scientific research and public understanding—while taking into account fiscal and programmatic constraints. The Plan also stresses the improvement of data access, management, and interoperability, particularly with respect to Federal efforts such as the Climate Data Initiative and the Climate Resilience Toolkit (see *Section 2.2*).

The next step is the 2016 National Earth Observation Assessment (EOA 2016), which will build on its 2012 predecessor to evaluate the U.S. portfolio of Earth observations and consider how it benefits society in various areas of concern, including climate. Led by USGEO, with USGCRP contributions through agency expertise and shared working group membership, EOA 2016 will assess existing systems and provide insight into future research and data needs. The ultimate goal of this effort is to inform policy and budget decisions across the Federal Government for a robust, cost-effective national Earth-observing capacity. ♦

Highlight 9. Building Synergy in the U.S. Modeling Community

Modeling Earth's climate furthers priorities of national interest, from experimental research to understand the Earth system to operational forecasts and projections that inform decisions. Coordination among the Nation's premier modeling centers—particularly between experimental and operational programs (see also *Highlight 31*)—has the potential to advance forecasting capabilities, yield more robust predictions, and bridge models of near-term weather and longer-term climate that currently are separated by high-uncertainty gaps in coverage.

In February 2015, responding to a National Research Council report,[21] USGCRP convened the first annual U.S. Climate Modeling Summit to bring together scientists from CMIP-class experimental modeling centers and operational prediction centers. Participants included representatives from NOAA's Geophysical Fluid Dynamics Laboratory (GFDL) and National Centers for Environmental Prediction (NCEP); NASA's Goddard Institute for Space Studies (GISS) and Global Modeling and Assimilation Office (GMAO); the Community Earth System Model (CESM), which is hosted by the National Center for Atmospheric Research (NCAR) and funded by NSF and DOE; and the Accelerated Climate Model for Energy (ACME), funded by DOE with participation from eight national laboratories, NCAR, academic institutions, and the private sector.

The Summit facilitated a shared understanding of the distinct and complementary goals, strategies, and capabilities of each modeling center. Participants identified opportunities for better coordination and considered potential outreach opportunities to enhance the understandability and usability of climate model output. A white paper from the Summit on planned collaboration areas was released in April 2015. The Summit will continue to meet formally each year, buttressed by ongoing coordination to advance shared objectives and to accelerate the translation of knowledge and capabilities from research to operations. ♦

The U.S. Climate Modeling Summit brought together representatives from the Nation's major experimental and operational climate modeling programs. Above, Summit participants gather at the NOAA Center for Weather and Climate Prediction. (Source: NOAA)

Highlight 10. Carbon Community Collaboration

The carbon cycle—or the continual flux of carbon through the atmosphere, oceans, soil, and living organisms—is a foundational component of the Earth system that interacts with climate change and human activities. Through USGCRP and its U.S. Carbon Cycle Science Program, Federal agencies are working together and with the scientific community to advance fundamental and applied research in this critical field. Some examples are highlighted below:

- In 2014, NASA, USDA, DOE, and NOAA jointly invested $37 million in 41 new research projects through an interagency solicitation (NASA-ROSES Carbon Cycle Science). These projects will help to answer questions about carbon dynamics at the interface of water and land; in the Arctic, tropics, and high latitudes; in urban, suburban, forested, coastal, and agricultural landscapes; and below ground. Additionally, some projects will focus on synthesizing current research to identify knowledge gaps and provide a basis for future efforts.

- Since its initiation in 2007, the Coastal CARbon Synthesis (CCARS) activity has brought together international researchers to answer questions about how carbon moves through coastal environments in North America. This multi-year collaborative effort culminated in the 2014 CCARS Community Workshop, held at the Woods Hole Oceanographic Institution in Massachusetts, with representation and support from USGCRP agencies including NASA, USGS, NOAA, and NSF. Sixty participants working in different parts of coastal North America distilled near-term science priorities—including observations, modeling, and process studies—which will be summarized in a science plan currently under development.

- NASA's Carbon Monitoring System (CMS) program, as directed by Congress, continues to foster the development of a U.S. carbon monitoring capability that supports scientific research and local and regional management efforts. In addition to NASA, CMS involves significant participation by the U.S. Forest Service (USDA-FS), NOAA, DOE, USGS, academic institutions, and the private sector. Strong collaborations are also in place with USDA's Forest Inventory and Analysis National Program, the interagency SilvaCarbon program, and the United Nations' international Reducing Emissions from Deforestation and forest Degradation (REDD) program. Carbon monitoring and verification prototypes developed through the CMS program have emphasized the exploitation of satellite and airborne observational platforms, computational capabilities, and the inclusion of stakeholder expertise in combination with effective use of commercial off-the-shelf technologies. Significant effort is being devoted to evaluation of these approaches, even as new CMS projects are funded and developed. In the next few years, NASA will continue to strengthen ties with other Federal agencies involved in carbon monitoring, with the goal of collaboratively establishing a capability that fully meets the Nation's needs and provides a model for the world. ♦

2.2. Informing Decisions

From community planning efforts and local business decisions to considerations of national security, people in America and around the world are making decisions to mitigate (reduce) future climate change and adapt (become less vulnerable) to its impacts. USGCRP research creates a strong scientific foundation for informing and enabling such decisions. When considering options to respond to climate and related global change, decision makers need timely, actionable science on potential risks and opportunities (see also *Section 3.4*). Likewise, effective adaptation and mitigation strategies depend on monitoring and understanding how the Earth system responds to these approaches. USGCRP coordinates with producers and users of global change science to understand the decisions stakeholders are facing and to translate research into information, tools, and practices that meet their needs.

In the face of a changing climate, USGCRP is linking decision makers with resources and expertise to support resilient ecosystems (*Highlight 11*), sustainable water resources and utilities (*Highlight 12*; see also *Section 3.3*), improved public health (*Highlight 13*), increased disaster preparedness (*Highlight 14*), and other societal goals. To this end, several USGCRP agencies are contributing to the Administration's Priority Agenda[22] on enhancing climate resilience among America's natural resources—particularly coastlines, wetlands, and forests—and promoting their potential for accumulating and storing carbon. In addition to conserving lands and waters, the Agenda emphasizes the development of science, tools, and strategies to sustain the ecosystem services on which many communities and businesses rely.

A task force of state, local, and tribal leaders, established in 2013 by President Obama, recently provided recommendations[23] for how the Federal Government can support climate preparedness and resilience among American communities. The recommendations affirm the importance of efforts by USGCRP agencies to deliver science-based products and services that are tailored for local and regional needs. The reach and efficiency of this tailored decision-support approach are enhanced significantly by ongoing Federal coordination of regional science centers that serve a range of sectors (*Highlight 15*). Recent efforts also include scenario-driven exercises to empower states and communities with climate information specific to their local conditions (*Highlight 16*).

Finally, as global change research continues to grow and diversify, the demand for trusted, transparent, and systematically managed information is increasing. A major element of USGCRP's response to this need is the Global Change Information System (GCIS), a source of open, discoverable information that can serve a variety of digital platforms. GCIS became operational in May 2014, serving data and metadata related to findings and graphics in the Third National Climate Assessment (see *Section 2.3*). Since then, the scope of service available through GCIS has been growing to meet the needs of Federal agencies. For instance, by working with the international Committee on Earth Observation Satellites, GCIS is able to join Federally held Earth data with contextual information about the instruments and spacecraft used to collect them. This connection provides end-to-end traceability for scientific products that previously was not possible. In addition, efforts are underway to demonstrate how the GCIS information model can support digital components of the President's Climate Action Plan, including the growing Climate Data Initiative and the recently launched U.S. Climate Resilience Toolkit (*Highlight 17*). In the coming year, GCIS will enable greater traceability and transparency for these digital assets, providing paths from the datasets and tools to their underlying scientific foundations.

RECENT HIGHLIGHTS

Highlight 11. Adaptive Action for Fish, Wildlife, and Plants in a Changing Climate

Fish, wildlife, and plants are integral parts of ecosystems that provide jobs, food, clean water, storm protection, recreation, and many other services that benefit society. Observed changes in climate are already impacting these valuable living resources, and projected future changes threaten to displace or eliminate some species. In response to a call from Congress to meet this challenge, a partnership of Federal, state, and tribal agencies released the National Fish, Wildlife and Plants Climate Adaptation Strategy[24] in 2013. The Strategy is a call to action, laying out seven overarching science and management recommendations for a collective response to climate change.

The development of the Strategy was led by FWS, NOAA, and the New York State Department of Environmental Conservation (on behalf of states more broadly). Since its release, agencies have worked across levels of government to promote it as a resource for adaptation planning, to engage stakeholders and conservation partners, and to evaluate progress. Public meetings and webinars reaching hundreds of stakeholders and a recently developed engagement plan are helping to share information and connect new audiences with this important collaborative effort.

A Progress Report[25] released in September 2014 highlighted 50 examples of agencies and stakeholders working together to address the impacts of climate change on fish, wildlife, and plants. These examples demonstrate the diversity of projects, scales of planning, and breadth of partnerships needed to integrate climate change in conservation planning. Over the next year, a forward-looking report on planned activities will provide a more complete picture of how the Strategy is being applied, and its implementation will help to fill critical gaps in research, monitoring, and training. ♦

Case studies in the 2014 Progress Report illustrate how the Strategy is being applied to promote adaptation on multiple scales and in a variety of ecosystems.

Highlight 12. Supporting Resilient Water Resources and Utilities

Water resources in the United States are affected by a number of climate stressors—including increasing temperatures, changing precipitation patterns, and extreme events like storms and droughts—and these changing conditions have implications for drinking water and stormwater utilities. Federal agencies are working with one another and with state and local partners to build preparedness and sustainability in this essential sector. For instance, the Federal Support Toolbox—grown out of an initiative led by the U.S. Army Corps of Engineers (USACE)—serves as a one-stop online portal to databases, tools, best practices, and other resources supporting effective and efficient water management. Information is available from all 50 states, a number of Federal agencies, tribes, NGOs, academia, private industry, and international sources. In addition to USACE, Toolbox partner organizations include state governments, river basin commissions, the Tennessee Valley Authority, EPA, and agencies within DOT, DOI, and USDA.

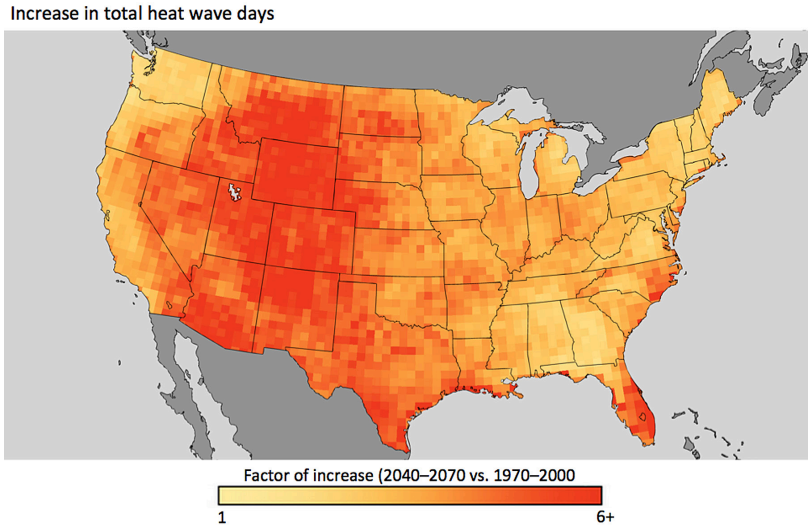
In another example, NASA, NOAA, and the University Corporation for Atmospheric Research recently supported research to develop and test a new statistical indicator of drought. The research, conducted by the University of Texas at Austin in coordination with the Texas Water Development Board, demonstrated that the new drought indicator could outperform the official forecast in predicting summer precipitation. In addition, the research showed that the indicator could have predicted the summer 2011 drought in Texas as early as January of that year—providing critical lead time for the state's water providers to prepare (see also *Highlight 36*).[26]

Lastly, EPA and NOAA recently held a series of workshops with stormwater managers in cities and counties across the Chesapeake Bay and Great Lakes regions. These events initiated conversations about how projected changes in land use and climate might impact local water conditions, and about how planning for resiliency can fit into decision making and help meet existing regulatory requirements. Several takeaway messages emerged from these workshops that can inform future approaches: for example, issues of scale and uncertainty in climate change projections present challenges to local decision makers, but leveraging scenarios and existing historical data can help. In addition, enhanced local-level capacity to plan, design, and implement green infrastructure projects and other strategies for sustainability—plus better information about the long-term costs and (co)benefits—is necessary to effectively integrate such solutions into local stormwater management. Finally, the enactment of resilient management strategies can be spurred by changes in economic conditions, heightened awareness among residents, new regulations, and coordination between agencies and jurisdictions. ♦

Green infrastructure projects, such as this stormwater planter, help to collect and absorb runoff, among other benefits. Local-level capacity and reliable cost-benefit information are needed to effectively incorporate such solutions into stormwater management. (Source: EPA)

Highlight 13. Preparing for the Health Hazards of Extreme Heat

Climate change is expected to increase the number of extremely hot days,[27] posing health risks to vulnerable populations such as the elderly, children, and those with existing cardiovascular and respiratory diseases.[2] To streamline prediction of and adaptation to these events, HHS's Centers for Disease Control and Prevention (CDC) and NOAA held a Heat Health Summit in Silver Spring, MD, in October 2014. The Summit drew participants from across NOAA, CDC, EPA, DOE, and the Occupational Safety and Health Administration; state and local health departments; NOAA-funded cooperative science centers; and international partners including Health Canada, Environment Canada, and the International Association for Urban Climate.



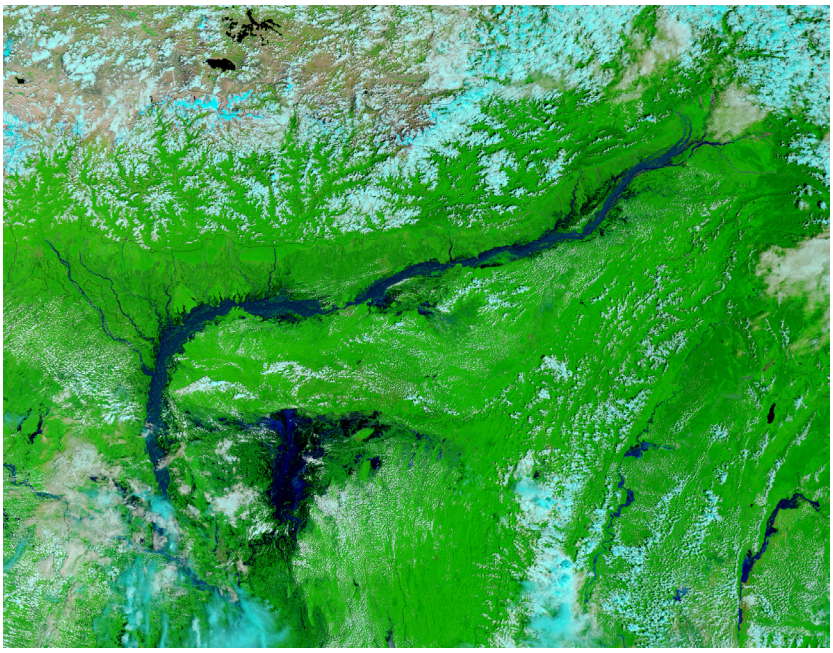
This map shows the number of total heat wave days per summer projected for the mid-21st century, as a factor of increase relative to the end of the 20th century (assuming a scenario of rapid economic growth driven by a balanced portfolio of energy sources). As the occurrence of extremely hot days increases with rising greenhouse gases, meteorologists and public health practitioners have an opportunity to work together to protect communities from heat-related hazards. (Source: NOAA Climate.gov)

The Summit emphasized the importance of partnerships and knowledge sharing between communities of practice in meteorology and public health, driven by a shared interest in protecting people. Summit discussions focused on 1) understanding decision-making contexts, such as the process by which the NOAA National Weather Service issues a heat watch, warning, or advisory; 2) the need for better access to heat-related health data, which is currently limited by privacy issues; and 3) the need for both national consistency and local-scale flexibility in heat forecasting approaches, statistical studies, messaging and outreach efforts, and reporting of heat-related fatalities. Outcomes from the Summit, which are intended to advance cooperation between the meteorology and public health communities include guidance documents for engaging local offices, joint outreach and communications plans, collaborative research to investigate the utility of extended heat forecasts, and a meeting with international partners to compare methods and lessons learned. ♦

Highlight 14. From Space to Village: Satellite Data For Decisions in the Developing World

SERVIR—meaning "to serve" in Spanish—is a joint initiative that connects USAID's expertise in international development and training with NASA's portfolio of satellite observations. Its goal is to help decision makers in developing regions respond to global change. Over the past decade, SERVIR has worked closely with regional organizations in the developing world to provide analytical products and services that inform decisions about climate adaptation and mitigation, disaster risk reduction, water and natural resource management, land use planning, and infrastructure development. Most recently, in October 2014, SERVIR launched a new hub in Asia's Lower Mekong region, which joins regional hubs in Himalaya, Africa, and Mesoamerica to make up a global network.

