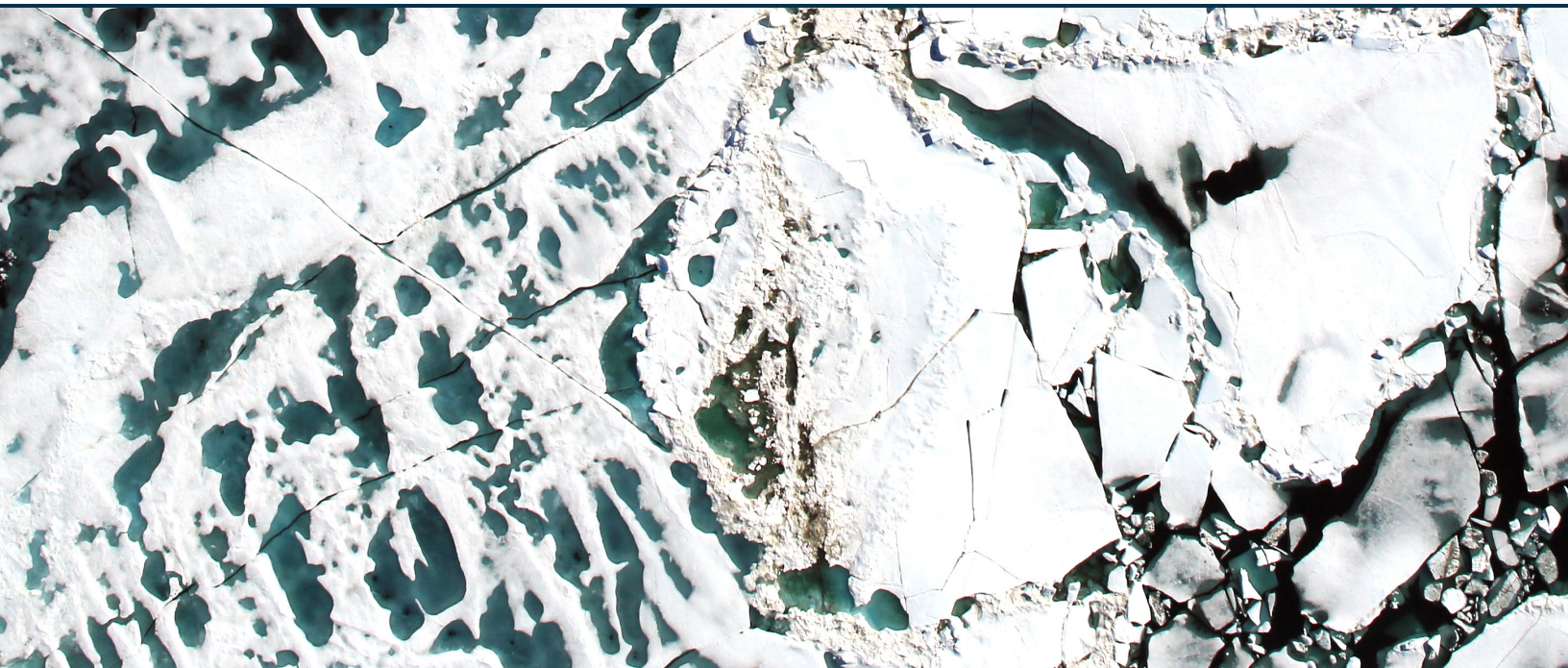
U.S. Global Change Research Program

# OUR CHANGING PLANET

The U.S. Global Change Research Program for Fiscal Year 2017

A Supplement to the President's Budget



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The U.S. Global Change Research Program for Fiscal Year 2017
A Supplement to the President's Budget

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

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Cover: Chukchi Sea, NASA/Goddard/Operation IceBridge. Page 1: 2016 blizzard, NASA/SuomiNPP/VIIRS. Page 5: Storm runoff interacting with ocean currents, NASA/Goddard/SuomiNPP/VIIRS via NASA's OceanColor. Page 29: Lake Powell, NASA/EarthKAM.org. Page 37: Melt water over Arctic sea ice, NASA/Operation IceBridge. Page 41: 2015 wildfires, Jeff Schmaltz LANCE/EOSDIS MODIS Rapid Response Team, GSFC. Page 43: Wetlands surrounding Delacroix, LA; NASA Earth Observatory images by Jesse Allen, using Landsat data from the U.S. Geological Survey.

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 Fiscal Year 2017 edition of Our Changing Planet provides a summary of programmatic achievements, recent progress, future priorities, and budgetary information for USGCRP. 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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November 2016

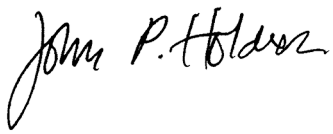
Members of the Congress:

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 (FY) 2017. 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 Arctic research and resilience, methane cycling in the context of the carbon cycle, and water-cycle extremes and their impacts. 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 scientific 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 2017 summarizes USGCRP's significant advancements toward achieving its scientific goals, delivering on its Congressional mandate, 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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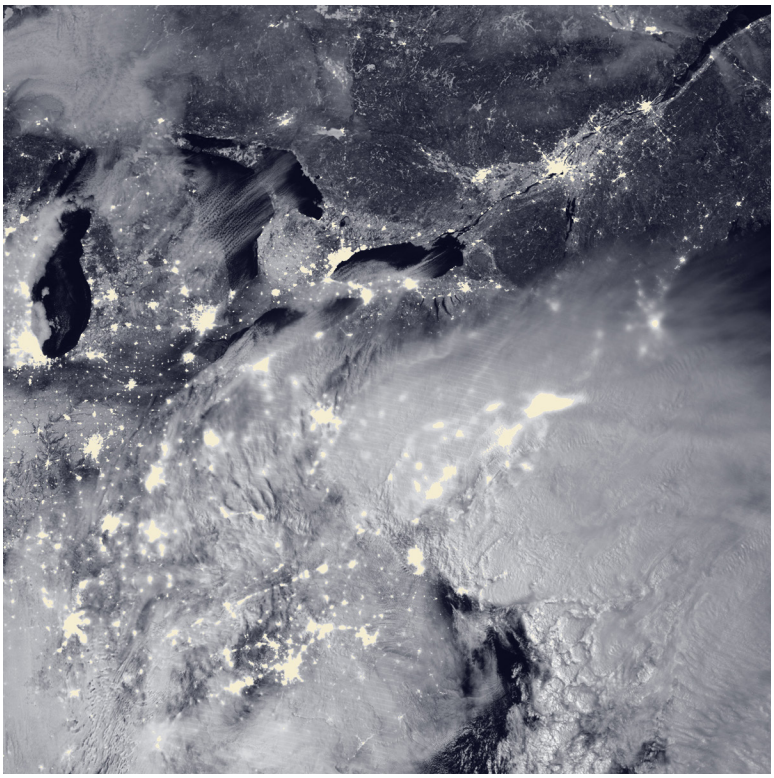

# 1 INTRODUCTION

# INTRODUCTION

The global environment is changing rapidly. This century has seen 15 of the 16 warmest years since adequate thermometer records became available in the late 1800s; globally-averaged temperatures in 2015 shattered the previous record, which was set in 2014[1]; and 2016 is on track to break the 2015 record[2]. Arctic sea-ice extent continues a dramatic, decades-long decline[3]. Many independent lines of evidence show a long-term warming trend driven by human activities, with cascading impacts that may outpace the ability of human and natural systems to adapt to change[4].

The impacts of global climate change interact with existing and evolving socioeconomic and environmental stressors, creating complex challenges for society. New research confirms that climate change will heighten risks to human health, which are likely to disproportionately impact many already-disadvantaged communities and individuals[5]. More frequent and more intense extreme weather and climatic events are threatening food security, infrastructure, and livelihoods[6]. Communities around the world are facing rising seas and higher coastal flooding risk, impacts that will intensify over the coming decades[7]. These impacts, separately and in combination, pose increasing risks to international stability and national security[8]. Of course, adaptation to, and mitigation of, climate change may also create certain long-term benefits and economic opportunities—such as building community resilience to extreme weather events and developing renewable energy technologies—but will require planning and investment.

Scientific understanding of how the climate is changing and how climate change interacts with other Earth-system dynamics underpins the Nation's ability to respond to change. For over 25 years, the U.S. Global Change Research Program (USGCRP or "the Program") has been 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[9], USGCRP has led advances in Earth-system science and expansion of the knowledge base needed to respond to a changing world. The Program's extensive body of work is carried out by 13 Federal agencies that conduct or use global-change research *(Figure 1: USGCRP Member Agencies)*, each contributing its distinct expertise while working together in a unified framework under the direction of the Subcommittee on Global Change Research (SGCR), which is overseen by the White House Committee on Environment, Natural Resources, and Sustainability (CENRS). USGCRP fulfills the mandate of the GCRA, executes the National Global Change Research Plan of 2012–2021 (hereafter, the 2012–2021

Figure 1:
USGCRP Member Agencies

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

Strategic Plan, *(Figure 2: The U.S. Global Change Research Program at a Glance)*, and contributes to the research and decision-support goals of the President's Climate Action Plan (CAP). Through the SGCR, USGCRP collaborates with other subgroups of CENRS, including those focused on Earth observations, ocean science, and Arctic research policy.

USGCRP agencies conduct fundamental research to understand the interacting processes that constitute the dynamic Earth system, which encompasses the atmosphere, oceans, land, ice, ecosystems, and human systems. Climate change is an essential focus of the Program, but USGCRP's mandate also encompasses global environmental changes related to, interacting with, or associated with climate—including agricultural land use, pollution, biodiversity loss, and energy production—that have implications for climate and society. USGCRP's fundamental research supports its mission and goals to inform responses to change through sustained scientific assessment, actionable science and decision support, and engagement and education *(Figure 2: The U.S. Global Change Research Program at a Glance)*.

Since USGCRP's inception, Federal global-change research programs have created and maintained atmospheric, oceanic, land, and space-based observing systems that generate a wealth of data and information about our changing planet *(Appendix III. Observations to Support Global-Change Research)*, and have driven major advances in understanding of Earth's climate and environment and the ability to model how they change over time. These investments support a sustained scientific assessment and engagement process that underpins the ability to inform responses to change. With the 2012–2021 Strategic Plan, USGCRP seeks to balance its basic science mission with the Nation's increasing needs for decision support, sustained scientific assessment, and engagement and education on global change.

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## Figure 2: The U.S. Global Change Research Program at a Glance

USGCRP coordinates and integrates scientific research across 13 Federal agencies whose missions include understanding changes in the global environment and their implications for society. It was established by a Presidential Initiative in 1989 and codified 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 decisions and actions that respond to global change. USGCRP's four strategic goals are as follows:

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

***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.

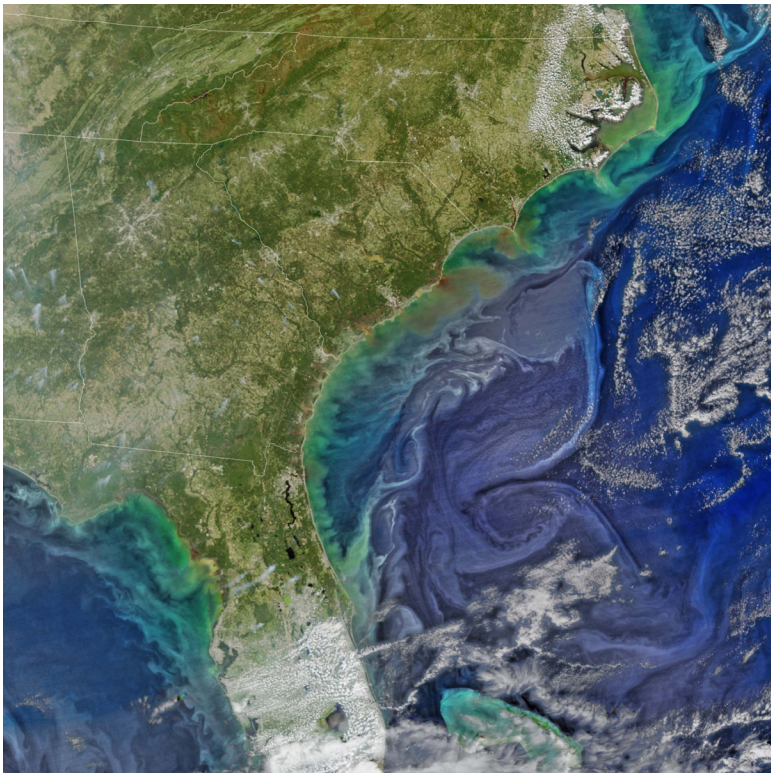
***Communicate and Educate.*** Advance communications and education to broaden public understanding of global change and develop the scientific workforce of the future.

In addition to the formal research contributions from its 13 member agencies, USGCRP cooperates with and leverages expertise from other Federal agencies and Programs that have an interest in understanding and responding to global change. This collaborative approach is facilitated by interagency working groups (IWGs) coordinated through USGCRP, with participants from USGCRP member agencies and 20 non-member Federal agencies. IWGs provide a framework for coordinating research efficiently, and a forum for exchange of knowledge and research needs among agencies studying global change and those responding to its impacts.

This report provides an overview of USGCRP's priority activities, with examples of recent progress in delivering on the goals of 2012–2021 Strategic Plan *(Figure 3: USGCRP Accomplishments under the 2012-2021 Strategic Plan)*, and in meeting research priorities that intersect with the President's CAP. It also provides an outlook on current activities and future directions within research priorities for Fiscal Year (FY) 2017 *(A Look Ahead at FY 2017)*, and supporting budgetary information *(Budget Information)*.