One of SERVIR's latest efforts to support disaster preparedness focused on Bangladesh, where flooding affects millions of people every year. In the summer of 2014, unusually severe flooding displaced more than 275,000 people and destroyed more than 31,000 homes.{28} An experimental flood forecasting system developed by the SERVIR Himalaya hub used altimeter data from the Jason-2 satellite to accurately predict the flooding eight days in advance—the longest lead time ever for a flood forecast in Bangladesh. Previously, forecasts and warnings were only available 3–5 days in advance because of reliance on conventional ground-based networks, which don't extend into countries upstream from Bangladesh. The efficacy of the satellite-based flood forecasting approach led to a recent decision by Bangladeshi officials to expand it for nationwide operational use in 2015. The new Mekong hub will look to this and other SERVIR success stories to bring similar tools to bear in Southeast Asia. ♦



In the summer of 2014, heavy monsoon rains combined with the arrival of meltwater from the Himalayas to cause unusually severe flooding in parts of Bangladesh (shown above: the flooded Brahmaputra River valley and Tanquar Haor wetlands). SERVIR's flood forecasting system, which uses altimeter data from the Jason-2 satellite, accurately predicted the flooding eight days in advance and is now being expanded for nationwide operational use. (Source: NASA Terra-MODIS)

Highlight 15. Regional Science Networks for Climate-Smart Decision Making

Climate change affects every region of the United States differently, and no single Federal program can tackle the full range of regional decision-support needs. Coordination at the regional scale is vital to ensuring that Federally supported science and risk management efforts best meet the information requirements of decision makers in a variety of sectors. USDA, NOAA, and DOI individually support a portfolio of complementary regional networks that deliver climate science and tools to public officials, agricultural producers, natural resource managers, and other stakeholders:

- USDA's Regional Climate Hubs, launched in 2014, package and convey scientific information to help farmers, ranchers, and forest landowners manage the region-specific impacts of climate variability and change.
- NOAA's regional climate partnerships provide science-based products and support partnership-building efforts for government entities at all scales seeking to manage climate risks. These efforts include, among others, the research-oriented Regional Integrated Sciences and Assessments (RISA) program and the NCDC Regional Climate Centers that focus on operational products and services.
- DOI's Climate Science Centers (CSCs), managed through USGS, supply resource managers in the public and private sectors with tools to monitor, anticipate, and adapt to climate impacts on natural and cultural assets. In addition, the FWS-managed Landscape Conservation Cooperatives are a network of 22 public–private, applied conservation science partnerships that deliver information and develop strategies to ensure the sustainability of natural and cultural resources. These two DOI networks are major components of a broader climate science and conservation initiative.

Federally coordinated regional science centers work individually and together on projects that support tangible outcomes in their regions. For example, Western Water Assessment (WWA, a NOAA RISA team) is partnering with the DOI North Central CSC on a collaboration also involving The Nature Conservancy and its regional partners in the Gunnison Basin, San Juan Mountains, and Four Corners areas. WWA scientists are producing narrative scenarios of future climate change that the regional partners can use to develop climate-adaptive strategies for land conservation—such as the sagebrush habitat restoration project shown above. (Source: B. Neely, The Nature Conservancy)

These and other Federally coordinated regional networks (for example, EPA's regional offices, USDA-FS's research stations) rely on strong partnerships between scientists and information users. Growing Federal support and interagency coordination for regional activities will help to better connect decision makers nationwide with the comprehensive, reliable information they need to capitalize on opportunities and manage risks associated with climate change. ♦

Highlight 16. Empowering States and Communities with Climate Science

In the fall of 2014, several USGCRP agencies and National Coordination Office (NCO) staff supported the Climate Change Preparedness and Resilience Exercise Series, a suite of daylong workshops targeted at state- and local-level decision makers. This initiative was sponsored by the National Security Council, the Council on Environmental Quality, and OSTP, in collaboration with the Federal Emergency Management Agency's (FEMA's) National Exercise Division. Exercises in this pilot series focused on the Houston-Galveston area of Texas, the Hampton Roads area of Virginia, and the States of Colorado and Alaska.

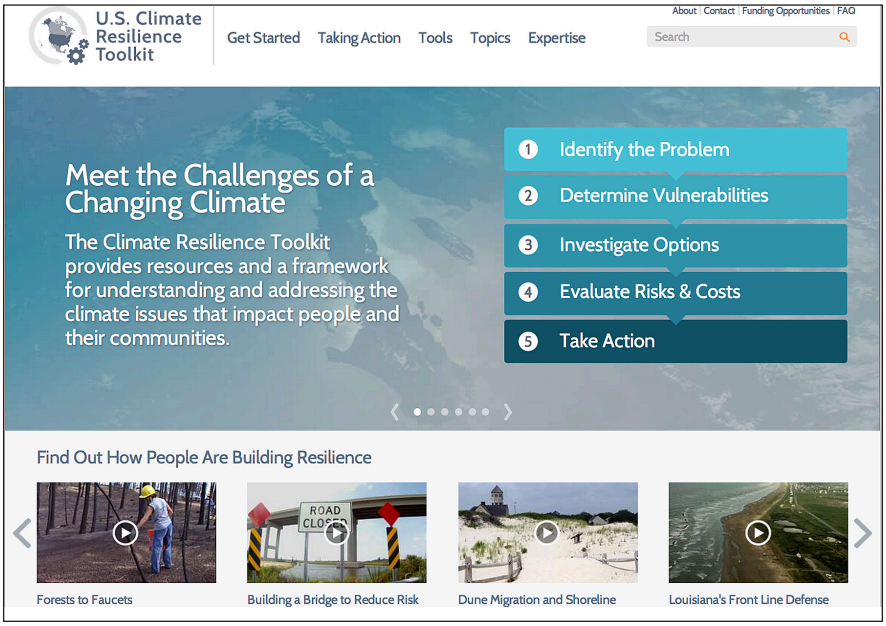
Each exercise used the Third National Climate Assessment as a basis for discussing regional climate impacts, with local expertise supplying additional context on issues of particular concern for each area—such as sea level rise and recurrent flooding in Hampton Roads, or dwindling water resources in Colorado. Exercise participants—including public officials from the local, state, and Federal levels as well as partners from the private sector, NGOs, and academia—worked through regionally tailored scenarios to consider the effects of climate change, the associated challenges and opportunities, and specific immediate actions to plan for or mitigate the impacts projected for their children's and grandchildren's lifetimes. As a whole, the exercises served to advance the dialogue on climate adaptation in each location, seeding ongoing efforts to collaboratively and sustainably build adaptive capabilities at the community level. ♦

Highlight 17. A Toolkit for Climate Resilience Nationwide

The Administration launched the U.S. Climate Resilience Toolkit in November 2014, with support from the coordinated efforts of various USGCRP agencies—especially NOAA, USGS, USDA, NASA, USACE, and HHS (CDC and the National Institute of Environmental Health Sciences). The Toolkit aims to help communities, businesses, natural resource managers, and others plan for and respond to the impacts of climate change where they live. As called for in the President's Climate Action Plan, the Toolkit provides decision makers with easy access to information ranging from which neighborhoods are likely to be flooded by storm surge as sea levels rise to how future drought conditions could affect regional crop growth. The Toolkit also features more than 20 case studies demonstrating how decision makers have used this information to build resilience.

Elements of the Toolkit include the Climate Explorer, a visualization tool that offers customizable maps of climate stressors, impacts, and historical information; a five-step process for developing and implementing projects to enhance resilience to climate-related hazards; and centralized access to Federal resources for accessing and analyzing climate data, estimating hazards, and engaging stakeholders in resilience-building efforts. The Toolkit currently encompasses the topics of coastal flood risk, food resilience, ecosystem vulnerability, water resources, and human health. In the future, it will be expanded to address additional topics such as transportation. ♦

The U.S. Climate Resilience Toolkit features science-based resources and real-world case studies to help communities adapt to climate change.



2.3. Assessing Change

Assessments—or syntheses of current scientific understanding—help scientists and decision makers anticipate likely changes, evaluate information for decision support, and pinpoint knowledge gaps and needs. Assessments are an integral part of the USGCRP enterprise: the Program is Congressionally mandated to conduct a National Climate Assessment (NCA) every four years and to coordinate Federal participation in international assessments, such as those led by the Intergovernmental Panel on Climate Change (IPCC).

In May 2014, USGCRP delivered the Third National Climate Assessment,[2] a report developed over four years by hundreds of technical experts within and outside the Federal Government. The Third NCA was informed by peer-reviewed results of research investments made by USGCRP agencies, as well as by extensive public input gathered through town hall meetings, public comment opportunities, and technical workshops across the country. Available in downloadable and digitally interactive formats, the Third NCA is the most comprehensive, authoritative, and transparent report to date on the current and projected future impacts of climate change in the United States. Its release garnered nationwide attention from the media, the scientific community, educators, policy makers at every level of government, and stakeholders in a range of sectors. Through cooperation among Federal agencies, NCA authors, and a network of partner organizations (NCAnet), the reach and usability of the Third NCA continues to grow (*Highlight 18*). In addition, plans are developing for an evaluation that will inform improvements in the process and outcomes of the next quadrennial report (*Highlight 19*).

USGCRP is currently implementing a sustained National Climate Assessment process to enable more efficient and effective production of quadrennial reports and to provide timely information to decision makers on an ongoing basis. Agencies are fostering the development of tools and data products to support this effort. For example, NOAA has supported the prototyping of a national climate indicators system (currently in pilot phase) that would unite and build on efforts from across several USGCRP agencies. NASA and NOAA have invested in the initial development and testing of indicators through competitive research solicitations, and a new NASA competition will fund the development of climate indicators and data products for future National Climate Assessments. Further, a number of USGCRP agencies are collaborating to develop and refine scenarios of changing climate, population, and land use dynamics that can inform ongoing assessment activities (*Highlight 20*).

Another cornerstone of the sustained assessment process is the production of interim special reports on key topics: USDA is spearheading an interagency report about the effects of climate change on food security and the U.S. food system; the U.S. Forest Service is preparing a series of technical syntheses about drought, agroforestry, and non-timber forest products; and HHS, NOAA, and EPA are leading a USGCRP assessment of climate impacts on human health (*Highlight 21*). These interim activities enable new information and insights to be synthesized and shared as they emerge. They will provide substantive technical input to the next quadrennial NCA report.

At the international level, USGCRP continues to ensure that U.S. research is integrated with global assessment efforts, particularly the IPCC Fifth Assessment Report (AR5),[29] which was completed in 2014. USGCRP supported U.S. participation in AR5 and helped to coordinate a transparent and comprehensive U.S. review process that set the benchmark for the rest of the world. The Program also made possible the development and release of the Working Group II contribution to AR5, which focuses on climate impacts and adaptation (*Highlight 22*). Other recent international assessment activities include (among others) coordinating U.S. review of the United Nations (UN) World Ocean Assessment, engaging closely with the Arctic Monitoring and Assessment Programme's Adaptation Actions for a

Changing Arctic (AACA) project, and supporting targeted efforts by international research programs to assess the impacts of global change in developing regions (*Highlight 23*). Scientists affiliated with and supported by USGCRP agencies continue to play key roles in the development of major international assessments as lead authors, editors, working group co-chairs, and reviewers who provide technical support and expertise. Moreover, research supported through USGCRP provides significant contributions to the scientific foundations for these assessments.

RECENT HIGHLIGHTS

Highlight 18. Beyond the Report: Extending the Reach of the National Climate Assessment

The Third National Climate Assessment has provided a basis for understanding change, informing decisions, and communicating about climate, not only on a national scale but also at the regional, state, and local levels. For example, a number of USGCRP agencies are incorporating the Third NCA into their regional-scale science and decision support programs (see related *Highlight 15*). NOAA and partners have developed regionally tailored guides based on the Third NCA for educators teaching climate (see related *Highlight 25*). USGCRP supported a series of scenario-driven exercises that used the Third NCA, in combination with local expertise, to open conversations with state- and local-level stakeholders about shifts in their regional climate (see related *Highlight 16*). In addition, participants in the NCA process—including NCA authors, staff from the USGCRP NCO, and Federal agency representatives—have engaged with a variety of audiences through more than 100 events and opportunities since the report's release. Examples include conference talks and panel discussions, regional and sectoral events, Federal and Congressional outreach, and professional development webinars.

The usability of the Third NCA is also being enhanced through access to its underlying information. For instance, NOAA's NCA Technical Support Unit (TSU) recently packaged the datasets and metadata associated with graphics in the report and made them publicly available online in multiple formats. The NCA TSU has also responded to a number of requests for NCA climate data, with example requests including downscaled temperature and precipitation data for CDC; observed temperature and precipitation data for the New York Times; frost-free season image files for Farm Journal Media; and temperature, precipitation, and soil moisture data covering various regions for research being conducted at Syracuse University. Finally, the NCA TSU is responding to growing interest in state-level information by developing summaries of observed and projected climate change on a state-by-state basis. This effort will begin with six example summaries, one from each of the NCA regions, ranging from 2 to 4 pages each. Summaries for all 50 states are expected to be available by fall 2015. ♦

Highlight 19. The NCA in Review: Frameworks for Evaluation

When the Third National Climate Assessment was released in May 2014, it made headlines in national and international media, local news outlets in every region of the country, and Federal, NGO, academic, and trade publications. The thousands of stories, blog posts, op-eds, and even comedy shows that have mentioned the Third NCA attest to its expansive reach, suggesting that the report is both in demand and accessible. But how can its success be measured, and how can that success be improved upon in the next quadrennial NCA?

As a first step in answering these questions, USGCRP held a workshop in June 2014 to gain input on frameworks and methodologies for evaluating the Third NCA. The workshop's 70 participants represented Federal agencies, NCA authors, the NCA and Development Advisory Committee (NCADAC), the USGCRP NCO, NOAA's NCA TSU, the National Climate Assessment engagement

network (NCAnet), users of the NCA, and evaluation experts. A report[30] summarizing the workshop discussions and outcomes was released in December with a set of overarching principles that will guide the development of an evaluation plan. Ultimately, evaluation results will inform USGCRP decisions about the sustained assessment process and the next quadrennial report, including how to embed evaluation into the process going forward. ♦

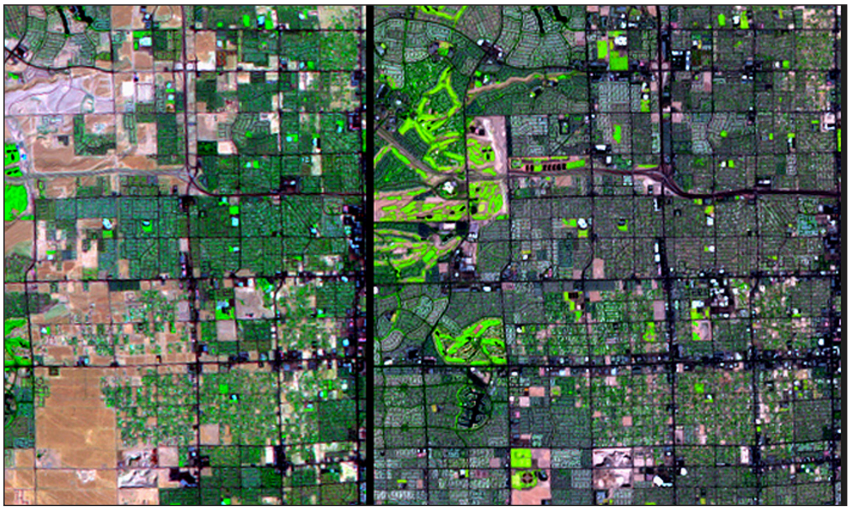
Participants in a brainstorming activity consider approaches for evaluating the Third NCA. (Source: B. Golden-Chen, USGCRP NCO)

Highlight 20. Scenarios of Change for Sustained Assessment

Scenarios are descriptions of plausible future conditions—either narrative or quantitative—that provide a basis for analyzing potential impacts of and responses to global change. Scenarios are not predictions or forecasts; rather, they are tools to understand how future conditions might evolve under a range of possible decisions. By providing detailed examples of how different factors could change and interact, scenarios constrain uncertainty and offer valuable input for assessments. USGCRP is working toward scenarios of change that can feed into the sustained assessment process and support the needs of scientists and stakeholders.

In June 2014, USGCRP convened two workshops, respectively focused on developing scenarios for changes in U.S. demographics and land use/land cover—both of which have the potential to interact with climate change. These workshops brought together modelers and scenario users to identify critical uncertainties in projections; key natural, socioeconomic, and policy variables to consider; and capabilities (or gaps therein) to produce long-term projections for future research and decisional needs. Resources and presentations from both workshops and a report[31] from the land use/land cover workshop are available online. The demographics workshop report is expected in 2015.

Looking ahead, a NOAA technical report expected in 2015 will compare climate projections for the United States from the third and fifth phases of CMIP, with an in-depth analysis of temperature and precipitation projections from the latter. This report will deliver a suite of climate model datasets that can be leveraged in the development of scenarios for the next quadrennial National Climate Assessment. In addition, USGCRP recently convened a workshop to facilitate interagency dialogue around the subject of downscaled climate projections; this workshop served as an early step in a broader suite of planned activities that will collectively inform future assessments and provide a focal point for technical expertise on climate projections. ♦



Land cover change, such as the rapid urban expansion of Las Vegas shown above (left: 1992; right: 2013), interacts with climate change in complex ways. Scenarios can be used to understand and plan for the plausible permutations of these and other interacting processes in the Earth system. (Source: USGS Landsat)

Highlight 21. Assessing the Public Health Risks of Climate Change

With leadership by EPA, NOAA, and HHS agencies including CDC and the National Institutes of Health (NIH), USGCRP is continuing development of its Climate and Health Assessment, a contribution to the sustained assessment process that will support the next quadrennial NCA report. The USGCRP Climate and Health Assessment will address the need for a more definitive understanding of climate impacts on public health, as called for in the President's Climate Action Plan. It will synthesize the available scientific literature to assess the observed and projected impacts of climate change on human health in the United States, with a particular focus on where impacts can be quantified. Topics such as weather and climate extremes, air quality, vectorborne disease, water- and food-related issues, and mental health and wellbeing will be covered. In addition, a chapter will be devoted to risks facing vulnerable segments of the U.S. population, such as children, the elderly, and people with existing health conditions. Similar to the Third National Climate Assessment, the findings of this report will be fully traceable and documented by detailed metadata through USGCRP's Global Change Information System (see *Section 2.2*).

Over the past year, and through a thorough scoping process that included opportunities for public input, the report's prospectus was finalized and made available online. In spring 2015, a Federal Register Notice was issued soliciting public comments on the draft report over a 60-day period. Concurrently with the public review, the report is undergoing peer review by the National Research Council. Expected to be released in 2016, the USGCRP Climate and Health Assessment is intended to inform public health officials, urban planners, and other stakeholders at multiple levels of government who are interested in better understanding the health hazards presented by climate change. ♦

Highlight 22. A Comprehensive Look at Climate Risks and Responses Worldwide

Following on a draft edition released in March 2014, the Working Group II (WGII) of the IPCC recently delivered its full contribution to AR5, the IPCC's latest authoritative global assessment of climate change. The product of years of work by leading experts from around the world, the WGII contribution is a thorough examination of the worldwide impacts of climate change and the opportunities for response. It is organized into two report volumes: 1) a global-scale assessment of impacts, risks, and adaptation options for economic sectors, human activities, and ecosystems,[32] and 2) a regional perspective that considers unique geographical and cultural aspects of major world regions.[33]

The release of the full contribution from WGII includes the final versions of the report, the cross-chapter materials, the technical summary, and the summary for policy makers (previously released as drafts). New materials in this release include high-resolution graphics, frequently asked questions, and process information such as early drafts and thousands of searchable comments from reviewers. The process information provides a complete and transparent view of how the author teams evaluated and addressed comments, verified facts, and reassessed interpretations; it also demonstrates the breadth and depth of input from across the international scientific community. This comprehensive release was made possible through coordination by the IPCC WGII Technical Support Unit, which is hosted and funded by USGCRP. ♦

Among many other impacts, the IPCC WGII report finds that the fraction of the world's population affected by major river floods will increase as the climate warms. Overall, the report concludes that the world is largely ill-prepared for the climate impacts that are already occurring globally; however, there are opportunities to respond with effective action.

Highlight 23. Urban Agriculture and Food Security: A Nine-City Assessment

Food security is a critical challenge in rapidly urbanizing, low-income regions of the world. Climate change is likely to increase disruptions to food availability and prices, further exacerbating food insecurity for the urban poor. Urban and peri-urban agriculture (UPA) can serve as an important food source for cities in the developing world, contributing to dietary diversity and economic activity. However, UPA systems are stressed by factors such as rapid urban growth, weak governance over land and water allocation, and pollution. Moreover, the potential of such systems to meet food security needs under changing climate conditions is not well understood. With support from USAID, USGCRP international funding, and international partners in research and policy, START (the global change SysTem for Analysis, Research, and Training) recently led an assessment effort focused on UPA and climate change in nine cities across Africa and South Asia.

The assessment reports examine UPA in the context of intensifying climate risks and increasing urban pressures on land and water resources, with the objective of identifying how these two drivers may interact to undermine long-term sustainability for UPA systems. This assessment effort employed a highly participatory approach to engage local stakeholders and was carried out by interdisciplinary teams of researchers in Dakar (Senegal), Tamale (Ghana), Ibadan (Nigeria), Dar es Salaam (Tanzania), Kampala (Uganda), Addis Ababa (Ethiopia), Dhaka (Bangladesh), Kathmandu (Nepal), and Chennai (India). The assessment reports are intended to better inform city-based decision making about risk management for UPA, with direct implications for advancing broader planning efforts on urban adaptation and resilience. ♦

A farmer works a plot in Accra, Ghana. Agriculture in urban and peri-urban (or urban–rural transition) zones can contribute to food security for cities in the developing world, but UPA systems face pressure from the impacts of urbanization and climate change. (Source: R. Kahane, GlobalHort)

2.4. Communicating and Educating

Effectively addressing the impacts of global change depends on an engaged, well-informed public and an appropriately trained workforce. As the Federal Government's scientific authority on this subject, USGCRP is ideally positioned to deliver credible communication, education, and capacity-building products and programs. USGCRP promotes public understanding through the dissemination of timely and trustworthy news and information, helps to coordinate educational initiatives across multiple agencies, and supports training to develop the scientific workforce of the future.

Several USGCRP agencies, for example, are capitalizing on their individual strengths in an array of complementary efforts to advance climate literacy, education, and training in the United States (*Highlight 24*). In addition, through partnerships with the education community, NOAA has developed resources for educators based on regional information in the Third National Climate Assessment, helping to frame climate change in the meaningful context of impacts that students may have witnessed in their home areas (*Highlight 25*).

USGCRP also uses outreach and dialogue to understand the public's information needs, connect with diverse audiences, and encourage public engagement around the issue of climate change. For instance, USGCRP employs an engagement strategy for the National Climate Assessment that leverages technical capacity throughout the United States while ensuring that the NCA process and products are useful to stakeholders and general audiences. USGCRP is exploring how crowdsourcing approaches can help to track climate change in support of the NCA, cultivating a stronger connection between people and their natural surroundings at the same time (*Highlight 26*). USGCRP agencies are also actively working to build partnerships in emerging areas of program engagement, such as the public health community of practice (*Highlight 27*) and the philanthropic sector (*Highlight 28*).

RECENT HIGHLIGHTS

Highlight 24. Toward a More Climate-Literate America

USGCRP agencies are at the center of a new initiative to advance climate education, literacy, and training in the United States. Led by OSTP, the interagency Climate Education and Literacy Initiative aims to connect students and citizens with the best-available scientific information about climate change. Agencies will apply their individual expertise to this unified Federal effort—for example:

- The National Park Service will develop a national interpretive plan to assist employees, volunteers, and other partners in effectively conveying climate change concepts to Park visitors.
- NOAA and partners will leverage interactive media, bringing together game developers, scientists, and educators to create new prototypes that allow students to learn about climate change through engaging, science-based gaming experiences.

Students gather around Science on a Sphere, an educational tool that displays and animates Earth data on a globe. The Climate Education and Literacy Initiative will harness innovative approaches like this one to build awareness and understanding among the American public. (Source: NOAA)

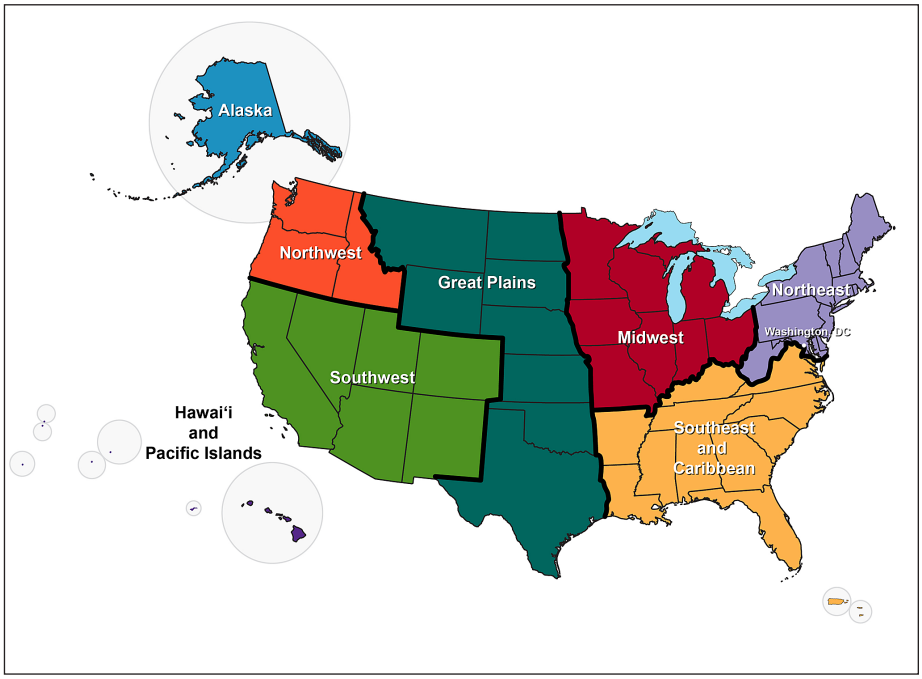
- An online video series will highlight each of the principles in DOE's Energy Literacy Framework.
- New training courses organized by the Office of Personnel Management, EPA, NOAA, DOI, and USACE will equip Federal senior executives with the information and skills they need to address climate change through their programs.
- Regional workshops sponsored by NOAA and an online professional development series produced by NASA (in collaboration with NPS and FWS) will connect formal and informal educators with the findings of the Third National Climate Assessment and other climate research undertaken by USGCRP agencies.

These Federal efforts will be complemented by a number of commitments from external partners in formal and informal education, including academic groups, educator associations, museums, zoos, and foundations. The Initiative ultimately seeks to foster a climate-smart citizenry and a next-generation workforce of planners, community leaders, engineers, and entrepreneurs who understand climate-related challenges and are equipped with the knowledge and training to find solutions. ♦

Highlight 25. Teaching Climate Where We Live

Although global climate change can be challenging to grasp as a seemingly abstract concept, connecting it to concrete impacts that are recognizable within a familiar region can be an effective approach for understanding and learning. The Third National Climate Assessment offers a wealth of accessible information about climate effects, risks, and response strategies at the regional scale. Capitalizing on this, NOAA, the NCAnet Education Affinity Group, and members of the Climate Literacy and Enery Awareness Network (CLEAN) have published a series of guides to help educators teach climate using the regional information in the Third NCA.

The tailored guides unpack key messages for each of the ten U.S. regions covered in the report (including coasts and oceans), allowing educators to home in on the impacts of climate change where they and their students live. Each key message is supported by guiding questions, graphics from the report, lesson plans, videos, and related web-based resources. The guides also demonstrate how the Third NCA can be applied to the integration of Next Generation Science Standards in science education, with an accompanying overview and specific examples that can be applied at the middle school and high school levels. ♦



The educational guides are tailored to each region of the country shown above, as well as coasts and oceans. (Source: The Third National Climate Assessment, 2014)

Highlight 26. Crowdsourcing Climate: Citizen Science and the National Climate Assessment

Citizen science—or the engagement of volunteers in scientific investigations—is a fast-growing field. By collecting data on natural phenomena such as the timing of bird migrations and plant flowering—sometimes from their own backyard—citizen scientists provide essential baseline information about key environmental indicators, in addition to strengthening their own awareness of and connection to their local environment. Citizen science has long been an important component of scientific endeavors and public engagement at USGCRP agencies such as DOI (particularly NPS and USGS), EPA, NOAA, NASA, NSF, and SI. As such, it presents a powerful opportunity for engaging the public in the sustained National Climate Assessment (see *Section 2.3*).

In cooperation with the Woodrow Wilson Center for International Scholars and the Federal Community of Practice for Crowdsourcing and Citizen Science, USGCRP recently held a public roundtable and an expert workshop to explore how citizen science can help to track indicators of climate change and shape indicator products. At the roundtable, leaders in the field from USGCRP agencies and from outside the government contributed to a panel discussion that addressed questions about public participation in science from the international scale to the K–12 level. The subsequent workshop afforded a hands-on opportunity to tackle practical questions about incorporating citizen science into climate indicators, and how the two can be used together to help a range of audiences better understand climate change. A synthesis of these discussions was shared at the inaugural Citizen Science Association Conference in February 2015. A workshop report, to be released later this year, will serve as input to the sustained assessment process. ♦

Citizen science refers to the engagement of non-professional volunteers in scientific investigations—asking questions, collecting data, or interpreting results. This approach can be especially useful in tracking environmental changes. (Source: NPS)

Highlight 27. Connecting With the Public Health Community of Practice

USGCRP has become a crossing ground for Federal health communities considering the risks of climate change. To expand the reach of this engagement within and beyond the Federal Government, USGCRP agencies supported a number of outreach events over the past year focused on climate and health (see related *Highlight 13*). As one example, USGCRP engaged a broad spectrum of health stakeholders around the release of the Third National Climate Assessment, disseminating key messages about health impacts through various networks, sharing supplementary resources, and highlighting findings at health-related workshops and conferences (see related *Highlight 18*). USGCRP also contributed to a July 2014 public workshop to explore the intersection of children's environmental health and climate change. The workshop brought together senior leadership from HHS, EPA, the Department of Housing and Urban Development (HUD), and CEQ, along with six expert panels, to discuss climate-related health risks to children in areas such as air quality, heat and other extreme weather, vector- and waterborne disease, and food safety and security.

Also in 2014, HHS held its first-ever all-hands briefing on climate change, with presentations by USGCRP participants from CDC, NIH, and NOAA. The briefing encompassed a national perspective on climate change, regional snapshots of impacts, and best practices to build health resilience in communities. USGCRP hosted a town hall at the 2014 American Public Health Association Annual Meeting, assembling researchers, stakeholders, and policy makers to discuss a broad range of intersections between climate and health. Agency representatives provided updates on relevant Federal initiatives and tools, and a panel of Federal grantees described their research, communication, and adaptation data needs to stimulate a group discussion. Activities such as these allow USGCRP to connect diverse communities of practice for a stronger response to the health-related challenges of climate change. ♦

Highlight 28. Engaging the Philanthropic Sector to Meet Climate Challenges

Philanthropic organizations can play a pivotal role in how communities strategize around education, housing, transportation, public health, and other social issues that link to the environment. These organizations are in a unique position to build synergy between Federal, local, and private efforts to improve climate literacy and help communities minimize and prepare for the consequences of climate change. As part of an ongoing tri-agency collaboration, program managers from NSF, NOAA, and NASA have been acting as government liaisons in bi-monthly meetings with the Council on Foundations (COF), a consortium of approximately 1600 philanthropic groups and corporate-giving programs in the United States and abroad. As a result of these discussions, COF and the three agencies organized a daylong workshop on the part that foundations can play in supporting communities as they confront climate impacts. The workshop was held in conjunction with COF's 2014 Fall Conference for Community Foundations in Cleveland, OH. Participants included about 30 in-person attendees and a live-stream audience, with foundations represented from as far away as Cape Town, South Africa.

This workshop was a significant first step in ongoing efforts to cultivate public-private partnerships related to climate education and preparedness. Participants gained a better understanding of current scientific knowledge on climate change, the types and magnitudes of impacts that communities might confront, and the regional variations in these impacts. Concrete examples were shared to illustrate how foundations can weave climate resilience into broader strategies to support education, health and nutrition, and diversity and equity issues, as well as the practical steps that foundations can take to develop targeted programs and overcome barriers to implementation. Participants also learned about educational resources and tools being developed through Federal investment that can benefit stakeholders seeking to improve climate literacy. As a result of this successful workshop, COF is planning to make climate change a major theme at its annual conference in spring 2015. ♦

3 CROSSCUTTING PRIORITIES TO SERVE SCIENCE AND SOCIETY

While the 2012–2021 Strategic Plan supplies the overarching decadal direction for USGCRP, the Program's annual research priorities provide an agile means to guide efforts from year to year. These priorities reach across agencies, scientific disciplines, and USGCRP's four strategic goals (see *Box 2* and *Section 2*). They also answer the Climate Action Plan's call to provide sound science on climate impacts, identify vulnerabilities in key sectors, develop information and tools that decision makers need, and help communities manage climate-related risks. Rather than changing dramatically on an annual basis, the priorities build each year on previous progress, with continual refinements to fill gaps in understanding and address prevailing challenges from new angles. USGCRP's priorities for FY 2015 relate closely to those for FY 2016 (see *Section 4*), and significant progress is already being made in these intersecting annual priority areas: predicting change in the climate system, especially on scales of time and space relevant for decision making (*Section 3.1*); understanding the impacts of global change in the Arctic and their effects on global climate (*Section 3.2*); understanding drought and other hydrologic extremes in the context of climate change (*Section 3.3*); and, across all research areas, providing actionable science that can support policy making and management (*Section 3.4*).