## Figure 3: USGCRP Accomplishments under the 2012-2021 Strategic Plan

- Delivery of the Third National Climate Assessment, the most comprehensive analysis to date of how climate change is affecting the United States and how it could affect it in the future, and development of a sustained approach to climate-change assessment that includes strong stakeholder engagement
- Delivery of The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment, a significant advancement in understanding of the impacts of climate change on human health that will contribute to the Fourth National Climate Assessment
- Production of actionable science that has informed policy decisions such as the President's Climate Action Plan of 2013, and provided the science that EPA considered in its 2016 endangerment finding for aircraft greenhouse gas emissions under the Clean Air Act
- Coordination of sustained observational campaigns to track global change and its impacts (*Appendix III. Observations to Support Global-Change Research*)
- Pioneering research on changing patterns of severe weather due to climate change
- Leadership of interagency reviews and author nominations for the Intergovernmental Panel on Climate Change assessment reports
- Contributions to Federal climate-related decision-support tools, including the Climate Resilience Toolkit and the Climate Data Initiative
- Convening of the first and second annual U.S. Climate Modeling Summit, bringing together the leaders of the six major U.S. modeling centers to promote collaboration and advancement in modeling the impacts of climate change.



# 2 DELIVERING ON THE 2012-2021 STRATEGIC PLAN

# DELIVERING ON THE 2012-2021 STRATEGIC PLAN

The complex nature and rapid pace of global change require adaptive management and science-based response strategies. Fundamental but applications-oriented research can provide the knowledge that governments, businesses, and communities need as they address global changes that pose growing risks to life, infrastructure, ecosystems and natural resources, and the economy.

The 2012–2021 Strategic Plan defined four goals for USGCRP: advance science, inform decisions, conduct sustained assessments, and communicate and educate *(Figure 2: The U.S. Global Change Research Program at a Glance).* The first of these goals guides continued advances in core Program capabilities—Earth-system understanding, integrative modeling, Earth observations, and accessible and actionable science—and provides the scientific foundation for the other three goals. Feedback from decision support, assessment, and engagement processes in turn shapes the development of future research priorities. The Strategic Plan guides the development of these capabilities and goals, and provides the flexibility for annual prioritization of particular research areas in response to new challenges *(A Look Ahead at FY 2017)*.

## Advancing Science

USGCRP agency and interagency research advances understanding of the interacting physical, chemical, biological, and societal components of the Earth system; how they are impacted by climate and other global changes; and the ways in which science can inform responses to change. Capabilities in observing and modeling Earth-system processes allow measurement of the natural and human-induced changes affecting the Earth system and enable a deepening understanding of how future changes may evolve.

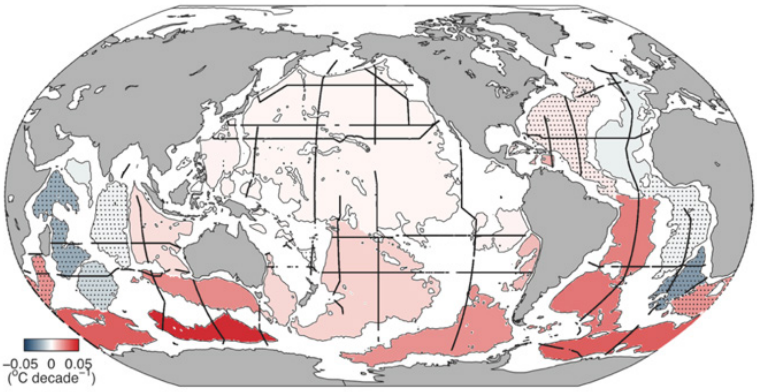
USGCRP's member agencies maintain long-term investments in multidisciplinary satellite, airborne, ground-based, and ocean-based observing systems. Information from these systems creates a record of change in Earth-system processes over time that advances understanding of their drivers and potential future behavior *(Appendix III. Observations to Support Global-Change Research)*. Both sustained and experimental observations provide critical information for understanding the Earth's climate system, how it interacts with other Earth-system processes, and the impacts on society *(Highlights 1-3)*.

Observational investments have helped reveal trends in atmospheric greenhouse gas levels over time. These measurements facilitate large-scale analysis of how greenhouse gas emissions levels from natural and human sources are being impacted by policy choices, how ecosystems respond to climate warming and other changes, and how natural emissions sources may evolve in the future. Under the Paris Agreement, adopted in December 2015 by the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change, 195 countries committed to nationally determined greenhouse gas emissions targets and regular reporting, with a U.S. target of a 26–28% reduction in emissions relative to 2005 levels by 2025. As the Paris Agreement is implemented, capacity for ongoing estimates of human emissions and monitoring of

natural sources, and assessment of the emissions-reduction potential of mitigation activities, is particularly relevant. Current USGCRP efforts include tracking how carbon-rich ecosystems respond to climate warming by measuring emissions of methane and carbon dioxide as soils warm and the resulting effects on the climate *(Highlight 4)*. Individual and multiagency observing systems also allow emissions monitoring for major urban areas *(Highlight 5)*, and calculation of the carbon and methane budgets for the entire globe *(Highlight 6)*.

In addition to their direct use in science and decision support, Earth observations are used to develop and test models of the Earth system and its changing dynamics. These models provide information about possible futures on different timescales, including longer-term projections of climate conditions under different global emissions scenarios *(Highlight 7)*, shorter-term predictions of climate conditions over an upcoming growing season *(Highlight 8)*, and the response of ecosystems to warming over decades to centuries.

## Highlight 1. Measuring Change at Sea




Multi-decadal ship-based surveys show that the ocean is taking up most of Earth's excess anthropogenic heat, with the deep ocean warming as well as the surface layers. The figure shows average warming rates (°C per decade) below 4,000 meters (color bar) estimated for deep ocean basins (thin gray outlines), centered on 1992–2005. Stippling indicates that warming rates in a given area are not significantly different from zero at 95% confidence—i.e., it is very unlikely that significant warming or cooling occurred in that basin over 1992-2005. The positions of the repeat surveys from which these warming rates are estimated are also shown (thick black lines) (Source: Talley et al, 2016, using data from Purkey and Johnson 2010[12]).

The oceans have absorbed almost all of the excess heat generated by increasing atmospheric greenhouse gas concentrations and a large fraction of anthropogenic carbon dioxide, with profound implications for ecosystems and the climate system[10]. Ship-based hydrographic surveys are the only current means for simultaneously measuring physical, biological, and biogeochemical properties of the global oceans from the surface to the seafloor and are a crucial resource for understanding ocean change and its role in the climate system. Building on global hydrographic surveys underway since the 1970s, the Global Ocean Ship-Based Hydrographic Investigations Program (GO-SHIP)—an international effort established in 2007 and funded by NSF and NOAA in the United States—samples selected hydrographic sections each decade. In combination with efforts from previous decades, data emerging from GO-SHIP reveals profound warming in deep ocean waters around the globe. In a warming climate, the global ocean is a major reservoir for excess heat and carbon dioxide generated by human activities—both vital components in understanding how much and how quickly the atmosphere will warm. New data show that the oceans have taken up the majority of anthropogenic heat in the Earth system in recent decades, with approximately 19% of this heat found below 2,000 meters, and the most intense warming in the Southern Ocean. The ocean is also acting as a major carbon sink: from 1994–2010, approximately 27% of carbon released by the burning of fossil fuels and land-use change was taken up by the oceans, acidifying the upper layers[11].

GO-SHIP builds on two decades of research under the World Ocean Circulation Experiment (WOCE) and the CLImate VARiability and Predictability (CLIVAR) programs and is a component of the Global Climate Observing System (GCOS) and the Global Ocean Observing System (GOOS). Together, these efforts have led to major scientific advances in understanding of the roles of the ocean in climate change, carbon cycling, and biogeochemical responses to climate change. These findings demonstrate the value of continuous time-series measurements and their ability to provide insights into why and how critical Earth systems are changing over time.

## Highlight 2. Connecting the Remote Ocean to Global Climate

Atmospheric composition and circulation over the tropical western Pacific Ocean play important roles in the Earth's climate system. In this remote region, rising air heated by some of the warmest seawater in the world moves gases produced by ocean organisms and other chemicals to higher altitudes, where water vapor and ozone exert their strongest influence on the climate. As the climate warms, the intensity of this transport mechanism will increase and may contribute to large-scale changes in atmospheric composition. Details of these dynamics, including how they vary over time and space, are needed to accurately model the distribution of water vapor and ozone at high altitudes and to predict their impacts on climate. To address gaps in knowledge about these dynamics, an intensive field study using three research aircraft was conducted jointly by scientists from the United States and the United Kingdom, affiliated with the NSF-funded National Center for Atmospheric Research, NASA, NOAA, and several U.S. and European universities.

Analyses show that in addition to the role of local transport mechanisms, large-scale circulations also alter atmospheric composition over the Pacific, creating distinct structures in ozone and water vapor[13]. Measurements also show that air over the remote, tropical-Pacific Ocean often contains significant amounts of pollutants associated with slash-and-burn agriculture in Asia and Africa[14]. In addition, rising-air movement in the region was observed to transport chemicals produced by biological processes in the ocean to the upper atmosphere, where they contribute to ozone destruction[15].

These findings provide important new insight into how the remote, tropical-Pacific atmosphere interacts with and influences the distribution of ozone, water vapor, and other particles in the upper atmosphere. Follow-on research will examine how improved understanding of these transport processes can improve the ability to model upper-atmospheric composition and regional- and global-climate forcings.

## Highlight 3. Studying Thunderstorms by Night

Over the Great Plains region of the United States, summertime thunderstorms often occur after sunset. Much of this nighttime rainfall is caused by large, organized storm systems and plays a critical role in the hydrology and agriculture of the region, especially over the more arid western Great

A Plains Elevated Convection at Night (PECAN) mobile observing station. The PECAN campaign focused on characterizing conditions that lead to nighttime storm formulation over the Great Plains, in order to improve the ability of climate models to make long-term projections about precipitation and hydrology. (Source: James Kurdzo).

Plains. During the summer months, these nighttime storm systems provide 30–70% of the region's precipitation and can also cause severe weather, including flash floods, intense damaging winds, and large hail. Current weather and climate models have difficulty predicting the onset, location, frequency, and intensity of these nighttime cloud systems. While understanding these systems is important for improved weather forecasts and predictability of extreme events, it is also critical for improving long-term, climate-model projections of shifts in precipitation and hydrology. The multiagency Plains Elevated Convection at Night (PECAN) field campaign was sponsored by NSF, in collaboration with NOAA, NASA, and DOE, to obtain targeted observations before and during nighttime severe storms in order to learn how they form, why some become severe, and how to better predict their characteristics in weather and climate models.

The PECAN experiment took place June–July 2015, extending over most of western and central Kansas, northern Oklahoma, and southern Nebraska. A key focus was to better sample the atmospheric layer between 500–1000 meters above the ground, where rising-air motion related to rainfall initiates. The datasets collected during PECAN will help scientists characterize the conditions that lead to individual storm formation, as well as their organization into large-scale systems that can result in significant precipitation. The results will also have relevance beyond the Great Plains, as organized nighttime thunderstorms are common in mid-latitude regions around the globe.

## Highlight 4. Studying Northern-Ecosystem Response to a Changing Climate

Northern peatlands contain vast organic carbon stocks in danger of release into the atmosphere as greenhouse gases as the climate warms, leading to a positive-feedback cycle of further warming and carbon release. Through field experiments in a Minnesota peat bog, DOE's Oak Ridge National Laboratory, the USDA Forest Service (USDA-FS), and EPA are collaborating alongside university partners to test how peatland ecosystems respond to conditions that simulate the atmosphere of the future, and improve the ability to predict the release of stored carbon and its impact on climate warming. The Spruce and Peatland Responses Under Climatic and Environmental Change (SPRUCE) experiment is measuring changes in peatland biogeochemical cycles over ten years in the USDA-FS's Marcell Experimental Forest, using a DOE-designed facility for exposing forest plots to elevated temperatures and carbon dioxide levels and offering a look at below-ground activity where most of the ecosystem's carbon is stored.

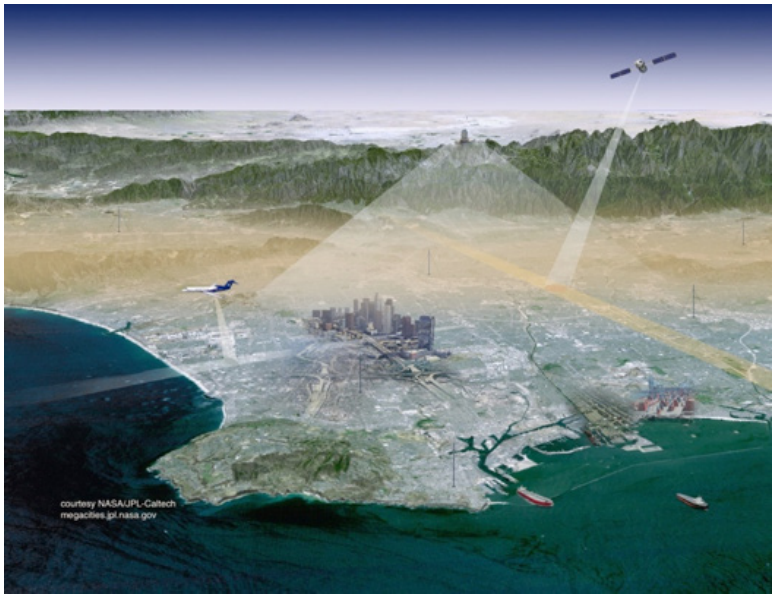
An aerial view of the SPRUCE site showing open-top chambers where experimentally-elevated atmospheric-carbon-dioxide concentrations and temperatures simulate future climatic conditions in a carbon-rich northern-peat bog. (Source: Oak Ridge National Laboratory).

DOE scientists are focused on how 10,000 years of accumulated carbon stored in the ecosystem responds to warming, particularly how likely it is for accumulated carbon to be released into the atmosphere as carbon dioxide and methane. USDA-FS scientists and colleagues are leading efforts to understand the effects of warming on wetland hy-

drology and the cycling of mercury, while EPA researchers are developing models to better understand how warming affects decomposition processes in the ecosystem. Results will help reveal the mechanics of peatland response to climate change, how quickly carbon might be released, and what that means for the ecosystem and for future climate change.

## Highlight 5. Monitoring Urban Emissions Hotspots

As of 2010, urban areas are home to more than half of the world's population, produce at least 70% of carbon-dioxide emissions from fossil fuels, and emit a significant amount of anthropogenic methane, but represent a small fraction of the Earth's land surface. Currently, greenhouse gas emissions estimates for many cities are either unavailable or are generated using self-reported data from particular sectors, and contain significant uncertainties. Although methods for comprehensive measurement of urban emissions have been tested in smaller cities with stable emissions, these techniques have not yet been extended to the more complex environments in growing megacities, and ultimately, to a global urban- monitoring system that can establish baseline-emissions estimates for large cities and help assess the efficacy of mitigation policies over time. To address this gap, the Megacities Carbon Project is developing and testing methods for measuring emissions trends of carbon dioxide, methane, and carbon monoxide from an individual megacity and in selected major sectors, beginning with pilot activities in Los Angeles.




As part of the Megacities Carbon Project, sensors located around the Los Angeles basin provide continuous ground-based measurements of the atmospheric concentrations of carbon dioxide, methane, and carbon monoxide. Remote-sensing instruments on Mt. Wilson and at Caltech provide measurements throughout the height of the atmosphere. Aircraft and mobile laboratories also provide infrequent but intensive measurements throughout the height of the atmosphere. (Source: NASA-Jet Propulsion Laboratory).

As part of this effort, a network of 14 surface-monitoring sites located within and around the Los Angeles basin provides continuous measurements of the atmospheric concentrations of carbon dioxide, methane, and carbon monoxide. Remote-sensing instruments provide emissions measurements from multiple sites.

Sustained measurement of atmospheric concentrations and emissions sources of greenhouse gases in urban areas, along with transparent data sharing, can help provide decision makers with the evidence base to evaluate emissions-mitigation policies and track how well policies are working over time. After pilot activities are established in several cities, the project may be expanded to include additional cities.

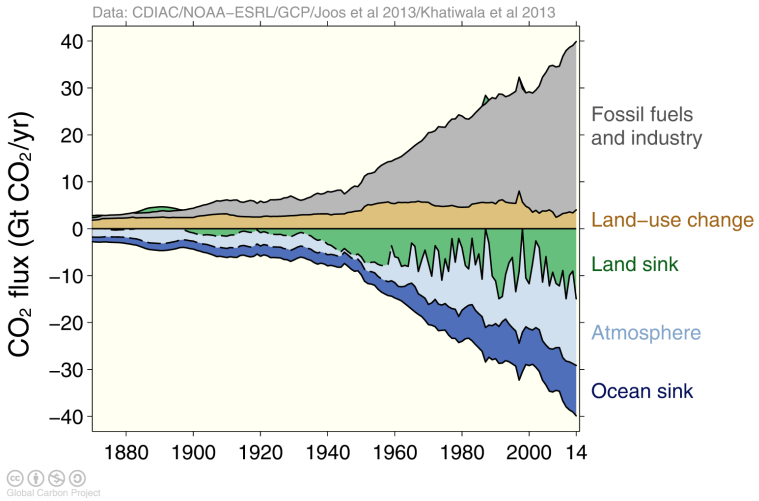
The Los Angeles component of the project is jointly funded by the U.S. National Institute of Standards and Technology, NASA, NOAA, and the Keck Institute for Space Studies. The California Air Resources Board and the University of California Discovery are also partners.

## Highlight 6. Tracking Earth's Carbon and Methane Budgets

Founded in 2001, the Global Carbon Project (GCP) is an international scientific collaboration investigating the biophysical and human components of the global carbon cycle, the interactions between them, and their response to a changing climate. The GCP tracks sources and sinks of carbon dioxide and methane, the two most important greenhouse gases directly emitted by human activities—providing annual updates on emissions trends, atmospheric concentrations, and sources of uncertainty, in a format accessible to policymakers.

The GCP released its annual update of the Global Carbon Budget (GCB) in December 2015, analyzing emissions trends through 2014. It found that carbon dioxide emissions from fossil-fuel combustion and industrial activity increased by just 0.6% in 2014, in contrast with the rapid growth in emissions in previous years. 2015 emissions are expected to flatten or drop slightly, despite continued economic growth worldwide. Still, 2014 emissions were the highest in human history, and 60% higher than in 1990. Ocean and land carbon sinks removed, respectively, 27% and 37% of the total quantity of carbon dioxide emitted from fossil fuel use and land-use change in 2014.

Because methane has a shorter atmospheric lifetime and stronger warming potential than carbon dioxide on a per unit basis, calculation of the global methane budget is increasingly important for identifying potential climate-change mitigation pathways, particularly in the short term. The GCP released a review draft of the Second Global Methane Budget (GMB) in July 2016, estimating that for the period 2000-2012, human activities accounted for about 60% of global methane emissions. Overall, uncertainties relating to emissions from natural sources—particularly wetlands and inland waters—were found to be higher than those from human sources. Improving methane observations at local-to-regional scales is one opportunity to reduce uncertainties in estimates of the total methane budget in the near future.




An accounting of global carbon dioxide sources and sinks, from 1870-2014. Carbon dioxide emissions from fossil fuels, industry, and land-use change are taken up by terrestrial ecosystems, the oceans, and the atmosphere. Increasing atmospheric carbon dioxide concentrations, in turn, are driving global warming. (Source: Global Carbon Project).

The GCB and GMB rely on observational data from many sources, with contributions from USGCRP agencies including NOAA, NASA, DOE, and NSF. USGCRP further contributes to the GCP through annual funding for the international programs that partner with the international research platform Future Earth. The U.S. Carbon Cycle Science Program Office, run through USGCRP, is an affiliated office of the GCP.

## Highlight 7. Modeling Ice Sheets and Sea-Level Rise

Recent evidence has revealed that the Antarctic and Greenland ice sheets are not as static as once thought. Accelerated ice loss from the Greenland Ice Sheet, disintegrating ice shelves around Antarctica, and signs that several marine-terminating glaciers in Antarctica have begun an irreversible retreat all signal that changes are taking place faster than was thought possible. Ice sheets are projected to contribute significantly to global sea-level rise, which poses dramatic risks for coastal communities and island nations worldwide. In response to these rapid changes, several USGCRP agencies are funding efforts to improve representation of ice-sheet behavior in Earth System Models (ESMs), aiming to better estimate the potential future impacts of climate change on communities around the world.

International model intercomparison efforts such as the Marine Ice Sheet-Ocean Model Intercomparison Project, with participation from DOE, NASA, NOAA, and NSF, test and validate techniques to allow ice sheets and ice shelves to interact with other components of the Earth system. The newest generation of ESMs is making strides in allowing model ice sheets to respond dynamically to forcings from the ocean, atmosphere, and land components of the system and feeding those changes back into the climate system. Led by NASA, models like these are now gearing up for a head-to-head comparison in the context of the Ice Sheet Model Intercomparison Project, a component of the Coupled Model Intercomparison Project Phase 6 that has officially been sanctioned by the World Climate Research Programme.

## Highlight 8. Improving Climate Predictability

As climate change increasingly impacts society and ecosystems, demand for reliable information about climate conditions now and in the future is growing. Climate research is conducted by two distinct communities, one working on climate forecasts for the near-term future and the other on climate-change projections over decades to centuries. Despite these different foci, the boundaries between these two communities increasingly overlap, and they share many common methods and challenges. Enhanced collaboration across modeling centers and communities can help create more valuable climate-information products for users at a broader range of timescales and higher spatial resolution.

With this goal in mind, USGCRP began convening an annual U.S. Climate Modeling Summit in 2015, bringing together institutional leaders from six leading climate model development centers and operational-climate-prediction centers in the United States. As recommended by the National Research Council, the 2016 Summit was dedicated to topical exchanges among centers with the goal of facilitating coordination on specific items of shared interest, including the upcoming 6$^{th}$ Coupled Model Intercomparison Project and other joint modeling activities, and opportunities and challenges for modeling with high resolution and advanced physical representation, which includes bridging timescales across weather and climate prediction and projection. Topics were discussed in the context of USGCRP research priorities, the evolving condition of Federal supercomputing and software, and interfaces with impacts and assessment models. Participants included representatives from NOAA's Earth System Models; NASA's Goddard Institute for Space Studies Model and Global Modeling Assimilation Office; the Community Earth System Model, which is hosted by the National Center for Atmospheric Research (NCAR) and funded by NSF and DOE; and the Accelerated Climate Model for Energy, funded by DOE with participation from eight national laboratories, NCAR, academic institutions, and the private sector.

Demand for reliable climate information at regional-to-local scales is also growing. To help address the common challenges both communities face in improving model resolution, DOE and NOAA jointly hosted a workshop on High-Resolution Coupling and Initialization to Improve Predictability and Predictions in Climate Models, September 30-October 2, 2015, with over 40 participants from both the prediction and projection communities. Participants summarized the current state of research surrounding high-resolution climate modeling, identified common challenges across communities, and proposed a collaborative research framework for quantifying the benefits of high-resolution coupled modeling for reducing model biases and for improving prediction skill on sub-seasonal to seasonal scales.

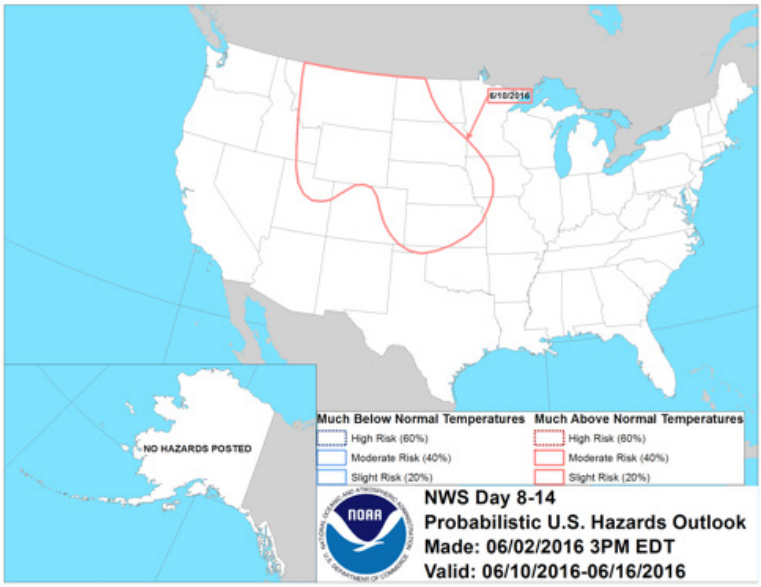
## Informing Decisions

As the impacts of global change become more apparent, demand for information at all scales appropriate for decision making is growing. From community-level efforts to adapt to sea-level rise and reduce urban emissions to analyses of supply-chain risk from extreme weather to the national-security implications of climate-driven conflict abroad, Americans are making decisions to mitigate future climate change and adapt to its impacts now and in the future. USGCRP research creates the scientific foundation for providing timely, actionable information on global-change impacts and response strategies and for understanding how response measures impact the Earth system. USGCRP coordinates with producers and users of global-change science to understand the decisions users are facing, adjust research priorities, and ensure that decision-support tools meet user needs.

Multiagency expertise in extreme-heat prediction and harm reduction is supporting a new national information network designed to combat the rising burden of death and illness associated with extreme-heat events, involving local, regional, and international partners *(Highlight 9)*. An expanded regional drought early-warning system relies on interagency drought science and connections with regional, state, tribal, and private sector partners *(Highlight 10)*. USGCRP interagency models successfully predicted the strong El Niño event of 2015/2016, providing a critical early warning for decision makers in many sectors, including agriculture, water-resources management, and public health *(Highlight 11)*.

Decision-support efforts also include working with meteorological and rural development services to deliver climate forecast information to small farmers that dramatically reduced agricultural production losses during a severe drought *(Highlight 12)*, partnering to provide innovative data and information services to international decision makers responding to global change *(Highlight 13)*, and engaging Federal, state, and tribal partners in a coordinated response to adaptation needs for fish, wildlife, and plants *(Highlight 14)*.

USGCRP continues to work to integrate social-science methodologies to better understand global-change impacts on society, improve decision support, and evaluate response options. Interagency efforts have provided guidance for incorporating social sciences into scientific assessment products, including methods for measuring societal impacts of climate change *(Highlight 15)*.




NOAA's U.S. Temperature Hazards Outlook, available on the National Integrated Heat Health Information System web portal, provides a probabilistic estimate of where temperatures are expected to be either much below normal (15th percentile) or much above normal (85th percentile), and where those conditions pose a hazard to life or property. Forecast confidence is categorized as slight, moderate, or high, with the categories indicating a 20%, 40%, or 60% chance of occurrence, respectively. Forecasts are available for 3-7 days or 8-14 days in the future; this image depicts a 8-14 day forecast. Short-range forecasts and region-specific information are available through local National Weather Service Forecast Offices. (Source: NOAA).

## Highlight 9. Reducing the Health Risks of Extreme Heat

Awareness surrounding the connection between climate change and human health is growing. USGCRP's The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment projected a potential increase of "thousands to tens of thousands of premature heat-related deaths in the summer" by 2100, driven by longer, more frequent, and more intense heat waves.

The National Integrated Heat Health Information System (NIHHIS), launched by NOAA and the Centers for Disease Control and Prevention (CDC) in June of 2015, has made significant progress towards linking early-warning capabilities to improve preparedness for extreme-heat events. Building on the October 2014 Heat Health Summit, a July 2015 planning workshop focused on developing NIHHIS and understanding local and international approaches to heat-health early warning and long-term risk reduction. These workshops catalyzed a global wave of interest in improving the heat-health information available to decision makers, as well as institutional capacity to build preparedness, communication, and knowledge sharing across disciplines and geographies. During the Federal Emergency Management Agency (FEMA) PrepareAthon! Extreme Heat Week in May of 2016, a White House webinar on preparing communities for extreme heat was held to share knowledge and build capacity for addressing heat risks, and the NIHHIS web portal was launched with multiagency support—including EPA, DOD, NOAA, FEMA, the Occupational Safety and Health Administration, the National Institutes of Health, the Centers for Disease Control and Prevention (CDC), and others.