3.1. Predicting A Changing Climate

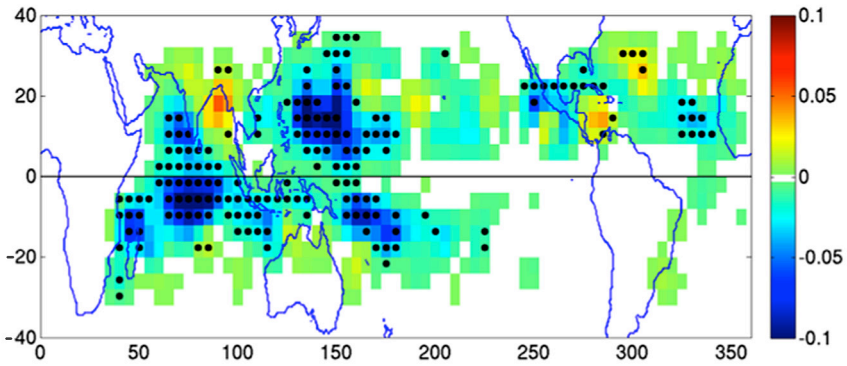
Predicting the response of the climate system to increasing greenhouse gas concentrations is a pressing and complex challenge. Experiments using models based on years of Earth system research offer an avenue to understand and evaluate the likelihood of potential changes over the next century—not only in global temperatures but also in phenomena such as tropical cyclones (*Highlight 29*) and other forms of extreme weather. Within the broader context of these longer-term changes in global climate, the behavior of the climate system on more immediate scales—between seasons, years, and decades, and over regional and local areas—poses challenges for scientific understanding, decision making, and risk management. Predictions on these time scales offer probabilistic information about climate variability and change that can benefit stakeholders in sectors as diverse as agriculture, public health, energy, shipping and transportation, facilities and infrastructure, and natural resource management. USGCRP agencies are working to better understand predictability in the Earth system, improve modeling systems and infrastructure for more realistic predictions (*Highlight 30*), and quantify uncertainties to make predictions more useful. In addition, efforts are underway to advance seasonal predictions at the interface of research and operational forecasting (*Highlight 31*).

RECENT HIGHLIGHTS

Highlight 29. Tropical Cyclones in a Warmer World

Tropical cyclones (hurricanes and typhoons) generate serious costs to human life, property, and the economy. Understanding how the behavior of tropical cyclones may change in a warmer climate is important for long-range coastal planning and infrastructure investments to minimize impacts. To help address this prediction challenge, NASA, NOAA, NSF, and DOE have cosponsored a Hurricane Working Group (HWG), organized through the interagency U.S. Climate Variability and Predictability (US CLIVAR) Program and composed of leading hurricane scientists and climate modelers from the United States and abroad. The HWG recently coordinated a set of experiments using seven atmospheric models to examine how the frequency of tropical cyclones may respond to future changes in the ocean–atmosphere system.{34} {35}

Though results varied somewhat from model to model, all of the models predicted a global decrease in tropical cyclone frequency in response to increases in both atmospheric carbon dioxide concentrations and sea surface temperatures. Regional differences were evident among ocean basins, with large decreases predicted in the frequency of tropical cyclones in the western Pacific and Indian Oceans, and smaller magnitude changes—both increases and decreases in frequency—in the Atlantic Ocean. These experiments build on a larger body of work that suggests that overall, tropical cyclones will occur less frequently as climate change progresses. However, the best-available science also projects an increase in the annual number of the strongest (Category 4 and 5) hurricanes, as well as increases in tropical cyclone intensity and rainfall rates.{2} Although they may occur less frequently, future storms that make landfall (even at today's intensity levels) are likely to have increasingly destructive effects as a result of rising sea levels. ♦



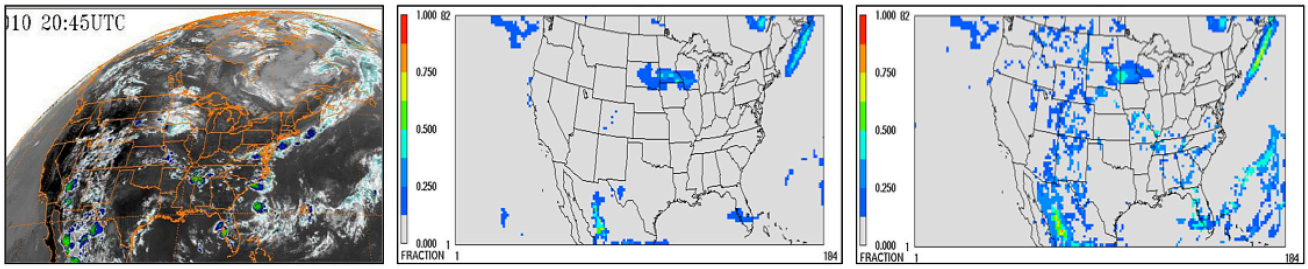
This map shows projected changes in the annual frequency of tropical cyclone formation, averaged from the output of seven models, under the combined conditions of 1) a 2°C increase in sea surface temperatures, and 2) a doubling of atmospheric carbon dioxide concentrations relative to the present day. Dots denote areas where at least five of the seven models agree on the direction (increase or decrease) of the change in frequency. Although localized increases are projected, the models point to an overall global decrease in the formation of tropical cyclones. (Source: Zhao et al., 2013)

Highlight 30. Modeling Thunderstorm Clouds for Better Regional Climate Predictions

Thunderstorm clouds play an important role in regional atmospheric dynamics, modulating such factors as air pollution, acid deposition, and—critically for climate models—precipitation and the balance of heat throughout the atmosphere. To date, in part because of the computing power constraints associated with running models at high resolutions, it has proved challenging to model in detail the effects of thunderstorm clouds on the solar radiation that drives the climate system.

Recognizing this opportunity for improvement, scientists with EPA, NOAA, and NCAR have developed a methodology to better represent thunderstorm clouds in regional climate models.{36} {37} Outcomes include more realistic simulations of these clouds, improved estimates of precipitation, and more credible short- and long-term predictions of regional climate and extreme weather events. This

next-generation methodology has been incorporated into the Weather Research and Forecasting Model, a weather prediction system involving Federal and academic partners and designed to serve both atmospheric research and meteorological forecasting. ♦

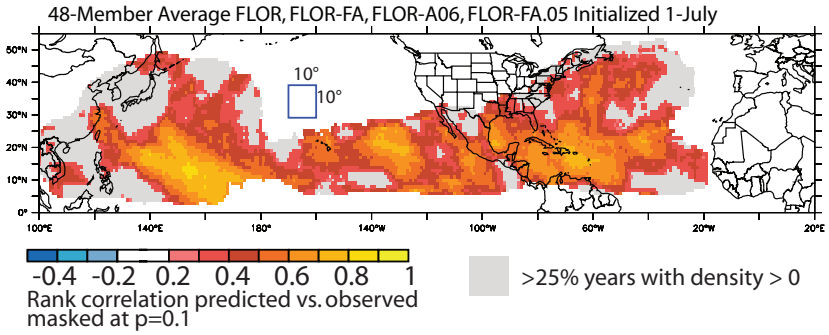


The left panel shows an image of clouds over the United States captured by the weather satellite GOES-13 (20:45 UTC, July 29, 2010). The other two panels show model simulations of cloudiness for the same date and approximate time, first excluding (middle) and then including (right) the effects of thunderstorm clouds on the climate system. Cloud cover in the right panel matches the satellite image much more closely, demonstrating that the new modeling approach better represents the real world—and thus enables greater confidence in regional climate predictions. (Source: Adapted from Alapaty et al., 2012)

Highlight 31. Seasonal Prediction Systems: From Research to Operations

Predicting climate on a seasonal basis can benefit decision makers in key sectors like energy, water resources, and agriculture, among others. A number of USGCRP agencies are working to improve the Nation's seasonal forecasting capacity through major investments in innovative climate models that can bridge the needs of atmospheric research and operational forecasts. As one example, a new model developed by NOAA's Geophysical Fluid Dynamics Laboratory, known as GFDL-FLOR, demonstrates skill in predicting the behavior of cyclones—including extratropical cyclone activity over North America[38] and tropical cyclone activity over the Northern Hemisphere[39]—a season or more in advance. Such predictions can shed light on changing patterns of extreme storms and can be used to inform storm planning and preparation efforts.

This model is just one of several that contribute to the North American Multi-Model Ensemble (NMME), a multi-agency and multi-institutional effort that produces seasonal climate forecasts by combining leading-edge predictive systems. Led by NOAA in partnership with DOE, NSF, and NASA, the NMME works by harnessing the unique capabilities of each individual model to produce a cumulative climate prediction that is, as a whole, more accurate than what a single model could produce. Publicly available NMME data have enabled novel research on seasonal predictability, and the NMME's coordinated experiments have facilitated progress among leading national prediction systems. Furthermore, although the NMME is an experimental project, it has been delivering real-time seasonal predictions on the NOAA Climate Prediction Center's operational schedule, and these predictions are used as guidance for operational forecasters. Next steps for the NMME include research and evaluation to lay the groundwork for using the system as a core element of seasonal early warning systems, as well as for expanding it to other time scales of societal relevance. ♦



Warm colors on this map show where output from NOAA's GFDL-FLOR model correlates positively (yellow = strongest correlation) with seasonal observations of tropical cyclone activity, demonstrating the model's capacity for predicting such phenomena. (Source: Adapted from Vecchi et al., 2014)

3.2. Global Change in the Arctic

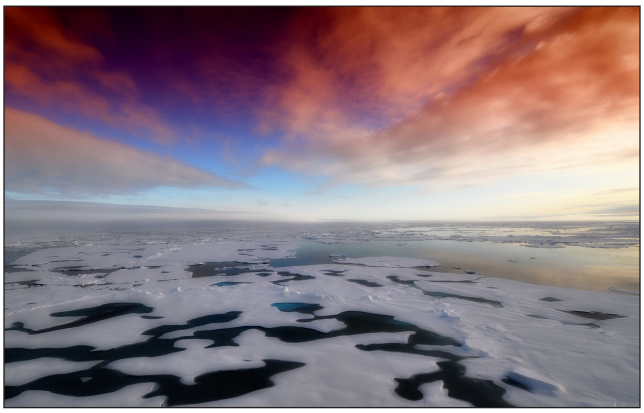
The United States is one of only eight countries in the world that hold territory above the Arctic Circle, an increasingly important region for trade, tourism, and energy prospects. Although most Americans live outside of this remote region, the effects of rapid warming in the Arctic reach across the Nation and around the world: melting glaciers and ice sheets are driving sea levels up, changes in Arctic ecosystems are affecting the global carbon budget, and changing dynamics in the Arctic's physical environment have the potential to alter global weather patterns. Assuming the role of chair of the Arctic Council in April 2015, the U.S. Government has a unique opportunity to leverage global change research for informed policy making and management in this critical region. In addition, the difficulty and expense of conducting research in such an isolated, austere location present an ideal opportunity for collaboration among Federal agencies and cooperation among international partners. USGCRP agencies are working together and with the broader scientific community to track the drivers of change in the Arctic (*Highlight 32*), to understand how the Arctic is affecting the global climate system (*Highlight 33*), and to develop approaches for forecasting Arctic conditions that impact the environment and human activities (*Highlight 34*).

RECENT HIGHLIGHTS

Highlight 32. Tracing Short-Lived Climate Forcers in the Arctic

The Arctic is facing rapid climate and environmental change relative to many other parts of the world. In addition to long-lived greenhouse gases like carbon dioxide, short-lived climate forcers—in the form of pollutants such as black carbon and trace gases—contribute to warming in this region. A new synthesis,[40] recently published in *BAMS*, highlights the key results emerging from POLARCAT—an international effort initiated during the most recent International Polar Year to track these pollutants and better understand their role in Arctic climate.

POLARCAT measurements were collected by aircraft from the United States, Germany, Russia, and France, flying from bases in Alaska, Canada, Greenland, Sweden, and Russia. These missions were complemented by data from ground-based stations and a research ship. Collectively, the measurements provide a comprehensive picture of the sources, chemical compositions, and transport paths of short-lived pollutants in the Arctic. Analyses indicate that emissions from human activities in East Asia and agricultural and boreal fires in Eurasia were important sources of pollutants in the Arctic during the observation period. The Eurasian fires primarily produced organic aerosols, human activities in East Asia produced sulfates, and black carbon originated from both regions.

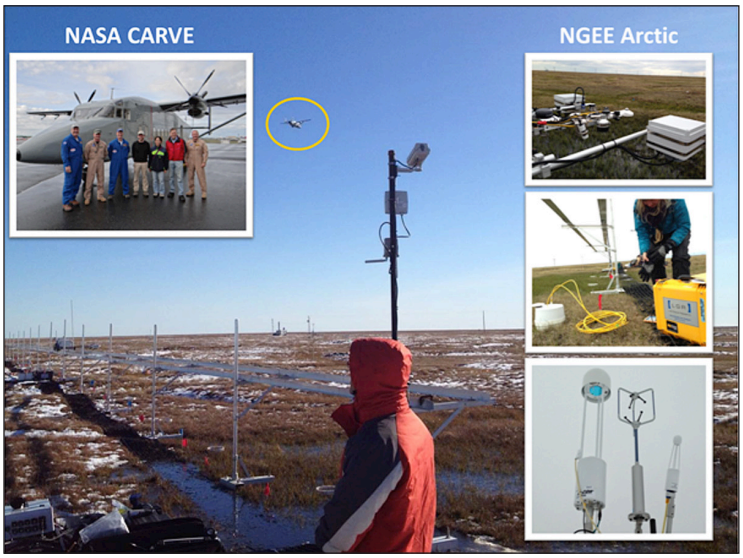


POLARCAT measured short-lived atmospheric pollutants, such as black carbon, which affect regional climate in the Arctic.

POLARCAT data are now informing studies that seek to estimate how and to what extent black carbon is affecting climate in the Arctic. Additionally, data on the vertical distributions of pollutants throughout the lower atmosphere are aiding the evaluation and improvement of climate-chemistry models. POLARCAT was co-sponsored by core projects of the International Geosphere-Biosphere Programme (IGBP) and WCRP, both of which receive support from USGCRP funding and scientific participation. Science agencies from around the world contributed to POLARCAT, including NOAA and NASA. ♦

Highlight 33. Measuring Natural Greenhouse Gas Emissions in Alaska

In addition to emissions from human activities, natural emissions of greenhouse gases such as carbon dioxide and methane can affect the climate system, and vice versa. Quantifying these natural fluxes, especially in Arctic ecosystems, is critical to understanding how they may interact with human-driven changes to affect future climate. Some research has shown increased emissions of greenhouse gases from tundra and boreal forests during warming in the spring, but little is known about what causes this or whether its occurrence is widespread enough to influence atmospheric greenhouse gas concentrations. To better understand the link between natural emissions and atmospheric chemistry in the Arctic, DOE and NASA are collaborating through complementary campaigns in Alaska. Researchers participating in DOE's Next-Generation Ecosystem Experiments (NGEE)-Arctic are using ground-based instruments to measure emissions from the tundra near Barrow, AK. Scientists with NASA's Carbon in Arctic Reservoirs Vulnerability Experiment (CARVE) are collecting airborne observations of atmospheric chemistry across the state.