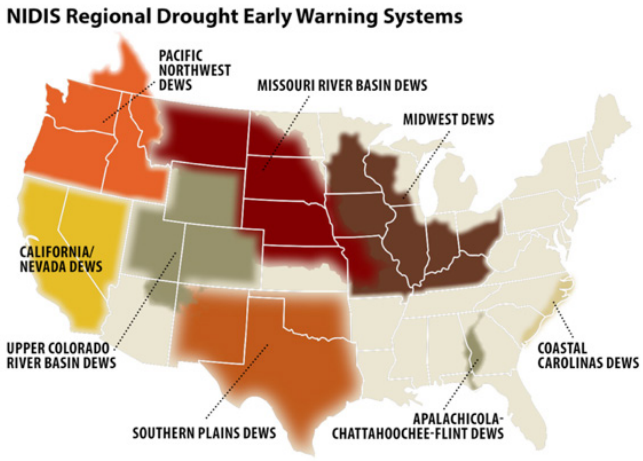
NOAA-supported research on prediction of extreme heat from weather-to-climate timescales continued while CDC pursued a comprehensive national assessment of health risks associated with extreme heat. Local NIHHIS engagements in the Southwest and Northeast, based in El Paso, Texas and New York, New York, respectively, are developing a thorough understanding of the local experience of extreme heat, as well as research and integrated climate-health-information needs. Additional local-regional engagements are planned for 2017 and onward in the West, Midwest, and Southeastern United States. At the international scale, partnerships have expanded with government agencies and nongovernmental actors, including the India Meteorological Department and the Natural Resources Defense Council. NIHHIS was visible at the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change in Paris in December 2015, and the South Asian Climate Outlook Forum in April 2016.

## Highlight 10. Building Regional Collaboration for Drought Resilience

In 2015, drought impacts in the Western United States cost an estimated $4.5 billion[16]. Impacts included the fallowing of hundreds of thousands of acres of farmland, excess groundwater pumping, and the exacerbation of wildfire conditions, which contributed to fires that caused the highest annual total of U.S. acreage burned since record-keeping began in 1960. As these impacts become more prevalent under a changing climate, preparedness, including an early-warning system for drought conditions, is increasingly important in many parts of the United States. The National Integrated Drought Information System (NIDIS) has an interagency mandate to create a nationwide Drought Early Warning System (DEWS) by integrating and coordinating efforts to research, monitor, predict, prepare for, and mitigate drought conditions. The goal of the DEWS is to make climate and drought science easily understandable, usable, and readily available to decision makers and improve the capacity of stakeholders to cope with the impacts of drought.

NIDIS has taken a regional approach to building a national system. Since 2007, NIDIS and its interagency partners have established regional DEWS in the Upper Colorado River Basin, Southern Plains states, the Apalachicola-Chattahoochee-Flint River Basin states, the Missouri River Basin, the coastal Carolinas, and California/Nevada. In February 2016, NIDIS and its partners launched new regional DEWS in the Pacific Northwest and the Midwest.

NIDIS works together with representatives and agencies of the USDA, EPA, Bureau of Reclamation, NASA, DOE, Army Corps of Engineers, USGS, FEMA, NOAA, state natural resource and water departments, state climatologists, tribal representatives, and stakeholders from the private sector. In addition, the National Drought Resilience Partnership, a group of seven Federal agencies spearheaded by USDA and NOAA, was established to enhance access to Federal drought resources to help communities better prepare for drought and reduce its impacts on families and businesses.



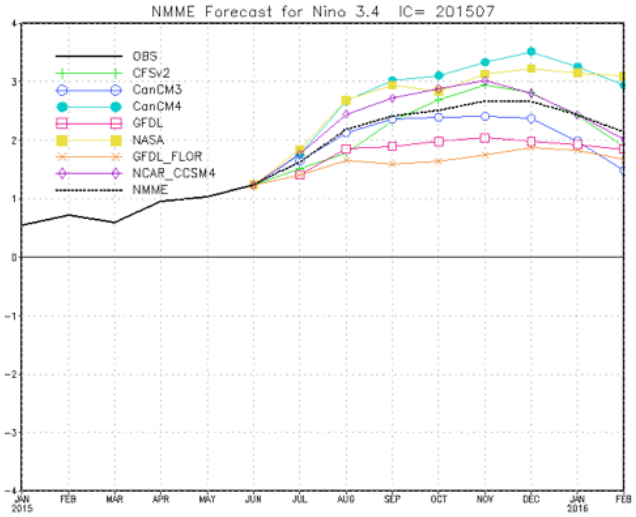

Map of regions with National Integrated Drought Information System (NIDIS) Regional Drought Early Warning Systems (DEWS) currently underway. DEWS coordinate and provide climate and drought science, monitoring, and forecast products; identify user needs for information and resources; and help build stakeholder capacity to cope with the impacts of drought. (Source: NIDIS).

## Highlight 11. Successfully Predicting the Large 2015/2016 El Niño

The El Niño/Southern Oscillation (ENSO) phenomenon is a periodic fluctuation of sea-surface temperatures and atmospheric pressure across the tropical Pacific Ocean. During the El Niño phase of the cycle, the eastern tropical Pacific Ocean warms substantially. This can cause significant short-term increases in global-average surface temperatures, and through atmospheric teleconnections, a strong El Niño event can affect weather patterns around the globe. A particularly strong El Niño emerged during the winter/spring season of 2015/2016,

rivaling the major El Niño of 1998. Using a state-of-the-art seasonal forecasting and research tool, USGCRP agencies successfully forecasted the event six months before it occurred, providing advance warning of potentially disruptive shifts in weather and climate patterns.

Based on models from NOAA, DOE, NSF, NASA, and other modeling centers, the North American Multi-Model Ensemble (NMME) produces skillful short-term (intra-seasonal to interannual) climate forecasts on a routine basis. El Niño forecasting aids decision makers in many different industries, including agriculture, water-resources management, public health, emergency management, and national security, who stand to benefit from more accurate forecasts of climate extremes. NMME seasonal forecasts are disseminated via NOAA's National Weather Service and U.S. Drought Outlook.




Forecast of the NINO3.4 index made by members of the North American Multi-Model Ensemble in June 2015. Individual model forecasts are indicated by colored lines; the ensemble average is the black dotted line. The NINO3.4 index is the sea-surface temperature anomaly (departure from average) in degrees centigrade (C), averaged across the region between +/- 5 degrees latitude and 170W to 120W longitude. An El Niño event is typically defined as the NINO3.4 index exceeding 0.4 C for a period of six months or more. (Source: NOAA).

## Highlight 12. Providing Drought Information to Farmers

Since 2014, Jamaica has experienced one of its worst droughts in a decade, and the fourth worst on record since the 1970s. The drought has profoundly affected the agricultural sector: agricultural production fell by roughly 50% between 2013 and 2014. In response, Jamaica's Rural Agricultural Development Authority (RADA) and the Jamaican Meteorological Service (JMS), in collaboration with the International Research Institute for Climate and Society (IRI) and with support from USAID and NOAA, produced new seasonal drought-related forecast information for farmers. Combining information from the Standardized Precipitation Index and IRI's Climate Predictability Tool, the tool forecasted con-

Jamaican farmers discuss the drought outlook with agricultural-extension agents. When shared with farmers effectively, seasonal drought-related forecast information has been shown to significantly cut agricultural-production losses under drought conditions. (Source: Zack Guido).

ditions up to three months into the future.

Forecast information was then provided to hundreds of farmers across Jamaica by JMS and RADA during June 2014-June 2015, via farmer forums, text messages, extension agents, and direct contact with JMS. In doing so, JMS and RADA tested an innovative model for providing climate-information services to farmers, with potential for generating new insights relevant to delivering climate-information services for agriculture in different contexts.

In 2015, USAID and NOAA supported an economic-impact evaluation study by researchers from the University of Arizona of the information service[17]. The study documents that agricultural-production losses of the farmers who received the information service were significantly smaller. More specifically, some farmers were able to prevent agricultural-production losses by up to 40%. This can be attributed to the coping strategies adopted by farmers in light of the information service: they adjusted planting and sowing time, choice of crops, harvesting time, amount of land cultivated, mulching practices, chemical and fertilizer use, and irrigation.

## Highlight 13. Implementing Data Services for Development


An example of the web-based information products available through the Agricultural Atlas of Nepal, created under the SERVIR-Himalaya initiative supported by USAID and NOAA. (Source: ICIMOD).

SERVIR—meaning "to serve" in Spanish—combines NASA's Earth-observations data and tools with USAID's expertise in international development, supporting the use of geospatial technologies to help decision makers in developing countries respond to environmental change. Through the SERVIR network, experts at regional hubs in Eastern and Southern Africa, Hindu Kush-Himalaya, and the Mekong River Basin partner with local decision makers and U.S.-based scientists to create new datasets, maps, and decision-support tools related to climate adaptation and mitigation, disaster-risk reduction, water and natural- resource management, land-use planning, and infrastructure development. SERVIR hubs also provide training to build capacity in local institutions for accessing and using scientific data and tools for decision making.

The SERVIR website offers access to a range of environmental information, maps, satellite and sensor data, and other analysis tools. In countries such as Nepal, where a large percentage of the population depends on rainfed agriculture for subsistence, climate-related risks to crop production pose serious challenges to food security and economic stability. To help address this critical issue, SERVIR-Himalaya and its partner organization the International Centre for Integrated Mountain Development (ICIMOD) worked with the Nepal Ministry of Agricultural Development (MoAD) to create the first-ever web-based Agricultural Atlas of Nepal. The Atlas, which provides free access to information on crops and livestock products to a wide audience, is one component of an Agriculture Management Information System that serves as a basis for agricultural and food-security analysis and planning in Nepal. MoAD and ICIMOD are also developing an agricultural-monitoring system

based on satellite data to provide key agricultural information on crop growth and stress as well as early signs of drought, enabling officials to plan for and mitigate the effects.

## Highlight 14. Protecting Fish, Wildlife, Plants, and Ecosystems in a Changing Climate

As climate change and other stressors increasingly threaten ecosystem health, natural-resource agencies and their partners and stakeholders are wrestling with similar management challenges and seeking common, coordinated solutions. Called for by both Congress and the Executive Branch, the National Fish, Wildlife, and Plants Climate Adaptation Strategy (NFWPCAS or Strategy) was developed collectively by diverse teams of experts from Federal, state, and tribal conservation agencies and through an extensive national dialogue.

The Pacific walrus in Alaska is threatened by reductions in the thickness and extent of sea ice driven by climate change. The National Fish, Wildlife, and Plants Climate Adaptation Strategy aims to protect species like the Pacific walrus under pressure in a changing climate. (Source: U.S. Fish and Wildlife Service).

The Strategy identifies seven goals for helping fish, wildlife, plants, and ecosystems cope with the impacts of climate change and identifies the scientific and technical capacity needed to implement them. Since its release in 2013, Federal, state, and tribal agencies have worked together through a Joint Implementation Working Group (JIWG) to promote the Strategy as a resource for adaptation planning at national to local levels and to support partners in implementing recommended strategies and actions.

In 2016, the partnership launched the first national Climate Adaptation Leadership Award for Natural Resources to recognize exemplary efforts by Federal, state, tribal, local, and non-governmental individuals and entities to help safeguard America's living natural resources from climate change. The first-ever award recipients were chosen from among 47 diverse nominees from Federal, state, tribal, local, and non-governmental organizations. The JIWG is also assisting in the coordination of the Resilient Lands and Waters Initiative, a focused Federal effort by NOAA, DOI, EPA, and the U.S. Army Corps of Engineers that builds on existing collaborative landscape-conservation partnerships to help ensure that long-term conservation efforts take climate change into account.

There are many examples of efforts across the United States that have been informed by the Strategy and the JIWG. The state of California is working with partners to develop a reintroduction plan for winter-run Chinook salmon that will support a more resilient population in the face of climate change. NOAA Fisheries has released a climate-change science strategy to increase the production, delivery, and use of climate-related information to fulfill agency mandates. An interagency collaboration, led by the Bureau of Land Management, is developing a National Seed Strategy to ensure the availability of appropriate seeds in a changing climate. The Swinomish Indian Tribal Community is modeling future conditions to estimate the impacts from sea-level

rise and storm surge on the near-shore environment of their reservation. Finally, the U.S. Fish and Wildlife Service (FWS) is working to incorporate climate-change considerations into a variety of areas including refuge planning, land acquisition, and financial assistance.

Going forward, the continued success of this effort relies on sustained action and engagement by Federal, state, local, and tribal governments, and many partners at all levels. This effort is led by the FWS, NOAA, the California Department of Fish and Wildlife (on behalf of states more broadly), and the Great Lakes Indian Fish and Wildlife Commission.

### Highlight 15. Increasing Representation of the Social Sciences in Global Change Research

USGCRP's 2012-2021 Strategic Plan recognized the need for better representation of the social dimensions of global change within the Program's activities, in order to fulfill its goals of advancing fundamental global-change science while informing decisions and engaging stakeholders. Under this impetus, the interagency Social Science Coordinating Committee (SSCC) was established in 2014 and has made progress in developing strategies for integrating the methods, findings, and disciplinary perspectives of the social and behavioral sciences into USGCRP's activities.

Since its inception, the SSCC has engaged with the USGCRP National Coordination Office, various USGCRP interagency working groups, and scientists outside of USGCRP agencies and the government to better incorporate social-science considerations into USGCRP programs and activities. Most significantly, the SSCC reviewed the 2014 National Climate Assessment (NCA) to identify ways authors can better incorporate social sciences in future NCAs and other assessment products to enhance climate research and its communication and the relevance of the NCA to decision makers. Considerations range from the structuring of future reports, to new topics (e.g., scenario analysis and economic valuation of climate-change impacts), to best practices for integrating social-science methodologies and expertise and the human dimensions of climate change into the NCA. The SSCC also reviewed the USGCRP indicators system *(Highlight 17)* and developed recommendations for the inclusion of societal indicators of climate-change impacts, vulnerability, and adaptive capacity. In addition, planning for a workshop with several social-science professional associations is underway. The workshop will identify specific actions that USGCRP and its member agencies could take to enhance the effectiveness of Federal climate-change research activities.

## Conducting Sustained Assessments

Scientific assessments provide a snapshot of current scientific understanding on a topic, synthesizing large amounts of research to help scientists and decision makers anticipate change, evaluate information available for decision support, and identify knowledge gaps and needs. With a rapidly evolving, policy-relevant issue such as climate change, frequent assessments are key inputs for decision making. USGCRP is mandated by the GCRA to conduct a quadrennial National Climate Assessment (NCA) on the impacts of climate change in the United States, and to coordinate Federal participation in relevant international assessments, such as those led by the Intergovernmental Panel on Climate Change (IPCC). Under the 2012-2021 Strategic Plan, USGCRP

began the transition to a sustained-assessment process to provide timely information to decision makers on an ongoing basis and to enable more efficient and effective production of quadrennial reports.

Sustained assessment capacity directly connects research with decision making, providing a mechanism for regularly evaluating the state of knowledge while engaging with stakeholders to ensure that emerging tools and capabilities meet their needs[18]. Special reports on key topics allow new syntheses and insights to be released as they emerge, and provide substantive technical inputs to the NCA. In April 2016, USGCRP released a major assessment of the impacts of climate change on human health in the United States, led by EPA, NOAA, and HHS, that broke new ground in quantifying projected health impacts and identifying vulnerable populations *(Highlight 15)*. As a contribution to the NCA, a 2015 USDA-led assessment addressed climate change-related disruptions to the U.S. food system and global food security, and a 2016 USDA-Forest Service-led assessment provided a scientific basis for drought management on forests and rangelands. Interagency reports to update the state of knowledge on climate science and the carbon cycle are also underway.

Agencies are investing in research, tools and products to support a sustained assessment capacity, relying on interagency investments in observational systems and modeling capabilities to document, understand, and communicate change. USGCRP is supporting pilot testing of a climate-indicators platform that can clearly convey key climate-change impacts to decision makers *(Highlight 16)*. A number of USGCRP agencies are collaborating to develop and refine scenarios of changing climate, population, and land-use/land-cover dynamics that can inform ongoing assessment activities and decision-support tools *(Highlight 17)*. USGCRP's Global Change Information System provides traceability for datasets, figures, and publications used in all of these efforts *(Highlight 18)*.

At the international level, USGCRP serves as a locus of U.S. activity in support of the IPCC, including its periodic Assessment Reports as well as its occasional topic-focused special reports. The USGCRP agencies support most of the authors, observations, and model projections that the United States contributes to these reports. Through their support of researchers, observations, and model projections, USGCRP agencies similarly contribute to a number of ongoing international assessments, including the quadrennial ozone assessment of the World Meteorological Organization and United Nations Environment Programme, the United Nations World Ocean Assessment, and assessments conducted by the Arctic Monitoring and Assessment Program.

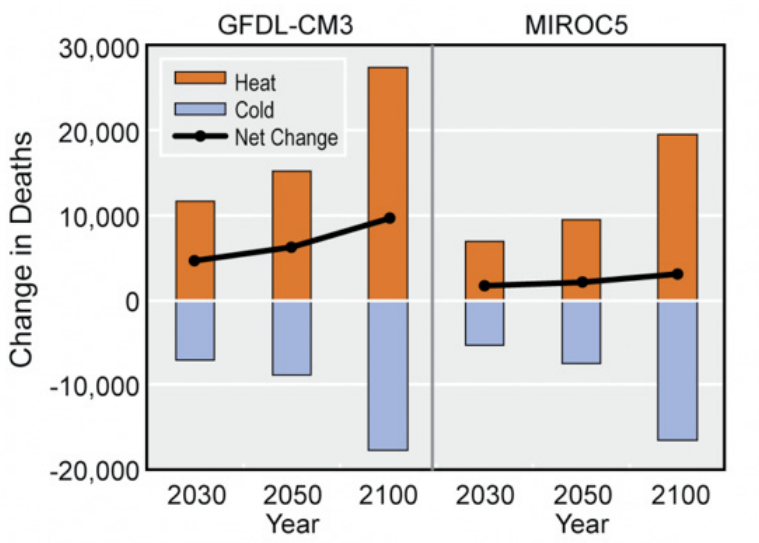
The sustained-assessment process is a key avenue of engagement with USGCRP's stakeholders. Recognizing the value of a wide range of expertise and experience in fulfilling its goals, USGCRP has built engagement into the sustained-assessment process at multiple levels, including program planning, implementation, and evaluation and has convened a Federal Advisory Committee to advise the Program on all aspects of the sustained-assessment process, including its engagement efforts *(Highlight 19)*.

## Highlight 16. Analyzing the Rising Costs of Climate Change to Human Health

In April 2016, USGCRP released The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment (Climate and Health Assessment), a significant advancement in understanding of the impacts of climate change on human health. It strengthens the finding in previous literature that climate change increases health risks for all Americans, that certain populations are particularly vulnerable, and that these threats are likely to increase as climate change progresses[19]. In particular, an annual increase of

thousands to tens of thousands of premature heat-related deaths in the summer, and a smaller decrease of premature cold-related deaths in the winter, are projected each year as a result of climate change by the end of the century. Other topics covered include weather and climate extremes, air quality, vector-borne disease, water- and food-related issues, and mental health and well-being.

The Climate and Health Assessment is the product of more than 100 experts and eight Federal agencies and represents a major effort of the sustained National Climate Assessment process. The report was informed by input gathered in listening sessions, scientific and technical information contributed through open solicitations, and peer-reviewed literature. It underwent rigorous reviews by the public and by scientific experts inside and outside of the government, including a special committee of the National Academies of Sciences, Engineering, and Medicine. The three-year development was overseen by the USGCRP-coordinated Interagency Working Group on Climate Change and Human Health and was led by EPA, HHS, and NOAA.




This figure depicts the projected increase in deaths due to warming in the summer months (hot season, April–September), the projected decrease in deaths due to warming in the winter months (cold season, October–March), and the projected net change in deaths compared to a 1990 baseline period for 209 U.S. cities, using the GFDL–CM3 and MIROC5 climate models. Both models project a net increase in deaths. (Source: USGCRP, adapted from Schwartz et al. 2015).

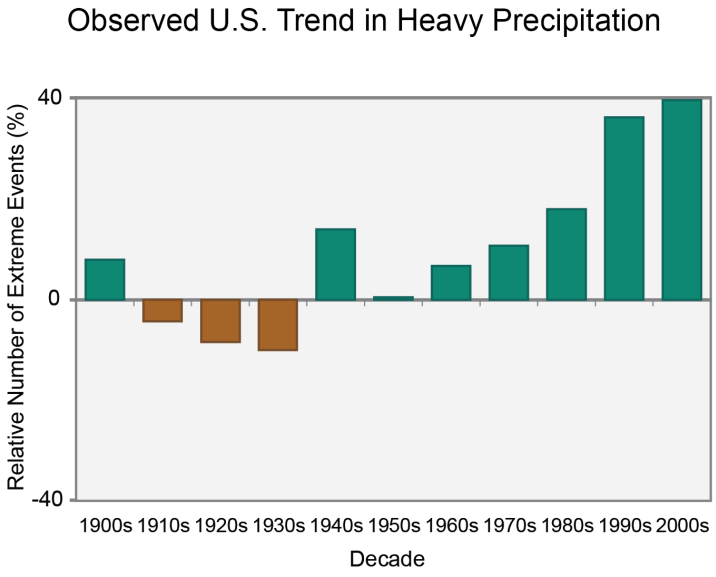
A companion website, health2016.globalchange.gov, was released with the report. It allows users to explore and share the content of the report from desktop, tablet, and mobile devices and received over 36,000 visits in its first month. Integration with USGCRP's Global Change Information System provides connection and discoverability of the 60 figures, 29 findings, and over 1,500 references contained in the report *(Highlight 18)*. The Climate and Health Assessment products offer a wealth of data and knowledge to support decision making, ensuring that the information provided is accessible and readable by a wide audience.

## Highlight 17. Improving Indicators of Change

Indicators are measurements or calculations that represent how a complex system is changing over time—for instance, the unemployment rate is an indicator of overall economic health. For the climate system, indicators offer a simple representation of how a highly complex system is changing, providing a benchmark for decision makers that can be used as a gateway into more complex and context-specific information. Indicators allow multiple audiences—including scientists, planners, policy makers, educators, and the public—to better understand and communicate the causes and effects of climate change. USGCRP has developed a pilot set of climate indicators to communicate some of the key aspects of a changing climate, including temperatures over land and at sea, greenhouse-gas levels in the atmosphere, observed trends in heavy precipitation, and related effects in sectors such as public health and agriculture.

This pilot indicators platform is the first step in developing a more comprehensive interagency indicators system that can support the sustained National Climate Assessment. Agency contributions to the indicators effort include 25 new NASA-funded three-year projects to support the development of a broader suite of climate indicators. Projects include potential indicators related to extratropical cyclone activity, vegetation water stress, extreme precipitation, and agricultural productivity. EPA continues to update its suite of climate-change indicators, and published a new report in summer 2016. EPA indicators updated with 2015 data include drought, extreme temperature, heat-related deaths, U.S. and global sea level, wildfires, and ragweed- pollen season. NOAA continues to provide funding, technical support, and data services for the interagency indicators system. These indicators draw from multidisciplinary observational capabilities that provide the ability to monitor and understand change over time *(Appendix III. Observations to Support Global-Change Research)*.

USGCRP is also testing ways to connect indicators to other agency products, information, and resources that can help people make decisions.




One measure of a heavy precipitation event is a two-day precipitation total that is exceeded on average only once in a five-year period, also known as a once-in-five-year event. As this extreme precipitation index for 1901-2012 shows, the occurrence of such events has become much more common in recent decades. Changes are compared to the period 1901-1960, and do not include Alaska or Hawai'i. The 2000s decade (far right bar) includes 2001-2012. (Source: USGCRP, adapted from Kunkel et al. 2013[20]).

## Highlight 18. Developing Scenarios of Change

Scenarios are plausible alternative futures, each describing what might happen under a range of possible assumptions about policy decisions and the behavior of the Earth system. By illustrating possible future conditions, scenarios provide a basis for analyzing the potential impacts of and responses to global change. USGCRP is working to develop scenarios of change for the United States that can feed into the sustained-assessment process and support the needs of both scientists and stakeholders, focused on population, demographics, land-use change, sea-level rise and coastal flood risk, and climate change.

**Population, demographics, and land-use change**: Changes in future population and land use have the potential to affect—and be affected by—climate change. In 2015, USGCRP convened two workshops on developing demographic and land-use scenarios for the United States. Modelers and scenario users convened 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 decision-support needs. USGCRP is coordinating the development of U.S. population scenarios using Integrated Climate and Land-Use Scenarios (ICLUS), a suite of models representing demography, migration, and spatial allocation of

housing that are consistent with the Shared Socioeconomic Pathways, a set of possible development pathways used by the climate-change-research community to standardize analyses. The use of ICLUS v2 allows the exploration of a range of development pathways, improving the ability to understand climate-change impacts, vulnerability, and mitigation and adaptation options.

**Sea-level rise**: In 2015, at the request of the White House Council on Climate Preparedness and Resilience, USGCRP and the National Ocean Council convened an interagency task force to develop consistent, accessible, authoritative, and regionally-appropriate scenarios of future sea-level rise and coastal-flood hazard for the United States, and to integrate these scenarios into existing Federal tools and capabilities for supporting preparedness planning. These scenarios are intended to serve as a starting point for coastal preparedness planning and risk-management processes and provide a basis for assessing societal and ecological risks associated with sea-level rise in the Fourth National Climate Assessment (NCA4). The task force is developing regional-scale scenarios for the entire U.S. coastline based on the global scenarios developed for the Third National Climate Assessment (NCA3), accounting for key determinants of local variability in sea-level rise. The task force is also developing scenarios of extreme-water levels associated with these sea-level rise scenarios. Participating agencies are working to integrate these scenarios with existing tools and approaches useful to communities and stakeholders, such as floodplain mapping and visualization, flood-elevation engineering tools, and tools for estimating the future extent of coastal erosion. Participating agencies include USGS, U.S. Army Corps of Engineers, FEMA, NOAA, EPA, and NASA.

**Climate change**: In May 2015, USGCRP released a memo entitled "U.S. Global Change Research Program General Decisions Regarding Climate-Related Scenarios for Framing NCA4", signaling to the climate change and impacts scientific communities that NCA4 would base its climate scenario development on the IPCC Representative Concentration Pathways and Coupled Model Intercomparison Project Phase 5 ensemble of model runs. Subsequently, USGCRP is developing and implementing an overall strategy for developing authoritative, relevant, and accessible climate-change scenarios for NCA4 and the Sustained Assessment. Participating agencies include NASA, NOAA, DOE, the Bureau of Reclamation, USGS, U.S. Army Corps of Engineers, EPA, and the Office of Science and Technology Policy.

These efforts are focused on the development of scenario products, and accompanying guidance, for NCA4 author teams and for Federal, state, tribal, and local users in need of scenarios to support their planning and decision making. Scenarios are based on aspects of the U.S. climate most relevant for assessing key societal risks, such as changes in the frequency and intensity of weather and climate extremes, and attempt to characterize these risk-relevant climate changes in the face of current scientific uncertainties.

## Highlight 19. Expanding the Global Change Information System

The Global Change Information System (GCIS) was launched in May 2014 as a repository of global-change data that could be easily and efficiently accessed, integrated with other data sets, and maintained and expanded over time. GCIS initially supported traceable data and metadata for findings and graphics in the Third National Climate Assessment (NCA3) and expanded considerably in support of the 2016 assessment The Impacts of Climate Change on Human Health in the United States *(Highlight 15)*.

From the 2014 release of NCA3 to September 2016, the number of authors catalogued in GCIS (which include

report authors as well as those contributing to input references) expanded from 1,141 to 9,500, and the number of datasets from 23 to 3,133. These inter-linked resources provide traceability and transparency of Federal global-change assessments, tools, and data, allowing users to discover authors and organizations who produced a figure within a report, trace the datasets used to produce the figure, and learn about who produced the data. In addition to providing traceability of global-change assessments and tools, efforts are underway to demonstrate how the GCIS can support the charge of the President's Climate Action Plan by facilitating an integration of the Climate Data Initiative with other Federal initiatives.

| GCIS Resources | May 2014 | September 2016 |
|---|---|---|
| Authors | 1,141 | 9,500 |
| Books | 166 | 199 |
| Datasets | 23 | 3,133 |
| Figures | 490 | 680 |
| Instruments | 0 | 530 |
| Journal Articles | 2,086 | 3,368 |
| Journals | 536 | 841 |
| Organizations | 845 | 5,268 |
| Platforms | 0 | 282 |
| Reports | 704 | 1,060 |

USGCRP's Global Change Information System (GCIS) has expanded significantly since its initial support of the Third National Climate Assessment (2014). GCIS provides traceability and transparency of Federal global-change assessments, tools, and data. (Source: USGCRP).