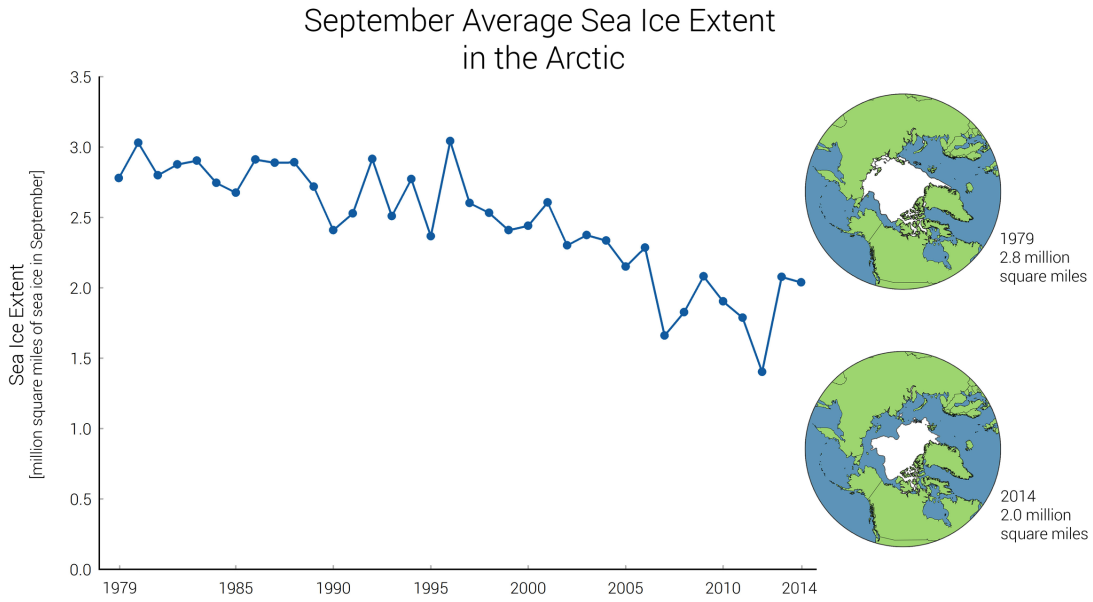
The NASA CARVE and DOE NGEE-Arctic projects are combining airborne and ground-based campaigns to understand the importance of natural emissions from the Alaskan tundra. (Source: J. B. Curtis, LBNL [main photo and left inset]; S. Wullschleger, ORNL [right insets])

Recent analyses[41] of CARVE data indicate that the Alaskan tundra contributed less than 0.5% to total global methane emissions during the 2012 growing season. Although recent climate-driven changes in Alaska's environment, such as thawing permafrost, have the potential to release methane into the atmosphere, these findings suggest that such changes have not yet increased methane emissions by enough to impact the global carbon budget. Thus, the 2012 growing season can provide a baseline against which future changes in methane release from the Alaskan tundra can be assessed. CARVE and NGEE-Arctic researchers next will be able to compare these growing season results with interannual observations collected by the latter over all seasons at Barrow. ♦

Highlight 34. Predicting Changes in Arctic Sea Ice

Although the volume and surface extent of Arctic sea ice varies between seasons and years, observations show a long-term downward trend over the last three decades. Variability in Arctic sea ice is an important indicator of global climate change, and also has implications for increasing human activity in the Arctic. In an effort to improve forecasts of Arctic sea ice on seasonal to interannual time scales, the Sea Ice Prediction Network (SIPN) was recently created with support from several USGCRP agencies (NSF, NASA, NOAA, DOE, and DOD's Office of Naval Research) affiliated with the Interagency Arctic Research Policy Committee (IARPC). SIPN involves participation from multiple investigators, institutions, and countries.

Since its inception in 2013, SIPN has brought together Arctic sea ice researchers and stakeholders through workshops, meetings, online seminars, and outreach efforts. One of SIPN's primary activities is the Sea Ice Outlook (SIO),[42] an open community effort that coordinates and synthesizes predictions of Arctic sea ice throughout the summer. In 2014, 28 groups submitted pan-Arctic outlooks and five submitted regional outlooks—a record level of participation for the SIO. About one third of these outlooks were



Sea ice in the Arctic fluctuates from year to year, but the annual minimum extent (measured each year in September) has decreased overall since measurements began in the late 1970s. Changes in sea ice have implications both for the environment and for human activities such as shipping. The Sea Ice Prediction Network aims to improve forecasts of Arctic sea ice for use by scientists and stakeholders. (Source: USGCRP indicators pilot, with data from NASA)

generated using numerical models, with the rest using statistical and heuristic approaches. The ensemble of different approaches reported in the SIO helps to characterize levels and sources of uncertainty in seasonal sea ice predictions. Next steps for the SIO, as recommended by participants in a 2014 workshop, may include more formal intercomparison studies to investigate sources of predictability and determine where new observations could improve prediction efforts. ♦

3.3. Water Extremes: From Droughts to Heavy Rains

Recent severe droughts in the United States highlight the vulnerability of sectors such as water supply and quality, food security, energy supply, and ecosystem services to the impacts associated with an increasingly warmer world. Whereas droughts are projected to become more intense in the Southwest, heavy rains and floods have been increasing in the northern Great Plains, the Midwest, and the Northeast.[2] These examples illustrate that the interplay between climate change and Earth's water cycle is not uniform across the globe or even across the Nation. Moreover, climate change challenges the idea of hydrologic stationarity, which assumes that the statistical characteristics of hydrologic data are constant over time—in other words, that water dynamics of the future can be expected to be similar to those of the past. Climate change means that this assumption may not hold for all cases, undermining fundamental paradigms of water resource management and infrastructure design. Nonstationary conditions and changing patterns of both wet and dry extremes present risks for ecosystems, the economy, and people. USGCRP agencies are responding with science: from research on the concatenated effects of abnormal precipitation events (*Highlight 35*), to new uses of satellite imagery for timely decisions during drought (*Highlight 36*), to training for water resource managers dealing with changing conditions and extremes on the ground (*Highlight 37*).

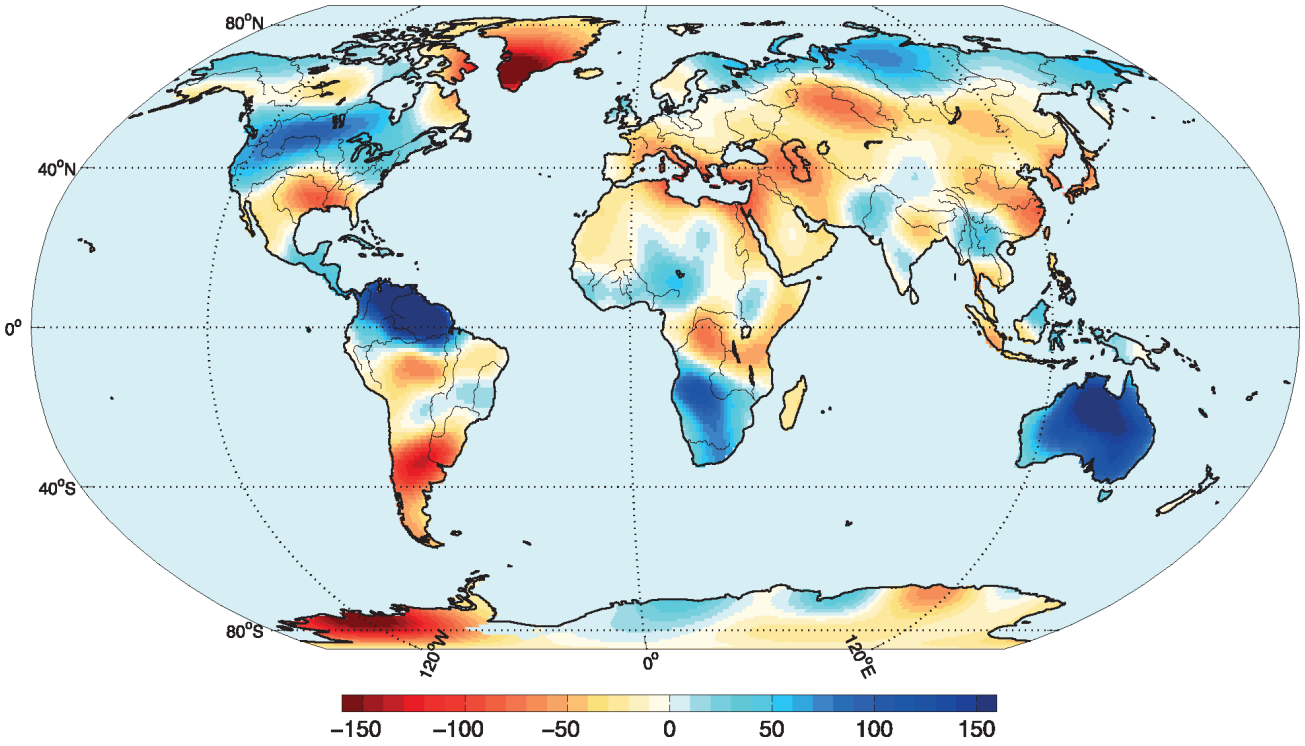
RECENT HIGHLIGHTS

Highlight 35. La Niña and the Greening of the Southern Hemisphere

La Niña is a periodic extreme phase of the El Niño/Southern Oscillation (ENSO) cycle that brings wetter weather to certain parts of the world. The exceptional La Niña event of 2010–2011 led to heavy rainfall in the Southern Hemisphere[43] and widespread flooding in Australia, where 35 people died, 30,000 homes and business were damaged, and an area the combined size of France, Germany, and Italy was submerged.

In May 2014, a study[44] published in *Nature* by scientists associated with WCRP and the Global Carbon Project (international partners of USGCRP; see related *Highlight 3*) reported that this wet phase also led to a "greening" of semi-arid ecosystems in the Southern Hemisphere. Globally, the increase in vegetation production had a major effect on terrestrial carbon storage: in 2011, vegetation soaked up 4.1 billion metric tons of carbon (significantly more than usual) and offset about 40% of annual emissions from burning fossil fuels. In addition, fires that typically affect semi-arid regions were suppressed during the wet phase by 30%. This research drew attention to the effect that water extremes can have on the global carbon cycle. Because semi-arid regions make up 40% of the world's land area, a change in hydrology could have concatenated effects on vegetation, fire, carbon storage, and ultimately the climate system. These findings underscore the need to better understand how atmospheric phenomena like ENSO may behave under future climate conditions. ♦

The 2010–2011 La Niña caused unusually high rainfall and flooding in some regions of the Southern Hemisphere, with major effects on ecosystems and thereby on the carbon cycle. This map shows the change in water mass over continents between the beginning of 2010 and mid-2011 (shades of blue indicate increases). (Source: Boening et al., 2012)



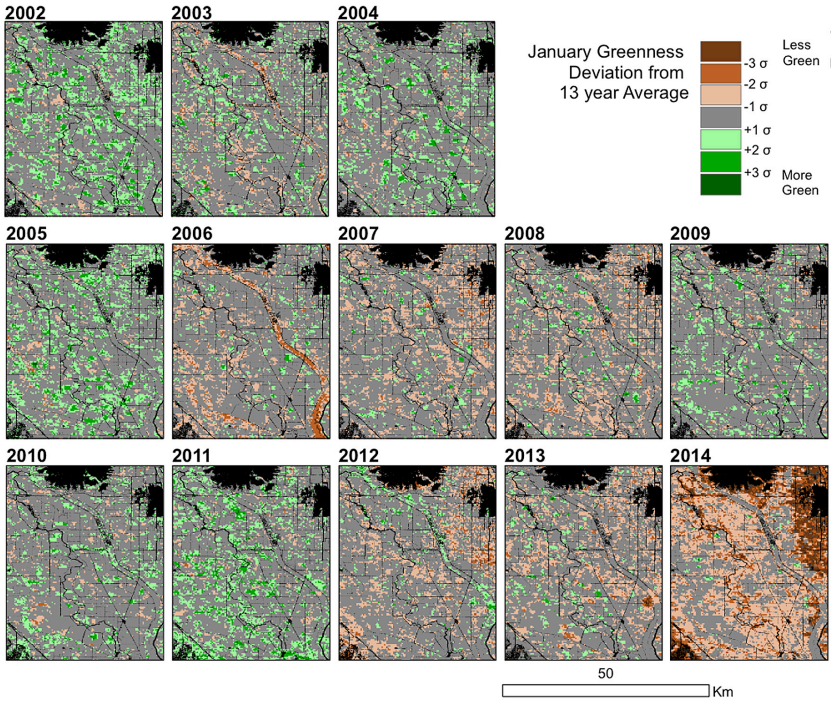
Highlight 36. Mapping Fallowed Farmland During Drought

The severe, sustained drought affecting the Central Valley of California has caused a shortage of water for irrigation and crop production. The effect of this shortage is most immediately evident as an increase in the extent of fallowed farmland (or land taken out of agricultural production), which in turn serves as a proxy for socioeconomic impacts. Decision makers can use information about fallowed land to better understand the severity of drought impacts and to support requests for USDA drought disaster designations or emergency proclamations. USDA designations can trigger eligibility for low-interest loans and debt set-aside programs.

However, currently there is no comprehensive, systematic measurement of fallowed land to support within-season decision making. To address this need, NASA, the National Integrated Drought Information System (NIDIS)/NOAA, and the USGS WaterSMART Program funded a study to test the feasibility of using satellite imagery to map fallowed areas rapidly. The study, which was described in the April 2014 NIDIS Newsletter,[45] was carried out by a team of researchers from NASA Ames Research Center/California State University Monterey Bay, the USDA National Agricultural Statistics Service, USGS, and the California Department of Water Resources.

The study showed that satellite-based mapping can provide datasets on fallowed acreage six months sooner (in July of the current year instead of in January of the following year). Furthermore, the historical context for these datasets can be extended backward through 2001 by applying an automated cropland classification algorithm to monthly imagery from the satellite-borne NASA MODIS instrument. Finally, the study demonstrated the capacity to provide early-season estimates of potentially fallowed acreage as far in advance as mid-April of the current year, and to provide monthly updates from April through November. The early-season estimates, with historical context, provide information in time for the California Department of Water Resources to adjust plans for water transfers, and for state and Federal agencies to anticipate disaster requests (see also *Highlight 12*). These results point the way to the establishment of an ongoing service for monitoring fallowed land, which will be put in place over the next three years. ♦

The greenness of croplands in January is shown relative to the 13-year average from NASA MODIS records. Satellite imagery can be a powerful tool for understanding the impacts of drought on agricultural lands. (Source: NIDIS Newsletter, April 2014)



Highlight 37. Building Capacity Among Water Resource Managers

Climate change presents new challenges for managing water quality and quantity, particularly in areas where water resources are already stressed. Resource managers need scientifically sound, usable information and training to deal with changing patterns of water extremes and other climate-related issues facing the water sector.

To help meet this need, USACE and DOI's Bureau of Reclamation have developed a training series titled Assessing Natural System Impacts under Climate Change, offered by the University Corporation for Atmospheric Research as part of the long-standing COMET Professional Development Series. An initial set of courses piloted in 2012–2013 were followed in 2014 by a virtual learning course about climate hydrology and a resident course on water temperature effects. Courses in 2015 will cover impacts to hydrology and sedimentation (including extremes) under changing climate conditions. In addition to these resident and virtual learning courses, Reclamation and USACE are developing online, self-directed learning tools. This dual-agency collaboration grew out of a broader interagency partnership dealing with climate change and water resources, which also involves USGS, NOAA, EPA, the USDA Agricultural Research Service, NASA, and FEMA. ♦

In the Southwest, reservoirs such as Lake Powell (above) have reached record-low levels in recent periods of drought. Training for water resource managers is an essential step in preparing for hydrologic extremes in a changing climate.

3.4. Science for Action

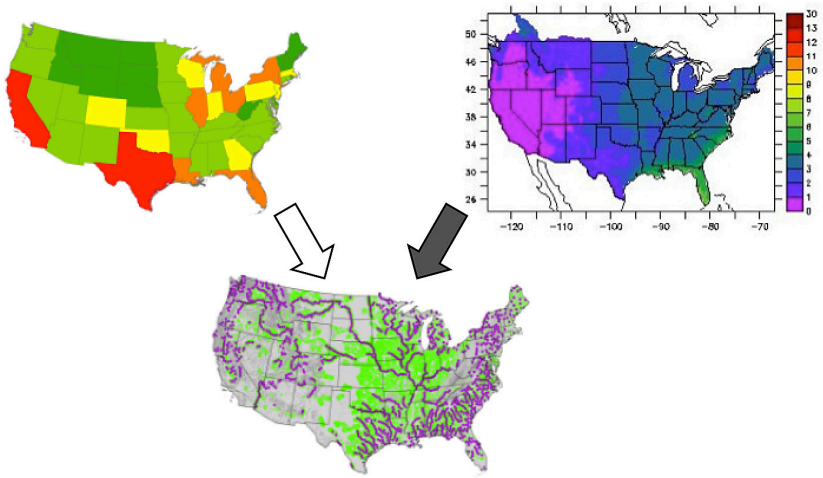
As governments, businesses, and communities become more aware of the impacts of climate and related global change, there is an increasing demand for science that can directly inform action. Data and insights produced by USGCRP agencies are essential to helping decision makers better understand and manage the risks that global change presents. Across all research areas of the Program, USGCRP is working to strengthen the scientific basis for effective action and to enhance the accessibility and utility of scientific products and tools. Efforts include, for example, developing approaches to analyze risks and opportunities in key sectors (*Highlight 38*), providing data at relevant scales for decision making (*Highlight 39*), and contributing to global efforts to understand and support sustainability (*Highlight 40*).

RECENT HIGHLIGHTS

Highlight 38. Understanding Risks and Opportunities for the Energy Sector

The Nation's energy infrastructure is vulnerable to a range of climate impacts, particularly in areas prone to severe storms or water shortages. These impacts may be exacerbated or mitigated by other systemic factors, such as increasing energy demands, infrastructure interdependencies, and changes in technology, demographics, land use and land cover, and regional industries and economies. Although existing models can capture some of these factors, there is a growing need for modeling frameworks and tools that can explore their collective behaviors.