## Highlight 20. Expanding Engagement with USGCRP

Recognizing the value of a wide range of expertise and experience in building its decision-support capacity, USGCRP has built engagement into the sustained-assessment process at multiple levels. Public comment periods, town-hall events, and calls for technical contributions encourage input from state, local, and tribal governments; academic institutions; the private sector; and the interested public. NCAnet, a network of organizations involved in the National Climate Assessment (NCA) and its communication, has grown to include more than 180 organizations and played an important role in the release of the interagency assessment report The Impacts of Climate Change on Human Health in the United States *(Highlight 15)*. Supporting groups such as Resilience AmeriCorps and Climate Action Champions help connect USGCRP science with practitioners making adaptation and mitigation choices. The information exchanged through these interactions is helping USGCRP develop more relevant and more useful scientific products.

A better understanding of the needs of USGCRP stakeholders helps ensure that the scientific products USGCRP provides are clear, topical, and applicable to the specific needs of users at multiple levels. As USGRCP looks ahead, the information gained from engagement activities will help shape the future of the Program. NOAA, on USGCRP's behalf, has convened a 15-member Federal Advisory Committee (FAC) to advise the sustained-assessment process on enhancing engagement with stakeholders, assessment activities, and the quadrennial NCA report. FAC members are strategic thought leaders with expertise in science, communications, engagement, and education, and will advise USGCRP on how to make the sustained-assessment process and products more useful to USGCRP stakeholders, as well as to connect the Program to new groups that would not be reached otherwise.

# Communicating and Educating

An engaged, well-informed public and an appropriately-trained workforce are key components of building a national response to global change. As the coordinating body for Federal global-change research, USGCRP is in a unique position to deliver credible communication, education, and capacity-building products and programs that integrate across a diverse knowledge base. USGCRP promotes public understanding of global-change science through the development and dissemination of educational products, coordination of multi-agency initiatives, and support for training to develop the scientific workforce of the future.

An interagency initiative on climate education and literacy is putting tools and information on climate risks and solutions, including climate-based learning activities, into the hands of educators, students, and the public *(Highlights 21–22)*. Consistent with the GCRA directive to promote international cooperation on global-change research, and involve scientists and policymakers from developing nations in these activities, other initiatives include international outreach on public health and through training of young scientists in global-change research and adaptation *(Highlight 23)*, and capacity-building in India to increase resilience of the public-health sector to climate risk *(Highlight 24)*.

## Highlight 21. Implementing the Climate Education and Literacy Initiative

The Climate Education and Literacy Initiative, launched by the White House Office of Science and Technology Policy in coordination with USGCRP and many of its member agencies, helps connect American students and citizens with the best available, science-based information about climate change. Efforts through the Initiative are increasing learning opportunities for students, equipping educators with science-based information and resources, enhancing climate-related professional development and training, and engaging citizens through informal climate education where they work and play.


The "Our Time to Lead: Youth Engagement in Climate Change" event at COP21 on November 30, 2015. As part of the Climate Education and Literacy Initiative, the event engaged young leaders from around the world. (Source: Frank Niepold, NOAA).

As commitments in support of the Initiative, a group of Federal and non-Federal collaborators formed the #Youth4Climate coalition in advance of the 21st Conference of the Parties (COP21) to the United Nations Framework Convention on Climate Change in Paris, December 2015. Participants included NOAA, DOE, Connect4Climate, the Association of Science-Technology Centers (ASTC), the Climate Literacy and Energy Awareness Network, the Wild Center, Climate Generation: A Will Steger Legacy, Alliance for Climate Education, Earth Day Network, Climate Interactive, and other organizations. The program at COP21 included the U.S. Center-hosted "Our Time to Lead: Youth Engagement on Climate Change," an ASTC, Universcience, and NOAA interactive video conference to engage young leaders from around the world. Many students and educators from the United States and around the world were at events in Paris, amplifying the need for progress back

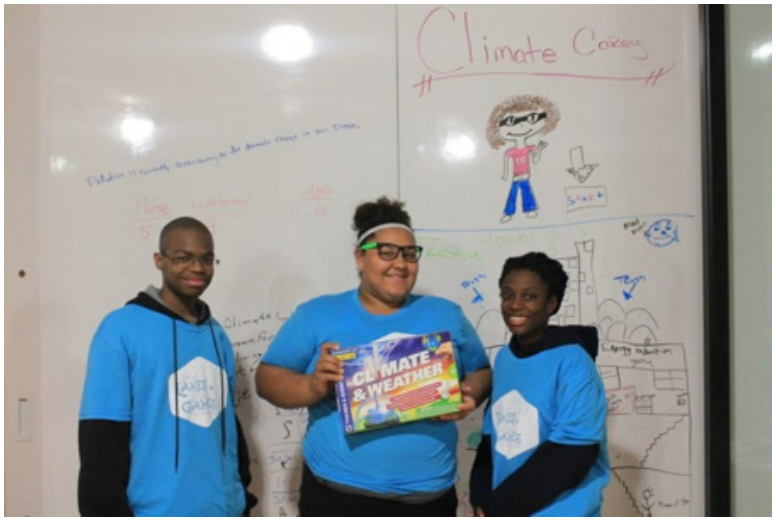
home and participating through social media, using the hashtags #Youth4Climate and #COP21 to bring their knowledge and enthusiasm to the climate discussions.

Participants in the Initiative have so far included hundreds of educators, thousands of students, and millions of engaged citizens. These leaders have reached tens of thousands directly through their work and countless more through social media and by delivering quality educational resources online and through other channels.

## Highlight 22. Using Games for Climate Education

As a part of the White House Office of Science and Technology Policy's Climate Education and Literacy Initiative *(Highlight 21)*, Federal and non-governmental experts are collaborating to harness the promise of educational games and interactive media to enhance understanding and awareness of climate-change impacts and solutions. Games are increasingly used in educational settings to help inspire curiosity, creativity, collaboration, optimism, and problem-solving skills among a wide variety of audiences. Games address real-world challenges, compress time and space, encourage systems thinking, and promote active engagement, making them particularly well-suited to climate-change education.

Two "game jams" in the past year have helped to connect American students and citizens with the best-available science-based information about climate change. In October 2015, the Climate Game Jam—held simultaneously at 11 sites across the United States—resulted in 30 new game prototypes that allow players of all ages to learn about climate change and resilience through analog and digital games. In April 2016, the Climate Game Jam Water invited teams of students in grades K-16 at nine sites to modify existing games and create new games that explored topics such as changing precipitation patterns, freshwater supply, ocean acidification, polar issues, water use, and marine and freshwater ecosystems. Selected winners from both game jams were invited to showcase their creations during special events at the Smithsonian National Museum of Natural History.



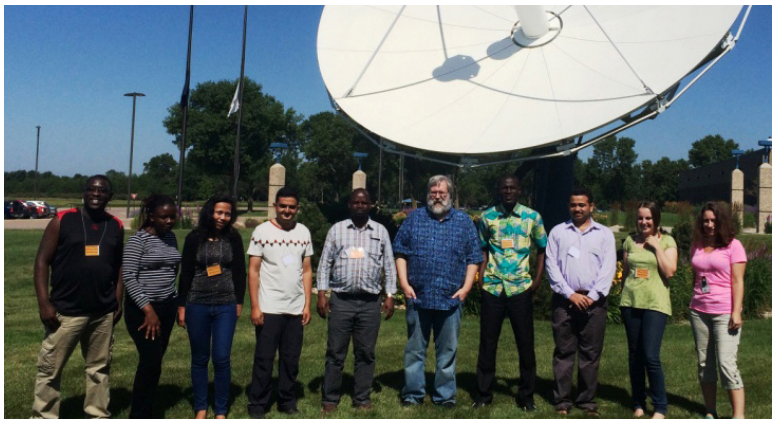
Participants at the Climate Game Jam. (Source: Frank Niepold, NOAA).

## Highlight 23. Advancing Knowledge on Global Environmental Change in Africa and Asia-Pacific

START (global change SysTem for Analysis, Research and Training) promotes research-driven capacity-building to advance knowledge on global environmental change in Africa and Asia-Pacific, through research grants and fellowships, knowledge assessments and syntheses, curricula development, advanced-training institutes, multi-stakeholder dialogues, and place-based strategic planning. In 2015, with support from USGCRP, START

enhanced the ability of over 300 researchers selected as fellows and their partners to incorporate climate information into decision making and strengthened the capacities of over 250 partner institutions to more effectively address climate-change concerns related to disaster- risk reduction, adaptation, and Earth observations. To jumpstart their work in global-change research and adaptation, fellows received training and mentoring at host institutions. START also awarded nearly 30 follow-on grants to scientists and practitioners to extend their START learning experience at their home institutions.

START is an implementation partner of the Global Observation of Forest and Land Cover Dynamics (GOFC-GOLD) program, a global collaborative effort that includes NASA, USGS, Boston University, the University of Maryland, and Wageningen University in the Netherlands. This program is helping to strengthen skills of developing country scientists to access and use Earth-observation data and build networks for knowledge sharing on land-use/land-cover change. In 2015, the GOFC-GOLD project supported four regional network-building efforts in Asia, Africa, Eastern Europe, and Latin America; facilitated a Data Initiative advanced training event that enabled young developing country scientists to gain key skills in data management, analysis, and relevant software; and contributed to relevant Group on Earth Observations/ Global Earth Observation System of Systems activities.



Fellows representing nine countries attend a 2015 GOFC-GOLD Data Initiative Advanced Training in South Dakota. (Source: START).

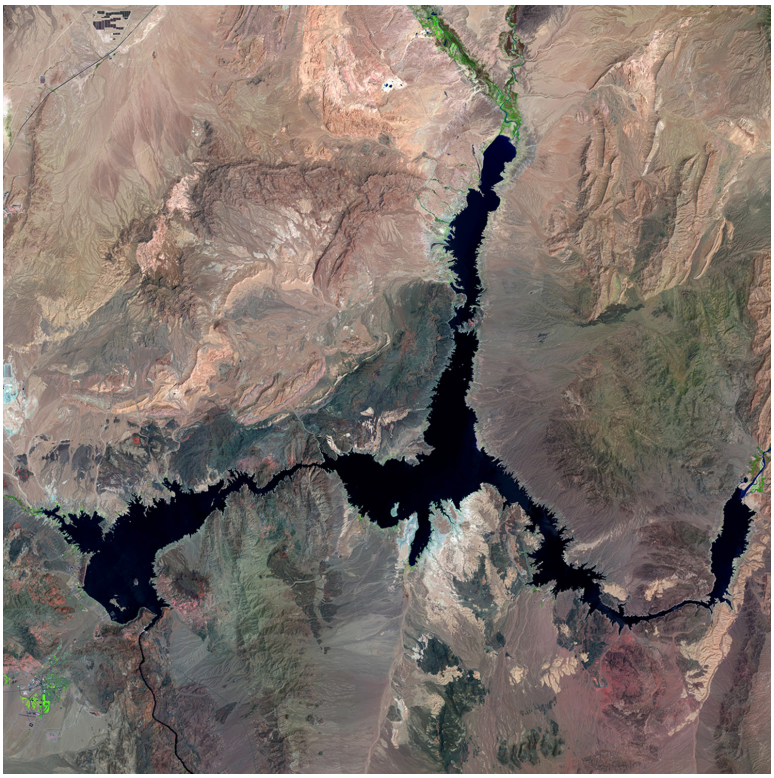
## Highlight 24. Building Public-Health Capacity for Adaptation in India

Like many developing countries, India faces a disproportionate share of adverse impacts from climate change, including the exacerbation of its already substantial public-health challenges. The government of India has recognized health as a priority area in its climate-adaptation strategy, and many states now include initiatives related to health in their climate action plans; however, internal public-health capacity for climate-change adaptation is limited. The National Institutes of Health, with support from NOAA and the Department of State, collaborated with organizers in India to host a three-day training workshop in 2015 for public-health researchers and professionals on the health impacts of climate change. This activity supports the U.S.-India Partnership for Climate Resilience, launched by President Obama and Prime Minister Modi in 2014 to catalyze inter-sectoral action on climate resilience. Health is a critical sector for adaptation and has been recognized as such in the adaptation assessments and plans published by both countries.

The workshop was a first step in developing a network, or community of practice, focused on the core topics of vulnerability, adaptation, and health co-benefits of efforts to reduce climate change. The organizers invited early-career faculty, researchers, and others in the hope of expanding the number of experts who can assist in the country's adaptation efforts. The importance of community-based participatory research, and in particular, the need to engage community stakeholders in research design and project implementation, was a key focus.

The meeting brought together a range of stakeholders from India, including the Ministries of Health and Environment, Forestry and Climate Change, Indian Meteorological Department, National Institute of Urban Affairs, National Health Systems Resource Center, Indian Institute of Public Health, and All India Institute of Medical Research.

Looking ahead, the network's goal is to help India build resilience in its health sector, particularly through rigorous adaptation planning at the subnational level. Planned activities include holding additional training events, facilitating local research, and assisting with the development of early-warning systems and health-related action plans. Through both domestic and U.S.-India collaborations, the organizers hope that the community of practice will play a central role in building India's capacity to address the health impacts of climate change.



# 3 RESEARCH FOR SOCIETAL NEEDS

# RESEARCH FOR SOCIETAL NEEDS

USGCRP's annual priorities respond to emerging challenges that tie science to society, supported by long-term Program investments in observations, modeling, process research, and actionable and accessible science. These priorities extend across agencies, scientific disciplines, and USGCRP's four strategic goals. They also answer the call from the President's Climate Action Plan to provide emerging science on climate impacts, identify vulnerabilities in key sectors, develop information and tools that decision makers need, and help communities manage climate-related risks. Annual priorities build upon previous progress, with continual refinements to fill gaps in understanding and address ongoing challenges from new angles.