Recently, scientists funded by DOE's Integrated Assessment Research Program have brought together models of weather extremes and climate change, infrastructure, socioeconomic factors, and other variables to better understand the complex dynamics that give rise to vulnerabilities and opportunities in the energy sector. Building on core capabilities supported through NASA, the Department of Homeland Security, and EPA, this research explores different climate futures, changing regional landscapes, and the direct implications for configuring energy infrastructure. Early evaluation of these modeling methodologies has illustrated the exposure of coastal energy systems to the combined effects of sea level rise, land subsidence, and storm surge along the U.S. Gulf Coast; explored the potential impacts of heat waves and droughts on electricity supply and demand; and begun to study the vulnerability of natural gas infrastructure under different scenarios of climate and energy supply and demand. These developing capabilities are advancing knowledge of how natural and human systems interact, and ultimately can inform resiliency planning in the energy sector. ♦



Future scenarios of natural gas supply and demand (top left) are generated using an integrated assessment model. This information serves as input (open arrow) to an infrastructure model, which projects required pipeline growth, new storage needs, and other infrastructural changes for each scenario (bottom). Finally, output from climate models (top right) is used to evaluate (shaded arrow) the resilience of each configuration produced by the infrastructure model. This multi-model approach helps to capture the complex dynamics that link human and natural systems. (Source: DOE)

Highlight 39. Data on Scales Needed by Resource Managers

Apart from serving scientists studying global change, output from the Coupled Model Intercomparison Project (CMIP; see related *Highlight 7*) can be useful to decision makers confronting regional and local climate impacts. A number of USGCRP agencies have supported the "downscaling" of CMIP output to provide climate information on scales of space and time that are relevant to decisions facing resource managers and planners. Downscaled data permit a range of analyses, such as evaluation of uncertainty in local and regional climate projections; assessment of potential climate impacts on ecosystems, water resources, and energy demands; and risk-based exploration of planning and policy responses framed by projected climatic changes.

Among other examples of downscaling services, NASA Earth Exchange (NEX) provides a dataset of downscaled U.S. climate scenarios that reflect a range of possible future emissions pathways, served to the public through the USGS National Climate Change Viewer. This CMIP-derived dataset is intended to enable analyses of the interplay between global climate change and local-scale climate processes and topography. In addition, DOE's LLNL hosts an archive of downscaled CMIP climate and hydrological data for the contiguous United States, in collaboration with USACE, USGS, Bureau of Reclamation, NCAR, and academic and NGO partners. Whereas most downscaled projection archives provide information on time scales of months or greater, the LLNL-hosted archive was recently expanded[46] to serve projections of daily future temperature, precipitation, and hydrologic conditions (including surface hydrology). As of June 2014, the archive had served projections to nearly 1800 users, collectively issued through approximately 34,000 requests. ♦

Highlight 40. Solutions-Oriented Research for Global Sustainability

The United States and other countries around the world are working together to implement Future Earth, an emerging global sustainability research program that emphasizes partnerships among scientific and stakeholder communities worldwide. Bringing together and in partnership with existing international research programs—including DIVERSITAS, the International Human Dimensions Programme, IGBP, and WCRP—Future Earth supports coordinated, interdisciplinary research that can be used by decision makers seeking to advance sustainability objectives. Better integration between natural and social sciences and a strong focus on societally relevant research are key goals shared by Future Earth and USGCRP's 2012–2021 Strategic Plan. USGCRP supports Future Earth through scientific participation in and annual funding for its constituent and partner programs.

Future Earth focuses on actionable research with the potential to accelerate global transformations toward sustainability.

In 2014, Future Earth released its first Strategic Research Agenda,{47} which calls for a step-change in research to accelerate sustainable development and address serious environmental, social, and economic threats. The agenda is the product of a year-long global consultation with research communities and stakeholders from business, government, and civil society, as well as an open online survey that received contributions from people in over 70 countries. Some of the challenges that drive the agenda include supporting basic human needs while safeguarding natural assets, promoting resilience in urban and rural areas, decoupling carbon emissions from economic growth, and encouraging sustainable production and consumption patterns. Implementation of this solutions-oriented research agenda will be overseen by an internationally distributed secretariat—including hubs in the United States, Canada, Japan, France, and Sweden—functioning as a unified entity. This cooperative effort provides a global platform for translating scientific discoveries into action. ♦

4 A LOOK AHEAD AT FY 2016

Moving forward, USGCRP will continue to foster its core agency and interagency capabilities in building and sharing scientific knowledge. From the Program's strong foundation in research, USGCRP agencies are making the necessary long-term investments to understand global change and respond to its pressing impacts—such as changing patterns of extreme weather, rising sea levels, and tipping points in natural and human systems.

To help the Nation successfully meet the challenges of climate and global change, USGCRP agencies will continue to support the scientific research needed to advance our understanding of Earth system processes; characterize past and current environmental changes; and identify, understand, and project the associated impacts and risks. Moreover, the Program will further develop capacity and tools to help decision makers anticipate and manage those risks. Because scientific progress requires sustained focus, the FY 2016 priorities relate closely to those of FY 2015, building on headway made to best address scientific challenges of societal concern. They are organized within four areas:

1. **Predictions:** Predict and project changes in climate on scales ranging from intra-seasonal to centennial, with an emphasis on shorter time scales and the predictability of climate extremes and related impacts.

2. **Water Cycle Research**: Improve understanding of the water cycle in a changing climate, expanding the focus from drought to emphasize both wet and dry extremes.

3. **Arctic Research:** Understand the impacts of global change on the Arctic region and their effects on global climate (including sea level rise and methane release to the atmosphere), support the U.S. chairmanship of the Arctic Council, and cooperate with related international research and assessment efforts.

4. **Actionable Science:** Provide the science needed to inform policy making and management, with emphases on understanding 1) risks from and responses to extreme events and 2) co-benefits and conflicts between adaptation and mitigation.

In addition, USGCRP will continue to emphasize the foundational capabilities needed to reach decision makers. These include continued support for sustained assessment activities building toward the 4th quadrennial National Climate Assessment report; further development of the Global Change Information System to support the Climate Data Initiative and assessment activities; and communication and education efforts organized around USGCRP science.

The FY 2016 priorities link to and support one another, and they advance the goals of the 2012–2021 Strategic Plan (see *Box 2*). As a whole, they reflect the strengths of USGCRP as an integrated program, where recent science advances can be turned into tools for decision support, even as new scientific advances are being pursued. Fast-paced, collective, and collaborative development of tools and resources is only possible because of sustained investments in fundamental research and assessment.

5 BUDGET INFORMATION

The FY 2016 President's Budget requests approximately $2.7 billion for USGCRP research programs, an increase of $223 million over FY 2015 levels. This request represents a commitment by the Administration to ensure that USGCRP can fulfill its responsibilities under the law. The budget crosscut (*Table 1*) represents the funds self-identified by USGCRP agencies as their contributions to USGCRP research.

It is important to note that USGCRP leverages other agency activities, outside the budget crosscut, to accomplish its mission. For example, many of the satellite systems and observing networks that are foundational to USGCRP research were originally implemented by their sponsoring agencies for operational purposes, and thus typically are not included in the crosscut. In addition, efforts related to communication, education, training, and engagement often are not reported in the crosscut because of its focus on research—yet these activities are essential to delivering on the 2012–2021 Strategic Plan. By leveraging capacity and cooperation, agencies make vital contributions toward USGCRP's goal of informing responses to global change with science.

Table 1. FY 2014 – FY 2016 USGCRP Budget Crosscut by Agency

Funding amounts are shown in millions of dollars ($M) and are rounded to the nearest million (totals reflect the rounded sum of the unrounded agency amounts). DOD does not report activities or funding through the USGCRP budget crosscut.

Agency	FY 2014 Budget Enacted ($M)	FY 2015 Budget Enacted ($M)	FY 2016 Budget Requested ($M)
Department of Agriculture (USDA)	111	94	111
Department of Commerce (DOC)	300	312	331
Department of Energy (DOE)	217	214	241
Department of Health and Human Services (HHS)	8	8	8
Department of the Interior (DOI)	54	58	83
Department of Transportation (DOT)	1	1	1
Environmental Protection Agency (EPA)	18	16	22
National Aeronautics and Space Administration (NASA)	1426	1419	1538
National Science Foundation (NSF)	313	331	341
Smithsonian Institution (SI)	8	8	8
TOTAL	**2455**	**2459**	**2682**
Non-Add Agency*	**FY 2014 Budget Enacted ($M)**	**FY 2015 Budget Enacted ($M)**	**FY 2016 Budget Requested ($M)**
Department of State (DOS)	3	0	3
U.S. Agency for International Development (USAID)	11	0	10

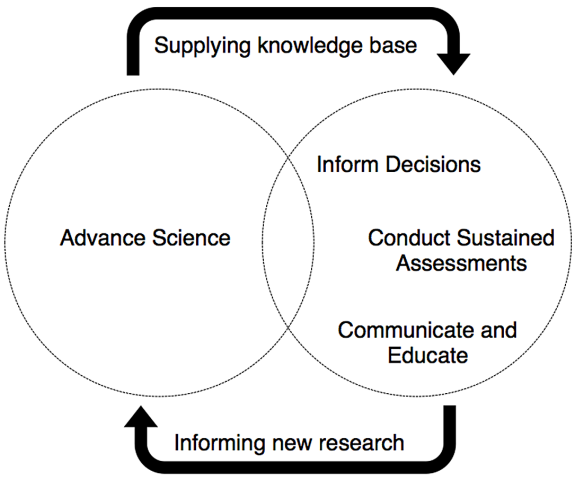
*DOS and USAID funding supports USGCRP and the Climate Change International Assistance effort. In the past, some of this funding was counted under both categories. These efforts do not add to the USGCRP total.

6 APPENDICES

6.1. About USGCRP

The U.S. Global Change Research Program (USGCRP) was established by Presidential Initiative in 1989 and mandated by Congress in the Global Change Research Act (GCRA) of 1990 to develop and coordinate "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."

USGCRP coordinates and integrates global change research across 13 Federal agencies (see *Box 1*; *Introduction*) to most effectively and efficiently serve the Nation and the world. Through interagency partnerships and collaborations with leading experts, USGCRP advances climate science and improves our understanding of how global change is impacting society, both today and into the future.



The four goals of USGCRP's 2012–2021 Strategic Plan (circled). Fundamental scientific research provides the foundation for the Program's decision-support, assessment, and communication and education activities, which in turn help to operationalize the existing knowledge base and continually inform new research priorities.

As mandated by Congress, USGCRP develops a new strategic research plan every ten years, with triennial revisions and updates. The 2012–2021 Strategic Plan is being implemented by the collective efforts of USGCRP's 13 member agencies. The goals laid out in the 2012–2021 Strategic Plan are to advance science, inform decisions, conduct sustained assessments, and communicate and educate in an integrated, end-to-end program.

USGCRP is steered by the Subcommittee on Global Change Research (SGCR) of the National Science and Technology Council's (NSTC's) Committee on Environment, Natural Resources, and Sustainability (CENRS), and overseen by the White House Office of Science and Technology Policy (OSTP). The SGCR, whose membership is listed in the front matter of this report, oversees interagency activities through the USGCRP National Coordination Office (NCO) and the interagency working groups (IWGs).

IWGs are the primary USGCRP vehicles for implementing and coordinating global change research activities within and across agencies. These groups are critical to integrating and assessing progress throughout the Program. The IWGs span a wide range of interconnected climate and global change issues and address major components of the Earth's environmental and human systems, as well as cross-disciplinary approaches for addressing these issues.

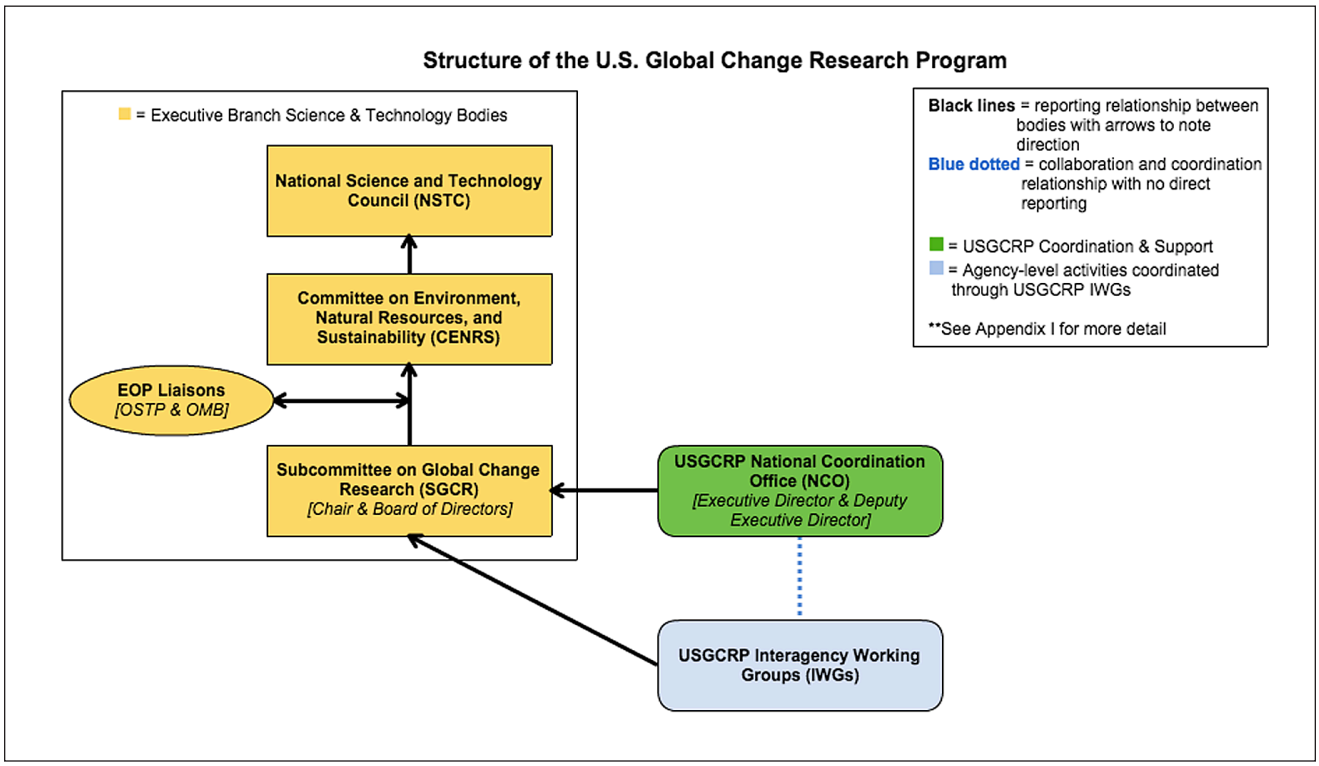
IWGs are designed to bring agencies together to plan, develop, and implement coordinated activities, and to identify and fill gaps in the Program's plans. They allow public officials to communicate with each other on emerging directions within their agencies,

their stakeholder needs, and best practices learned from agency activities. Together, these functions allow the agencies to work in a more coordinated and effective manner.

USGCRP currently comprises the following working groups:

- Integrated Observations Interagency Working Group
- Process Research Coordinating Committee—includes the following thematic clusters:
  - nitrogen cycle
  - biodiversity and ecosystems
  - clouds, chemistry, and aerosol processes
  - terrestrial water cycle and land-atmosphere interactions
- Interagency Group on Integrative Modeling
- Carbon Cycle Interagency Working Group
- Adaptation Science Interagency Working Group
- Social Sciences Coordinating Committee
- Interagency Crosscutting Group on Climate Change and Human Health
- Interagency National Climate Assessment Working Group
- Coordinating Group on Scenarios and Interpretative Science
- International Research and Cooperation Interagency Working Group
- Global Change Information System Interagency Coordination
- Education Interagency Working Group

USGCRP's organizational structure.



6.2. Member Agencies

This section summarizes the principal focus areas related to global change research for each USGCRP member agency.

Department of Agriculture

The U.S. Department of Agriculture's (USDA's) global change research program empowers land managers, policy makers, and Federal agencies with science-based knowledge to manage the risks and opportunities posed by climate change; reduce greenhouse gas (GHG) emissions; and enhance carbon sequestration. USDA's global change research program includes contributions from the Agricultural Research Service (ARS), the National Institute of Food and Agriculture (NIFA), the Forest Service (USDA-FS), Natural Resources Conservation Service (NRCS), National Agricultural Statistics Service (NASS), and Economic Research Service (ERS). These USDA entities ensure sustained food security for the Nation and the world. They maintain and enhance the health of U.S. forests and natural resources while identifying risks to agricultural production ranging from temperature and precipitation changes to the changing biology of pests, invasive species, and diseases.

Specifically, USDA develops GHG inventories and conducts assessments and projections of climate-change impacts on the natural and economic systems associated with agricultural production. USDA also develops cultivars, cropping systems, and management practices to improve drought tolerance and build resilience to climate variability. USDA promotes integration of USGCRP research findings into farm and natural resource management, and helps build resiliency to climate change by developing and deploying decision support. USDA maintains critical long-term data collection and observation networks, including the Long-Term Agro-ecosystem Research (LTAR) Network, the Snowpack Telemetry (SNOTEL) network, the Soil Climate Analysis Network (SCAN), the National Resources Inventory (NRI), and the Forest Inventory and Assessment (FIA). USDA has instituted 7 Regional Hubs for Risk Adaptation and Mitigation to Climate Change to develop and deliver science-based region-specific information and technology. Finally, USDA engages in communication, outreach, and education through multiple forums, including its vast network of agricultural extension services.