USGCRP has three thematic priorities for Fiscal Year (FY) 2017, two building from previous fiscal years and one new, respectively: understanding the impacts of climate change in the Arctic and their effects on global climate, water cycle extremes in the context of climate change, and methane cycling in the context of the carbon cycle. This section provides a snapshot of Program activities that respond to each priority area. Research objectives are discussed in greater detail in the following chapter, A Look Ahead at FY 2017.

## Arctic Research and Resilience

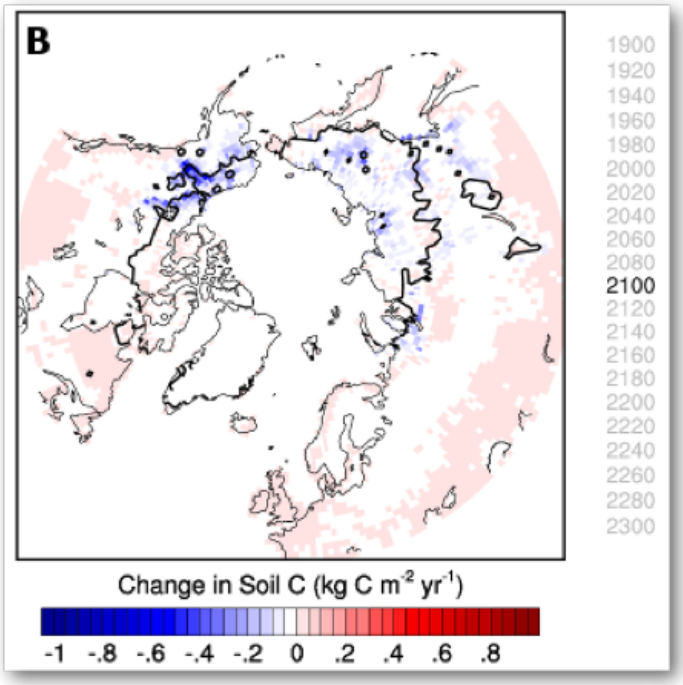
Recent observations confirm the heightened pace of climate change occurring in the Arctic, its profound impacts on Arctic ecosystems and communities, and its influence on global climate change. Global effects of Arctic change include sea-level rise, significant contribution to planetary warming, potential alteration of global weather patterns, and direct effects on the budget of global greenhouse gases, including methane. Large carbon stocks in frozen Arctic soils are particularly vulnerable to release as methane or carbon dioxide as the climate warms, and may have substantial climate feedbacks, further increasing warming and carbon release. Efforts are underway to reduce uncertainties surrounding the processes that control these feedbacks, and to better understand how much they could contribute to climate change *(Highlights 25-26)*.

In cooperation with other interagency groups, USGCRP emphases in FY 2017 include a focus on understanding Arctic ecosystem change and resulting societal vulnerabilities and on how change in the Arctic region influences weather and climate extremes, along with the use of Arctic assessments to support decision makers. Progress in these areas will contribute to U.S. goals as it completes its two-year term as Chair of the Arctic Council in the spring of 2017.

### Highlight 25. Modeling Permafrost Response to Climate Change

Vast quantities of carbon—twice the size of the current amount in the atmosphere—are stored in frozen permafrost soils in Arctic regions. The Arctic climate is warming much more rapidly than the global average, leaving these carbon pools highly vulnerable to release into the atmosphere as carbon dioxide and methane as

soils thaw and decompose, leading to a feedback cycle of further warming and increasing carbon release. The potential for these carbon stocks to increase global-warming rates, and the rapid changes already observed in the permafrost region, have captured the attention of scientists and policymakers. Scientists funded by several USGCRP agencies are working to quantify emissions from permafrost carbon, using observations and modeling to reduce uncertainties surrounding future carbon release. The Permafrost Carbon Network (PCN), with participation from USGCRP agencies and multiple countries, is working to evaluate the state of models that represent permafrost-carbon dynamics, and identify common approaches for improving model skill.




Model simulations showing the extent of permafrost loss and soil carbon change by 2100. As the climate warms, the permafrost boundary moves poleward; carbon losses from soils follow and loss rates persist long after the period of rapid thaw. (Source: Koven et al., 2015[21]).

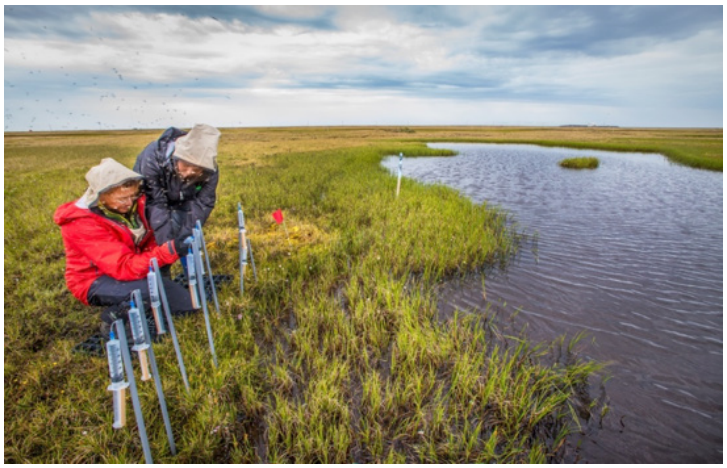
Underlying many of the uncertainties surrounding permafrost carbon release is the need to better integrate observations into models. By synthesizing observational data and model outputs from multiple sources, recent PCN activities have found that permafrost-carbon feedbacks to global warming are likely to be strong but relatively slow, operating on timescales of about a century or longer, and that carbon stocks are unlikely to be released abruptly. Permafrost carbon release is likely to be roughly linear with warming, with a feedback magnitude of about one third of the total estimated global carbon-climate feedback. However, uncertainty surrounding key processes that control the feedback from permafrost is high, particularly with regard to changes in the water cycle and soil moisture conditions. Further critical uncertainties include the decomposition dynamics of thawed permafrost soils, and how vegetation response to changing soil conditions affects the stability of carbon stocks.

Across USGCRP agencies, many activities focus on translating understanding derived from observations into climate models. Together, the DOE-led Next-Generation Ecosystem Experiments in the Arctic *(Highlight 26)*, NASA's Arctic-Boreal Vulnerability Experiment *(Appendix III. Observations to Support Global-Change Research)*, and complementary activities from other agencies are helping advance understanding of permafrost response to warming, and its implications for regional and global climate change.

## Highlight 26. Improving Predictions of Changing Arctic Ecosystems

A key challenge for Earth System Models is accurately representing land surface and subsurface processes and their complex interactions in a warming climate. This is true for ecosystems across the globe, but particularly critical for Arctic ecosystems, which are projected to warm at a rate twice that of the global average by the end of the 21st century. The Next-Generation Ecosystem Experiments in the Arctic (NGEE-Arctic) proj-

ect is addressing this challenge by integrating process studies, ecosystem observations, and computational modeling to improve the ability to understand, model, and predict important ecosystem-climate feedbacks in the Arctic. This research focuses on rapidly changing permafrost landscapes where large carbon stocks are vulnerable to release as greenhouse gases. Field research sites in different types of permafrost environments in Alaska allow researchers to test and apply a framework for measuring and modeling the evolution of terrestrial ecosystems in a changing climate.



The Next-Generation Ecosystems Experiment in the Arctic is integrating ecosystem observations with computational models to better understand, model, and predict climatically-important feedbacks from Arctic ecosystems. (Source: DOE).

NGEE-Arctic draws upon expertise from across a consortium of DOE National Laboratories, academic institutions, and international, state, and Federal agencies. The project benefits from regional co-location of sites with the DOE Atmospheric Radiation Measurement program, the NSF National Ecological Observatory Network program, and NOAA's Earth System Research Laboratory, each of which provide valuable data resources. In addition, researchers from NASA's Carbon in Arctic Reservoirs Vulnerability Experiment and Arctic-Boreal Vulnerability Experiment campaigns *(Appendix III. Observations to Support Global-Change Research)* are using NGEE-Arctic field sites for validation of remote-sensing products and, in turn, providing opportunities to extrapolate insights from field plots to landscapes and ultimately, to regions. A focus on scaling will enable these interagency activities to deliver a process-rich model allowing the evolution of Arctic ecosystems in a changing climate to be modeled at high resolution.

## Water-Cycle Extremes and their Impacts

Extremes in the water cycle impact all aspects of life on Earth, including food availability, infrastructure durability, human health, and energy production. As extreme weather and climate events become more frequent and more intense under a changing climate, basic and applied water-cycle science is increasingly vital to the health of the Nation. This research area addresses knowledge gaps that limit the ability to understand and predict the interplay between climate variability and change and extreme events associated with Earth's water cycle. In FY 2017, this priority includes a greater emphasis on assessing and anticipating the ecological impacts of such changes and their societal effects. This research area focuses on achieving a better understanding of changing patterns in both wet and dry extremes, including the impacts of, and responses to, such changes. In support of the President's Climate Action Plan, this priority will provide new knowledge that can be used for drought and flood preparedness and longer-term resilience strategies.

Efforts include research into the sources of variability in West Coast precipitation, which can lead to better predictive capabilities for droughts and floods *(Highlight 27)*, and research supporting drought prediction and the development of tools to communicate risk to stakeholders *(Highlight 28)*.

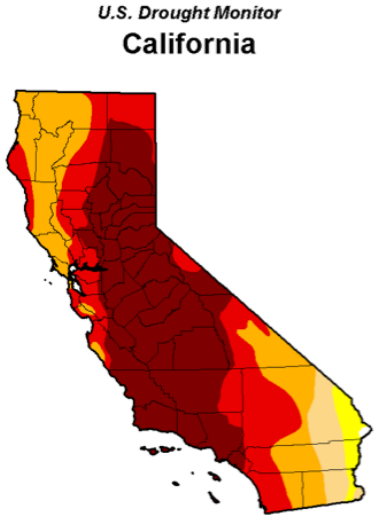
## Highlight 27. Understanding Atmospheric Rivers and West Coast Precipitation

Much of the precipitation along the U.S. West Coast is delivered by phenomena known as "atmospheric rivers"—narrow bands of moist air that may extend for thousands of miles across regions outside of the tropics, and play a critical role in regional water supply and storm activity. Atmospheric-river events play a beneficial role in building up Western water supply and snowpack but are also the source of a large majority of floods in the region[22]. Many uncertainties about key processes that affect storm development within atmospheric rivers limit the ability to predict atmospheric rivers and associated precipitation. An improved understanding of these processes is needed to reduce uncertainties in weather predictions and climate projections of droughts and floods, both now and under changing climate conditions. From January-March 2015, the joint NOAA, NASA, and DOE CalWater-2 campaign collected a comprehensive dataset in environments where atmospheric rivers develop and make landfall, including data on how atmospheric aerosols influence precipitation.

Aircraft instruments sampled aspects of atmospheric rivers and their associated environment, and researchers aboard a NOAA Research Vessel operated NOAA and DOE instrumentation, measuring energy flow between the ocean and the atmosphere and its influence on atmospheric rivers. The campaign also built on the new NOAA Hydrometeorology Testbed (HMT) ground sites, which contributed measurements of precipitation, winds, snowpack, soil moisture, snow level, and surface weather. Scripps Institution of Oceanography installed additional instrumentation at the Bodega Bay HMT site to study aerosol chemistry. This data will be used to improve short- and long-term precipitation predictions and develop decision-support tools for extreme-precipitation events, hazard response, and water-resources management.

## Highlight 28. Focusing on the California Drought

Since 2011, California has experienced one of its most severe and widespread droughts since record-keeping began in 1895. USGCRP-supported research helps advance drought science and provides the basis for the National Integrated Drought Information System (NIDIS) *(Highlight 10)*, which aims to increase the capacity of the public to better prepare for and respond to drought events through regional Drought Early Warning Systems (DEWS). The NOAA Drought Task Force, a group organized by NOAA and NIDIS involving scientists across the USGCRP agencies, helped bring drought science to decision makers. The group developed a timely assessment of the link between California droughts and El Niño events, of key relevance given the strong 2015–2016 El Niño. A new Task Force report demonstrates how research investments over the past decade have advanced the NIDIS DEWS and discusses opportunities




U.S. Drought Monitor map of California from November 3, 2015, when 71% of the state was experiencing extreme or exceptional drought. The National Integrated Drought Information System (NIDIS) assimilates drought-related information, data and products used to produce the Drought Monitor. The NOAA Drought Task Force, a group organized by NOAA and NIDIS involving scientists across the USGCRP agencies, helped bring relevant science to decision makers during the drought, developing a timely assessment of the link between California droughts and El Niño events. (Source: NIDIS).

for further progress in drought monitoring and prediction.

In addition, USDA-National Institute of Food and Agriculture and NOAA jointly funded a multi-university research team to work with agricultural producers and decision makers to better communicate the uses and limitations of currently available drought products, develop high-resolution drought-monitoring products tailored for planning purposes, and identify needs for new information products. USGCRP drought scientists also played a significant role in the American Geophysical Union Chapman Conference on the California Drought held in Irvine, California in April 2015. The conference examined the broad range of issues associated with the drought, including meteorological factors, the nature of California's water-delivery system, stakeholder needs and concerns, and policy and management solutions.

## A Changing Carbon Cycle: Focus on Methane Cycling

Increased atmospheric concentrations of carbon-based greenhouse gases are the main driver of climate change. Methane is the second-most important greenhouse gas emitted by human activities and has a much higher global-warming potential than carbon dioxide on a per unit basis[23]. Both human activities and natural processes release methane into the atmosphere, but the details of each source are insufficiently understood. Further, methane's atmospheric lifetime is significantly shorter than that of carbon dioxide, meaning that steps to mitigate methane emissions could have a relatively more rapid impact.

Building on its Carbon Cycle Science Program, and in support of the President's Climate Action Plan Strategy to Reduce Methane Emissions, USGCRP has adopted an FY 2017 interagency priority that includes strengthening capabilities to monitor natural and anthropogenic methane fluxes, understanding processes governing significant methane emissions sources, and improving models and predictions of methane cycling in the context of the carbon cycle. Efforts include campaigns to measure the largest known methane leak in U.S. history *(Highlight 29)* and reduce uncertainties in seasonal and climatic controls on methane emissions in the Arctic tundra, a major global source of methane that may increase substantially with warming *(Highlight 30)*.