Department of Commerce

The National Atmospheric and Oceanic Administration (NOAA) and the National Institute of Standards and Technology (NIST) comprise the Department of Commerce's (DOC's) participation in USGCRP.

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

- Improved scientific understanding of the changing climate system and its impacts;
- Assessments of current and future states of the climate system that identify potential impacts and inform science, service, and stewardship decisions;
- Mitigation and adaptation efforts supported by sustained, reliable, and timely climate services; and

- A climate-literate public that understands its vulnerabilities to a changing climate and makes informed decisions.

NIST works with other Federal agencies to develop or extend internationally accepted traceable measurement standards, methodologies, and technologies that enhance measurement capabilities for science-based GHG emission inventories and measurements critical to advancing climate science research. NIST provides measurements and standards that support accurate, comparable, and reliable climate observations and provides calibrations and special tests to improve the accuracy of a wide range of instruments and techniques used in climate research and monitoring. In FY 2009, NIST was included as a discrete element of USGCRP's budget crosscut to provide specific measurements and standards of direct relevance to the program.

Department of Defense

The Department of Defense (DOD)—while not supporting a formal mission dedicated to global change research—is developing policies and plans to manage and respond to the effects of climate change on DOD missions, assets, and the operational environment. Various research agencies within DOD sponsor and undertake basic research activities that concurrently satisfy both national security requirements as well as the strategic goals of USGCRP. These include the Office of Naval Research (ONR), the Air Force Office of Scientific Research (AFOSR), the Army Research Office (ARO), and the Defense Advanced Research Projects Agency (DARPA). When applicable, the research activities of these agencies are coordinated with other Federally sponsored research via USGCRP and other entities.

Because the performance of DOD systems and platforms are influenced by environmental conditions, understanding the variability of the Earth's environment and the potential for change is of great interest to the Department. DOD is responsible for the environmental stewardship of hundreds of installations throughout the U.S., and must continue incorporating geostrategic and operational energy considerations into force planning, requirements development, and acquisition processes. DOD relies on the Strategic Environmental Research and Development Program (SERDP), a joint effort among DOD, DOE, and EPA, to develop climate change assessment tools and to identify the environmental variables that must be forecast with sufficient lead time to facilitate appropriate adaptive responses. Each service agency within DOD incorporates the potential impact of global change into their long-range strategic plans. For example, the Navy's Task Force Climate Change (TFCC) assists in the development of science-based recommendations, plans, and actions to adapt to climate change. The USACE Engineer Research and Development Center (ERDC) Cold Regions Research and Engineering Laboratory (CRREL) also actively investigates the impacts of climate trends for DOD and other agencies. The CRREL research program responds to the needs of the military, but much of the research also benefits the civilian sector and is funded by non-military customers such as NSF, NOAA, NASA, DOE, and state governments.

Department of Energy

The Department of Energy's (DOE) Office of Science supports fundamental research to understand the energy-environment-climate connection and its implications for energy production, use, sustainability, and security—with particular emphasis on the potential impact of increased anthropogenic emissions. The ultimate goal is to advance a robust predictive understanding of Earth's climate and environmental systems and to inform the development of sustainable solutions to the Nation's energy and environmental challenges.

Two DOE research areas focus on areas of uncertainty in Earth systems models: Atmospheric System Research (science of aerosols, clouds, and radiative transfer); and Terrestrial Ecosystem Science (role of terrestrial ecosystems and carbon cycle observations). DOE also collaborates with NSF to develop

the widely used Community Earth System Model, supports methods to obtain regional climate information, integrates analysis of climate-change impacts, and analyzes and distributes large climate datasets through the Program for Climate Model Diagnosis and Intercomparison and the Earth System Grid. The Department also supports the ARM Climate Research Facility, a scientific user facility that provides the research community with unmatched measurements permitting the most detailed high-resolution, three-dimensional documentation of evolving cloud, aerosol, and precipitation characteristics in climate sensitive sites around the world.

Finally, DOE also conducts applied climate-related research, which is centered in DOE's Office of Energy Policy and Systems Analysis and Office of Policy and International Affairs. These programs develop and utilizes energy-economic models, including integrated assessment models, to evaluate policies and programs that enable cost-effective GHG reductions and accelerate the development and deployment of clean energy technologies. This includes supporting work to characterize climate-change impacts for use in policy analysis, vulnerability, and adaptation assessment and agency rulemakings. DOE also conducts assessments of climate change on electric grid stability, water availability for energy production, and site selection of the next generation of renewable energy infrastructure.

Department of Health and Human Services

The U.S. Department of Health and Human Services (HHS) supports a broad portfolio of research and decision support initiatives related to environmental health and the health effects of global climate change, primarily through the National Institutes of Health (NIH) and the Centers for Disease Control and Prevention (CDC). Research focuses on the need to better understand the vulnerabilities of individuals and communities to climate-related changes in health risks such as heat-related morbidity and mortality, respiratory effects of altered air contaminants, changes in transmission of infectious diseases, and impacts in the aftermath of severe weather events, among many others. Research efforts also seek to assess the effectiveness of various public health adaptation strategies to reduce climate vulnerability, as well as the potential health effects of interventions to reduce GHG emissions.

Specifically, HHS supports USGCRP by conducting fundamental and applied research on linkages between climate change and health, translating scientific advances into decision support tools for public health professionals, conducting ongoing monitoring and surveillance of climate-related health outcomes, and engaging the public health community in two-way communication about climate change.

Department of the Interior

The U.S. Geological Survey (USGS) conducts global change research for the Department of the Interior (DOI) and constitutes DOI's formal participation in USGCRP.

USGS scientists work with other agencies to provide policy makers and resource managers with scientifically valid information and predictive understanding of global change and its effects with the ultimate goal of helping the Nation understand, adapt to, and mitigate global change.

Specifically, the USGS Climate and Land Use Change Research and Development Program supports research to understand processes controlling Earth system responses to global change and model impacts of climate and land-cover change on natural resources. The USGS Land Change Science and Land Remote Sensing programs (such as the Landsat satellite mission and the National Land Cover Database) provide data that is used to assess changes in land use, land cover, ecosystems, and water resources resulting from the interactions between human activities and natural systems. The science products and datasets from these programs are essential for DOI's biological carbon sequestration project (LandCarbon), which is conducting quantitative studies

of carbon storage and GHG flux in the Nation's ecosystems.

USGS also leads the regional DOI Climate Science Centers that provide science and technical support to region-based partners dealing with the impacts of climate change on fish, wildlife, and ecological processes.

Department of State

Through the Department of State (DOS) annual funding, the U.S. is the world's leading financial contributor to the United Nations Framework Convention on Climate Change (UNFCCC) and to the IPCC—the principal international organization for the assessment of scientific, technical, and socioeconomic information relevant to the understanding of climate change, its potential impacts, and options for adaptation and mitigation. Recent DOS contributions to these organizations provide substantial support for global climate observation and assessment activities in developing countries. DOS also works with other agencies in promoting international cooperation in a range of bilateral and multilateral climate-change initiatives and partnerships.

Department of Transportation

The Department of Transportation (DOT) conducts research to examine potential climate-change impacts on transportation, methods for increasing transportation efficiency, and methods for reducing emissions that contribute to climate change. DOT's Center for Climate Change and Environmental Forecasting coordinates transportation and climate-change research, policies, and actions within DOT and promotes comprehensive approaches to reduce emissions, address climate-change impacts, and develop adaptation strategies. DOT also contributes directly to USGCRP's National Climate Assessment through focused research such as the Center's Gulf Coast Studies. The Gulf Coast Phase 2 study, completed in FY 2015, developed tools to assist transportation agencies in performing climate change and extreme weather vulnerability assessments and build resilience.

The Federal Aviation Administration (FAA) works closely with USGCRP and its participating agencies to identify and address key scientific gaps regarding aviation climate impacts and to inform mitigation solutions. Other DOT initiatives to address climate change and improve the sustainability of the U.S. transportation sector follow:

- The Federal Highway Administration (FHWA) and other DOT agencies are undertaking climate impact and adaptation studies (including vulnerability and risk assessments), working with science agencies to develop regional climate data and projections, conducting methodological research, supporting pilot programs, and providing assistance to transportation stakeholders including state and local agencies. DOT has requested additional funding in FY 2016 for these purposes. The Federal Transit Administration (FTA) completed seven Climate Change Adaptation Pilot studies to advance the state of the practice in adapting transit assets and operations to the impacts of climate change.

- The FAA manages the Continuous Lower Energy, Emissions, and Noise (CLEEN) program as a government–industry consortium to develop technologies for energy efficiency, noise and emissions reduction, and sustainable alternative jet fuel. FAA also participates in the Commercial Aviation Alternative Fuels Initiative (CAAFI), a public–private coalition to encourage the development of sustainable alternative jet fuel.

Environmental Protection Agency

The core purpose of the Environmental Protection Agency's (EPA's) Global Change Research Program is to develop scientific information that supports stakeholders, policy makers, and society at large as they respond to climate change and associated impacts on human health, ecosystems, and socioeconomic

systems. EPA's research is driven by the Agency's mission and statutory requirements, and includes: (1) improving scientific understanding of global change effects on air quality, water quality, ecosystems, and human health in the context of other stressors; (2) assessing and developing adaptation options to effectively respond to global change risks, increase resilience of human and natural systems, and promote their sustainability; and (3) developing an understanding of the potential environmental impacts and benefits of GHG emission reduction strategies to support sustainable mitigation solutions. This research is leveraged by EPA Program Offices and Regions to support mitigation and adaptation decisions and to promote communication with external stakeholders and the public.

EPA relies on USGCRP to develop high-quality scientific data and understanding about physical, chemical, and biological changes to the global environment and their relation to drivers of global change. EPA's Global Change Research Program connects these results to specific human and ecosystem health endpoints in ways that enable local, regional, and national decision makers to develop and implement strategies to protect human health and the environment. In turn, EPA's research provides USGCRP agencies with information about the connections between global change and local impacts and how local actions influence global changes.

Research activities include efforts to connect continental-scale temperature and precipitation changes to regional and local air quality and hydrology models to better understand the impacts of climate change on air quality and water quality, and to examine how watersheds will respond to large-scale climate and other global changes to inform decisions about management of aquatic ecosystems and expand understanding of the impacts of global change. Satellite and other observational efforts conducted by USGCRP are crucial to supporting EPA's efforts to understand how land use change, climate change, and other global changes are affecting watersheds and ecosystems, and the services they provide.

National Aeronautics and Space Administration

NASA's global change activities have four integrated foci: satellite observations, research and analysis, applications, and technology development. Satellites provide critical global atmosphere, ocean, land, sea ice, and ecosystem measurements. NASA's 21 on-orbit satellite missions (as of February, 2015) measure numerous variables required to enhance understanding of Earth interactions. NASA launched five Earth-observing missions in a 12-month period from February 2014 to January 2015: the free flying satellites Global Precipitation Measurement (GPM), Orbiting Carbon Observatory-2 (OCO-2), and Soil Moisture Active Passive (SMAP), and two payloads to the International Space Station, RapidScat and Cloud-Aerosol Transport System (CATS). In calendar year 2016, NASA is planning on launching two payloads to the International Space Station (Lightning Imaging Sensor, Stratospheric Aerosol and Gas Experiment III) and the Cyclone Global Navigation Satellite System (CYGNSS) constellation of eight nanosatellites to study winds associated with tropical cyclones. In 2014, NASA selected two additional payloads to go to the International Space Station as part of its Earth Venture–Instrument series of missions: 1) the Global Ecosystem Dynamics Investigation Lidar (GEDI), which will characterize the effects of changing climate and land use on ecosystem structure and dynamics to enable radically improved quantification and understanding of the Earth's carbon cycle and biodiversity; and 2) ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS), which will address critical questions on plant–water dynamics and future ecosystem changes with climate through an optimal combination of thermal infrared measurements.

The Administration's FY 2016 budget also outlines an approach for NASA to conduct a program in sustainable land imaging (in coordination with the U.S. Geological Survey) and to take on future long-term monitoring responsibility for environmental parameters not directly in support of weather forecasting,

such as solar radiation, Earth radiation budget, ozone vertical profile, and sea surface height.

NASA's program advances observing technology and leads to new and enhanced space-based observation and information systems. The Earth science research program explores interactions among the major components of the Earth system—continents, oceans, atmosphere, ice, and life—to distinguish natural from human-induced causes of change and to understand and predict the consequences of change. NASA makes significant investments to assure the quality and integration of data through calibration and validation efforts that include satellite, surface, and airborne measurements, as well as data intercomparisons. NASA also carries out observationally driven modeling projects that include data assimilation, reanalysis, process representation, initialization, and verification. Significant new multi-year airborne campaigns initiated in 2015 will address major global environmental issues: sources and sinks of atmospheric carbon in the continental United States; the role of the ocean in melting of ice sheets at the coast of Greenland; the effects of biomass burning in Africa on cloud structure off its western coast; the latitudinal variation of radiatively and chemically active trace constituents in the upper troposphere over the Atlantic and Pacific oceans; and the seasonal variation of biological productivity in the North Atlantic ocean and its implications for the atmosphere above. Applications projects extend the societal benefits of NASA's research, technology, and spaceflight programs to the broader U.S. public through the development and transition of user-defined tools for decision support. The Earth science technology program enables previously infeasible science investigations, improves existing measurement capabilities, and reduces the cost, risk, and/or development times for Earth science instruments.

National Science Foundation

The National Science Foundation (NSF) addresses global change issues through investments that advance frontiers of knowledge, provide state-of-the-art instrumentation and facilities, develop new analytical methods, and enable cross-disciplinary collaborations while also cultivating a diverse, highly trained workforce and developing educational resources. In particular, NSF global change programs support the research and related activities to advance fundamental understanding of physical, chemical, biological, and human systems and the interactions among them. The programs encourage interdisciplinary approaches to studying Earth system processes and the consequences of change, including how humans respond to changing environments and the impacts on ecosystems and the essential services they provide. NSF programs promote the development and enhancement of models to improve understanding of integrated Earth system processes and to advance predictive capability. NSF also supports fundamental research on the processes used by organizations and decision makers to identify and evaluate policies for mitigation, adaptation, and other responses to the challenge of a changing and variable environment. Long-term, continuous, and consistent observational records are essential for testing hypotheses quantitatively and are thus a cornerstone of global change research. NSF supports a variety of research observing networks that complement, and are dependent on, the climate monitoring systems maintained by its sister agencies.

NSF regularly collaborates with other USGCRP agencies to provide support for a range of multi-disciplinary research projects and is actively engaged in a number of international partnerships.

Smithsonian Institution

Within the Smithsonian Institution (SI), global change research is primarily conducted at the National Air and Space Museum, the National Museum of Natural History, the National Zoological Park, the Smithsonian Astrophysical Observatory, the Smithsonian Environmental Research Center, and the Smithsonian Tropical Research Institute. Research is organized around themes of atmospheric processes, ecosystem dynamics, observing natural and anthropogenic

environmental change on multiple time scales, and defining longer-term climate proxies present in the historical artifacts and records of the museums as well as in the geologic record. Most of these units participate in the Smithsonian's Global Earth Observatories, examining the dynamics of forests (ForestGEO, formerly SIGEO) and coastal marine habitats (MarineGEO) over decadal time frames.

The Smithsonian Grand Challenge Consortium for Understanding and Sustaining a Biodiverse Planet brings together researchers from around the Institution to focus on joint programs ranging from estimating volcanic emissions to ocean acidification measurement. Smithsonian paleontological research documents and interprets the history of terrestrial and marine ecosystems from 400 million years ago to the present. Other scientists study the impacts of historical environmental change on the ecology and evolution of organisms, including humans. Archaeobiologists examine the impact of early humans resulting from their domestication of plants and animals, creating the initial human impacts on planetary ecosystems. Together, these projects make up the Smithsonian's "Living in the Anthropocene" initiative.

These activities are joined by related efforts in the areas of history and art, such as the Center for Folklife and Cultural History, the National Museum of the American Indian, and the Cooper Hewitt Museum of Design to examine human responses to global change, within communities, reflected in art and culture, food, and music. Finally, Smithsonian outreach and education expands our scientific and social understanding of processes of change and represents them in exhibits and programs, including at the history and art museums of the Smithsonian. USGCRP funding enables the Smithsonian to leverage private funds for additional research and education programs on these topics.

U.S. Agency for International Development

The U.S. Agency for International Development (USAID) supports programs that enable decision makers to apply high-quality climate information to decision making. USAID's climate-change and development strategy calls for enabling countries to accelerate their transition to climate resilient, low emission sustainable economic development through direct programming and integrating climate-change adaptation and mitigation objectives across the Agency's development portfolio. USAID is the lead contributor to bilateral assistance, with a focus on capacity building, civil society building, and governance programming, and creating the legal and regulatory environments needed to address climate change. USAID leverages scientific and technical resources from across the U.S. Government (for example, NASA, NOAA, USDA, USGS) as it applies its significant technical expertise to provide leadership in development and implementation of low-emissions development strategies, creating policy frameworks for market-based approaches to emission reduction and energy sector reform, promoting sustainable management of agriculture lands and forests, and mainstreaming adaptation into development activities in countries most at risk. USAID has long-standing relationships with host country governments that enable them to work together to develop shared priorities and implementation plans. USAID's engagement and expertise in agriculture, biodiversity, infrastructure, and other critical climate sensitive sectors provide an opportunity to implement innovative cross-sectoral climate-change programs. Finally, USAID bilateral programs work in key political and governance areas where multilateral agencies cannot.

6.3. Glossary

A more comprehensive global change glossary is available on USGCRP's website.

Adaptation
Adjustment in natural or human systems to a new or changing environment that exploits beneficial opportunities or moderates negative effects. *Related terms: adapt, adaptation science. See also definition in Executive Order 13653.*

Adaptive capacity
The potential of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, take advantage of opportunities, and cope with the consequences.

Aerosol
Aerosols are fine solid or liquid particles, produced by human activities or natural processes, that are suspended in the atmosphere. Aerosols can cause cooling by scattering incoming radiation or by affecting cloud cover. Aerosols can also cause warming by absorbing radiation. *Related terms: aerosol effect, aerosols*

Atmospheric Rivers
Relatively narrow regions in the atmosphere that are responsible for most of the horizontal transport of water vapor outside of the tropics. Atmospheric rivers can create extreme rainfall and floods in some situations.

Biodiversity
The variety of life, including the number of plant and animal species, life forms, genetic types, habitats, and biomes (which are characteristic groupings of plant and animal species found in a particular climate), and their turnover across space.

Biogeochemical cycles
Fluxes, or flows, of chemical elements among different parts of the Earth: from living to non-living, from atmosphere to land to sea, from soils to plants.

Biogenic
Produced by living organisms.

Biomass
The mass of living organisms or material derived from organisms in a given area.

Carbon cycle
Circulation of carbon atoms through the Earth systems as a result of photosynthetic conversion of carbon dioxide into complex organic compounds by plants, which are consumed by other organisms, and return of the carbon to the atmosphere as carbon dioxide as a result of respiration, decay of organisms, and combustion of fossil fuels.

Carbon storage
Storing of carbon by natural or technological processes in biological or geological material such that it is unavailable to the atmosphere. Related terms: carbon sequestration

Climate change
Changes in average weather conditions that persist over multiple decades or longer. Climate change encompasses both increases and decreases in temperature, as well as shifts in precipitation, changing risk of certain types of severe weather events, and changes to other features of the climate system. *See also global change.*

Climate variability
Natural changes in climate that fall within the observed range of extremes for a particular region, as measured by temperature, precipitation, and frequency of events. Measurable drivers of climate variability include the El Niño Southern Oscillation and other phenomena. *Related term: natural variability*

Drought
A period of abnormally dry weather marked by little or no rain that lasts long enough to cause water shortage for people and natural systems.

Ecological gradient
A transition from one ecosystem to another over space (or time), controlled by changes in physical factors. Ecological gradients may be strong (i.e., pronounced or rapid) or weak (i.e., subtle or gradual). *Related term: environmental gradient*

Ecosystem
All the living things in a particular area as well as components of the physical environment with which they interact, such as air, soil, water, and sunlight.

Ecosystem services
The benefits produced by ecosystems on which people depend, including, for example, fisheries, drinking water, fertile soils for growing crops, climate regulation, and aesthetic and cultural value.

El Niño/Southern Oscillation (ENSO)
A natural variability in ocean water surface pressure that causes periodic changes in ocean surface temperatures in the tropical Pacific ocean. El Niño Southern Oscillation (ENSO) has two phases: the warm oceanic phase, El Niño, accompanies high air surface pressure in the western Pacific, while the cold phase, La Niña, accompanies low air surface pressure in the western Pacific. Each phase generally lasts for 6 to 18 months. ENSO events occur irregularly, roughly every 3 to 7 years. The extremes of this climate pattern's oscillations cause extreme weather (such as floods and droughts) in many regions of the world.

Extreme events
A weather event that is rare at a particular place and time of year, including, for example, heat waves, cold waves, heavy rains, periods of drought and flooding, and severe storms. Extreme events are often associated with significant economic damages. *Related term: extreme weather*

Fallowed land
Farmland that has been left unseeded or inactive during the growing season (for example, because of unfavorable climate conditions or to avoid surplus production).

Feedback
The phenomenon through which a process or system is controlled, changed, or modulated in response to its own output. A positive feedback results in amplification of the process or system output; a negative feedback dampens the process or system output.

Forcer
A factor that affects the Earth's climate, either in the short or long term; examples include natural factors such as volcanoes, and human factors, such as the release of heat-trapping gases and particles through fossil fuel combustion. *Related term: forcing*

Global change
Changes in the global environment that may alter the capacity of the Earth to sustain life. Global change encompasses climate change, but it also includes other critical drivers of environmental change that may interact with climate change, such as land use change, the alteration of the water cycle, changes in biogeochemical cycles, and biodiversity loss. *See also climate change.*

Global warming
The observed increase in average temperature near the Earth's surface and in the lowest layer of the atmosphere. In common usage, "global warming" often refers to the warming that has occurred as a result of increased emissions of greenhouse gases from human activities. Global warming is a type of climate change; it can also lead to other changes in climate conditions, such as changes in precipitation patterns.

Greenhouse gases
Gases that absorb heat in the atmosphere near the Earth's surface, preventing it from escaping into space. If the atmospheric concentrations of these gases rise, the average temperature of the lower atmosphere will gradually increase, a phenomenon known as the greenhouse effect. Greenhouse gases include, for example, carbon dioxide, water vapor, and methane. *Related term: heat-trapping gases*

Heat wave
A period of abnormally hot weather lasting days to weeks.

Heavy rains
An episode of abnormally high rain. The definition of "extreme" is a statistical concept that varies depending on location, season, and length of the historical record. *Related term: heavy downpours, extreme precipitation*

Indicator
An observation or calculation that allows scientists, analysts, decision makers, and others to track environmental conditions and trends, understand key factors that influence the environment, and assess risks and vulnerabilities.

Integrated assessment modeling
A systems analysis-based approach to environmental assessment that is capable of simulating both the drivers and consequences of environmental change, often within an economic or risk-based framework.

La Niña
See El Niño/Southern Oscillation (ENSO).

Land cover
The physical characteristics of the land surface, such as crops, trees, or concrete.

Land use
Activities taking place on land, such as growing food, cutting trees, or building cities.

Mitigation
Measures to reduce the amount and speed of future climate change by reducing emissions of heat-trapping gases or removing carbon dioxide from the atmosphere.

Ocean acidification
The process by which ocean waters have become more acidic due to the absorption of human-produced carbon dioxide, which interacts with ocean water to form carbonic acid and lower the ocean's pH. Acidity reduces the capacity of key plankton species and shelled animals to form and maintain shells.

Peri-urban
In or relating to the urban–rural transition zone. Peri-urban areas are also known as outskirts or hinterland.

Permafrost
Ground that remains at or below freezing for at least two consecutive years.

Phenology
The pattern of seasonal life cycle events in plants and animals, such as timing of blooming, hibernation, and migration.

Preparedness
Actions taken to build, apply, and sustain the capabilities necessary to prevent, protect against, and ameliorate negative effects. *See also definition in Executive Order 13653.*

Resilience
A capability to anticipate, prepare for, respond to, and recover from significant multi-hazard threats with minimum damage to social well-being, the economy, and the environment. *See also definition in Executive Order 13653.*

Risk assessment
Studies that estimate the likelihood of specific sets of events occurring and their potential positive or negative consequences.

Risk management
Planning to manage the effects of climate change to increase positive impacts and decrease negative impacts.

Risk-based framing
Planning based on the pros and cons of a given set of possibilities; includes assessment of a risk in terms of the likelihood of its occurrence and the magnitude of the impact associated with the risk.

Scenario
Sets of assumptions used to help understand potential future conditions such as temperature change, population growth, land use, and sea level rise. Scenarios are neither predictions nor forecasts. Scenarios are commonly used for planning purposes.

Sink
A natural or technological process that removes carbon from the atmosphere and stores it. *Related term: carbon sink*

Stakeholder
An individual or group that is directly or indirectly affected by or interested in the outcomes of decisions.

Storm surge
The sea height during storms such as hurricanes that is above the normal level expected at that time and place based on the tides alone.

Stressor
Something that has an effect on people and on natural, managed, and socioeconomic systems. Multiple stressors can have compounded effects, such as when economic or market stress combines with drought to negatively impact farmers.

Tipping point
The point at which a change in the climate triggers a significant environmental event, which may be permanent on human time scales, such as the melting and collapse of very large ice sheets. *Related term: threshold*

Tropopause
The boundary between the troposphere (the layer of the atmosphere closest to Earth) and the stratosphere (the layer above).

Uncertainty
An expression of the degree to which future conditions (such as climate) are unknown. Uncertainty about the future climate arises from the complexity of the climate system and the ability of models to represent it, as well as the inability to predict the decisions that society will make. There is also uncertainty about how climate change, in combination with other stressors, will affect people and natural systems.

Urbanization
The concentration of human populations into discrete areas, leading to transformation of land for residential, commercial, industrial, and transportation purposes.

Vectorborne disease
Disease transmitted to humans by an infectious agent, such as an insect. Some examples of vectorborne disease include Lyme disease, Rocky Mountain spotted fever, and West Nile virus.

Vulnerability
The degree to which physical, biological, and socio-economic systems are susceptible to and unable to cope with adverse impacts of climate change.

Vulnerability assessment
An analysis of the degree to which a system is susceptible to or unable to cope with the adverse effects of climate change. *Related term: vulnerability analysis*

6.4. Acronyms

AACA	Adaptation Actions in a Changing Arctic
ACAPEX	CalWater2/ARM Cloud Aerosol Precipitation Experiment
ACME	Accelerated Climate Model for Energy
AFOSR	Air Force Office of Scientific Research
AR5	PCC Fifth Assessment Report
ARISE	Arctic Radiation IceBridge Sea and Ice Experiment
ARM	Atmospheric Radiation Measurement program
ARO	Army Research Office
ARS	Agricultural Research Service
ASTER	Advanced Spaceborne Thermal Emission and Reflective Radiometer
ATTREX	Airborne Tropical Tropopause Experiment
BAECC	Biogenic Aerosols - Effects on Clouds and Climate
BAMS	Bulletin of the American Meteorological Society
CAAFI	Commercial Aviation Alternative Fuels Initiative
CARVE	Carbon in Arctic Reservoirs Vulnerability Experiment
CATS	Cloud-Aerosol Transport System
CCARS	Coastal CARbon Synthesis
CDC	Centers for Disease Control and Prevention
CENRS	Committee on Environment, Natural Resources, and Sustainability
CESM	Community Earth System Model
CLEAN	Climate Literacy and Energy Awareness Network
CLEEN	Continuous Lower Energy, Emissions, and Noise
CMS	Carbon Monitoring System
CMIP	Coupled Model Intercomparison Project
COF	Council on Foundations
CRREL	Cold Regions Research and Engineering Laboratory
CSC	Climate Science Center
CYGNSS	Cyclone Global Navigation Satellite System
DARPA	Defense Advanced Research Projects Agency
DISCOVER-AQ	Deriving Information on Surface Conditions from Column and Vertically Resolved Observations Relevant to Air Quality
DOD	Department of Defense
DOE	Department of Energy
DOI	Department of the Interior
DOS	Department of State
DOT	Department of Transportation
DSCOVR	Deep Space Climate Observatory
ECOSTRESS	ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station

ENSO	El Niño/Southern Oscillation
EOA	Earth Observation Assessment
EPA	Environmental Protection Agency
ERASMUS	Evaluation of Routine Measurements using UAS
ERDC	Engineer Research and Development Center
ERS	Economic Research Service
ERSDAC	Earth Remote Sensing Data Analysis Center (Japan)
FAA	Federal Aviation Administration
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
FIA	Forest Inventory and Assessment
ForestGEO	Forest Global Earth Observatories
FRAPPÉ	Front Range Air Pollution and Photochemistry Éxperiment
FTA	Federal Transit Authority
FWS	Fish and Wildlife Service
FY	Fiscal Year
GCIS	Global Change Information System
GCRA	Global Change Research Act
GEDI	Global Ecosystem Dynamics Investigation Lidar
GEOS-5	Goddard Earth Observing System-5
GFDL	Geophysical Fluid Dynamics Laboratory
GFDL-FLOR	GFDL Forecast-oriented Low Ocean Resolution model
GHG	Greenhouse gas
GISS	Goddard Institute for Space Studies
GMAO	Global Modeling and Assimilation Office
GOAmazon	Green Ocean Amazon
GPM	Global Precipitation Measurement
GSFC	Goddard Space Flight Center
HHS	Department of Health and Human Services
HS3	Hurricane and Severe Storm Sentinel
HWG	Hurricane Working Group (of US CLIVAR)
HyspIRI	Hyperspectral Infrared Imager
IARPC	Interagency Arctic Research Policy Committee
IGBP	International Geosphere-Biosphere Program
IHDP	International Human Dimensions Programme
IPCC	Intergovernmental Panel on Climate Change
IWG	Interagency Working Group
JAROS	Japan Resources Observation System and Space Utilization Organization
JAXA	Japan Aerospace Exploration Agency
JSC	Johnson Space Center
LBNL	Lawrence Berkeley National Laboratory
MarineGEO	Marine Global Earth Observatories

METI	Ministry of Economy, Trade, and Industry (Japan)
MODIS	Moderate Resolution Imaging Spectroradiometer
NASA	National Aeronautics and Space Administration
NASS	National Agricultural Statistics Service
NCA	National Climate Assessment
NCA TSU	National Climate Assessment Technical Support Unit
NCAR	National Center for Atmospheric Research
NCDC	National Climatic Data Center
NCEP	National Centers for Environmental Prediction
NCO	National Coordination Office
NEX	NASA Earth Exchange
NGEE	Next-Generation Ecosystem Experiments
NGO	Non-governmental organization
NIDIS	National Integrated Drought Information System
NIFA	National Institute of Food and Agriculture
NIH	National Institutes of Heath
NIST	National Institute of Standards and Technology
NMME	North American Multi-Model Ensemble
NPS	National Park Service
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
NRI	National Resources Inventory
NSF	National Science Foundation
NSTC	National Science and Technology Council
Obs4MIPs	Observations for Model Intercomparison Projects
OCO-2	Orbiting Carbon Observatory-2
OMB	Office of Management and Budget
ONR	Office of Naval Research
ORNL	Oak Ridge National Laboratory
OSTP	Office of Science and Technology Policy
PECAN	Plains Elevated Convection At Night
POLARCAT	Polar Study using Aircraft, Remote Sensing, Surface Measurements and Models, of Climate, Chemistry, Aerosols, and Transport
REDD	Reducing Emissions from Deforestation and forest Degradation
RISA	Regional Integrated Sciences and Assessments
ROSES	Research Opportunities in Space and Earth Sciences
SABOR	Ship-Aircraft Bio-Optical Research
SCAN	Soil Climate Analysis Network
SERDP	Strategic Environmental Research and Development Program
SGCR	Subcommittee for Global Change Research

SIO	Sea Ice Outlook
SIPN	Sea Ice Prediction Network
SMAP	Soil Moisture Active Passive mission
SNOTEL	Snowpack Telemetry network
SOM6	Sixth International Workshop on Soil and Sedimentary Organic Matter Stabilization and Destabilization
SONGNEX	Shale Oil and Natural Gas Nexus
START	global change SysTem for Analysis, Research, and Training
TFCC	Navy's Task Force Climate Change
UAS	Uninhabited aerial system
UN	United Nations
UNFCCC	UN Framework Convention on Climate Change
UPA	Urban and peri-urban agriculture
US CLIVAR	U.S. Climate Variability and Predictability Program
USACE	U.S. Army Corps of Engineers
USAID	U.S. Agency for International Development
USA-NPN	USA National Phenology Network
USDA	U.S. Department of Agriculture
USDA-FS	U.S. Forest Service
USGCRP	U.S. Global Change Research Program
USGEO	U.S. Group on Earth Observations
USGS	U.S. Geological Survey
WWA	Western Water Assessment
WGII	Working Group II (of the IPCC)
WRCP	World Climate Research Programme

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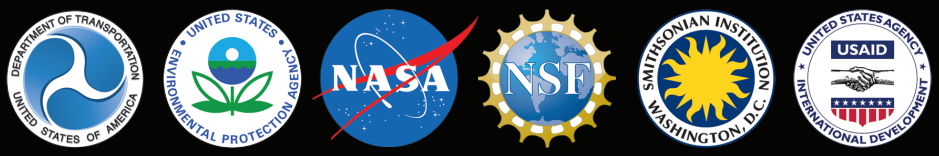

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