### Highlight 29. Measuring the Largest Methane Leak in U.S. History

On February 11, 2016, workers in California ended the largest reported natural gas leak in U.S. history. The Aliso Canyon leak released methane and other gases into the atmosphere from an underground-storage facility for over three months, causing the evacuation of more than 5,000 households. Researchers from NOAA, NASA, Scientific Aviation, the University of California, the National Institute of Standards and Technology (NIST), the California Air Resources Board, and South Coast Air Quality Management District mobilized rapidly to assess the environmental impacts of the leak, deploying existing measurement capabilities to quantify how much methane, a potent greenhouse gas, was escaping. The interagency response to this incident demonstrated the application of multiple, independent methane-measurement methods to address challenges ranging from rapid response to unplanned events, to ongoing emissions monitoring and characterization of emissions sources at fine scales.

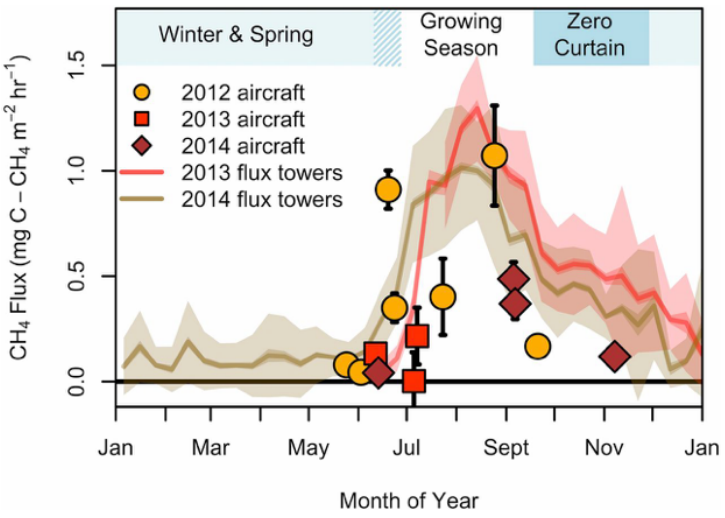
Thirteen research flights provided an unprecedented opportunity to document the total amount of methane

released over the 112-day leak. A study co-led by NOAA, published in Science just two weeks after the leak was stopped, estimated that about 97,000 tons of methane were released—one quarter of the methane that is typically emitted by the entire Los Angeles Basin over the course of a year—making the leak the largest reported accidental release of methane in U.S. history[24]. In addition, the Hyperion instrument on NASA's EO-1 satellite and NASA research aircraft successfully detected and quantified the leak plumes at high spatial resolution[25].

Instrumentation deployed through the Megacities Carbon Project *(Highlight 5)* provided data on background methane emissions in the area and documented abnormally large methane plumes crossing the Los Angeles basin during the Aliso Canyon incident. Analysis using data from the Megacities tower network and NASA's California Laboratory for Atmospheric Remote Sensing is underway to develop a record of methane emissions sufficient to attribute fluxes to the vicinity of the Aliso Canyon facility. These analyses will evaluate the potential for smaller emissions in the weeks preceding the leak onset, the potential for highly variable fluxes associated with early "top-kill" attempts to stop the leak, and subsequent evolution of the leak flux before and after the successful "bottom-kill" closure. Data from remote-sensing instrumentation mounted on aircraft is also being combined with NIST plume modeling to estimate emissions fluxes. Future analyses and synthesis of these data sets will further explore the physical mechanisms controlling methane leak rates and their potential broader applicability to other underground gas-storage facilities.

## Highlight 30. Tracking Methane Emissions from Arctic Tundra

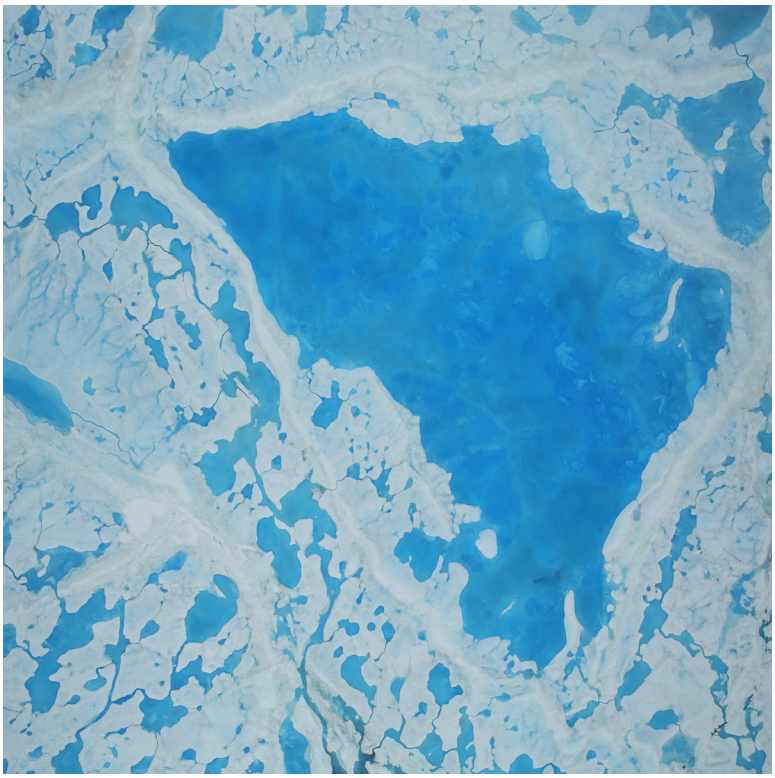
The Arctic tundra is a cold, desert-like biome, with a layer of permanently frozen soil and organic matter below the surface containing vast stocks of carbon. As Arctic tundra soils warm in response to climate change, methane emissions from decomposing organic material could increase dramatically, representing a potentially significant positive feedback on climate warming. However, seasonal and climatic influences on methane emissions from these systems are not well understood outside of the summer months, representing a major uncertainty for the Arctic methane budget. To help address a critical knowledge gap in cold-season methane emissions, a coordinated international, multiagency field study sponsored by NASA, NSF, and DOE made year-round measurements of methane emissions from Alaskan Arctic tundra eddy covariance towers and regional flux estimates from aircraft data. Recent findings report that emissions during the cold season account for approximately 50% of the annual methane flux, with the highest emissions from dry upland tundra[26].




Ten-day average of methane ($CH_4$) flux measured by five eddy covariance (EC) towers over a 300-kilometer transect across the North Slope of Alaska (shaded bands) for 2013 (red) and 2014 (brown), with the mean (solid line), 95% confidence intervals (darker shade), and standard deviation in the $CH_4$ data (lightest shade). The regional fluxes of $CH_4$ calculated from Carbon in Arctic Reservoirs Vulnerability Experiment aircraft data for the North Slope of Alaska are shown for 2012 (yellow circles), 2013 (red squares), and 2014 (brown diamonds). The mean dates for the onset of winter, the growing season, and the zero curtain are indicated in the band on top. Regional scale methane fluxes showed similar seasonal patterns to the five EC flux towers across multiple years. (Source: Zona et al. 2016).

Scaled to the global Arctic, cold-season fluxes from tundra represent about 25% of global emissions from wetlands outside of the tropics, or about 6% of total global wetland methane emissions.

Emissions of methane in the cold season are linked to the extended "zero curtain" period, when subsurface soil temperatures are poised near 0° Celsius, indicating that total emissions are very sensitive to soil conditions and related factors, such as snow depth. The dominance of late-season emissions, sensitivity to soil environmental conditions, and importance of dry tundra are not currently simulated in most global climate models. Because Arctic warming disproportionately impacts the cold season, results suggest that higher cold-season methane emissions will result from observed and predicted increases in snow thickness, active-layer depth, and soil temperature, representing important positive feedbacks on climate warming.



# 4 A LOOK AHEAD AT FY 2017

# A LOOK AHEAD AT FY 2017

USGCRP interagency research priorities draw from the breadth of the Program's capabilities in observations, integrated modeling, process research, and actionable science to address emerging research opportunities and key scientific gaps and respond to critical decision-support needs. Extremes, thresholds and tipping points form an overarching and longer-term theme for USGCRP that includes building observational and modeling capabilities and theoretical understanding. Continuing as priorities from FY 2015 and 2016, nearer-term foci within this theme include Arctic Research and Resilience and Water-Cycle Extremes and their Impacts. Methane Cycling within the Carbon Cycle Framework is a new focal area for FY 2017, but reflects an area of ongoing Program interest, as seen in Highlights 29-30. This section provides a high-level outline of research objectives for the priority areas in FY 2017.

## Arctic Research and Resilience

USGCRP aims to increase understanding of rapid Arctic environmental change and its implications for regional and global climate systems, as well as for societal risks and vulnerabilities in the region and worldwide. Under the auspices of the Arctic Executive Steering Committee, USGCRP is coordinating with other interagency groups (the Interagency Arctic Research Policy Committee, Subcommittee on Ocean Science and Technology, and U.S. Group on Earth Observations) to focus respective and collaborative efforts and leverage capabilities towards common goals. USGCRP's efforts within this arena include advancing Arctic observations, including field campaigns; contributing to assessments of Arctic adaptation and resilience; and improving understanding of the connections between Arctic change and global climate change. Enhanced understanding of the processes governing methane emissions in the Arctic, particularly as permafrost thaws, links USGCRP's Arctic and methane priorities.

NGEE-Arctic field research. (Source: DOE).

## Water-Cycle Extremes and their Impacts

This priority area addresses knowledge gaps that limit the ability to understand and predict the interplay between climate change and the Earth's changing water cycle, and the interdependent human and natural systems that rely on water and, in turn, influence regional water cycles. It expands on the FY 2015 and 2016 water-cycle priority by developing capabilities to better assess and anticipate the ecological and societal impacts of water-cycle extremes on key sectors, such as energy, agriculture, infrastructure, and health. This priority aims to improve the U.S. Government's ability to predict and characterize, especially on decadal timescales, extreme events including droughts and extreme precipitation, and advance understanding of the relationships between global climate change and national- and regional-scale water-cycle characteristics.

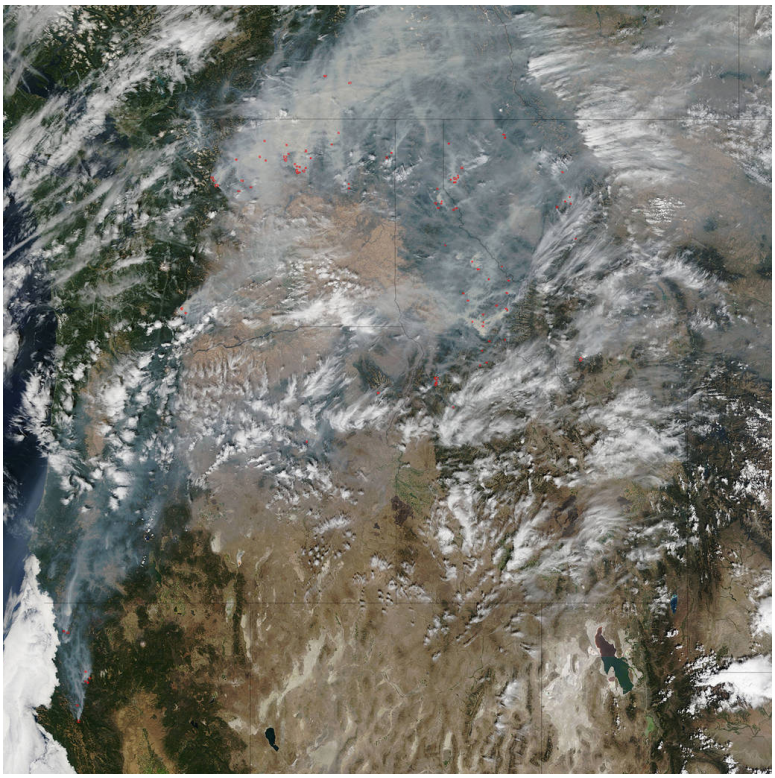
FEMA's Urban Search and Rescue Teams go through neighborhoods with the National Guard to look for residents that may be stranded in a neighborhood that was flooded following Hurricane Matthew. (Source: Jocelyn Augustino, FEMA).

## A Changing Carbon Cycle: Focus on Methane Cycling

Methane bubbles pop on the surface of a lake near Fairbanks, Alaska. Thawing permafrost in the lakebed soils releases old carbon, which microbes eat up and turn into methane. (Source: Kate Ramsayer, NASA).

USGCRP will spotlight its work on the carbon cycle over the next several years, with a FY 2017 focus on methane. This focus is intended to be supportive of, and complementary to, the "Strategy to Reduce Methane Emissions" announced in 2014 as part of the President's Climate Action Plan. Research objectives include enhancing understanding of processes governing methane emissions in key areas such as wetlands, the energy sector, agriculture and forestry, and oceans and permafrost regions as climate changes, and incorporating this understanding into climate models and projections of potential future releases and associated climate feedbacks. A major objective involves strength-

ening and expanding long-term monitoring efforts that are fundamental to understanding and modeling the interplay between atmospheric methane levels and methane sources from human activities and Earth's ecosystems, and that underlie needed improvements to estimates and predictions of methane emissions, inventories, radiative forcing, and attribution. On issues related to measurement and characterization of domestic anthropogenic methane emissions from all sectors, USGCRP will collaborate with the National Science and Technology Council's Methane Monitoring and Characterization Working Group. Other objectives include the improvement and utilization of climate models to simulate the evolving sources and sinks of methane and evaluate and project methane's climate effects and feedbacks.



# 5 BUDGET INFORMATION

# BUDGET INFORMATION

The FY 2017 President's Budget requests approximately $2.8 billion for USGCRP research programs, an increase of $190 million over FY 2016 levels. This request represents a commitment by the Administration to ensure that USGCRP can fulfill the mandate of the Global Change Research Act. The budget crosscut represents the funds self-identified by USGCRP agencies as their contributions to USGCRP research activities.

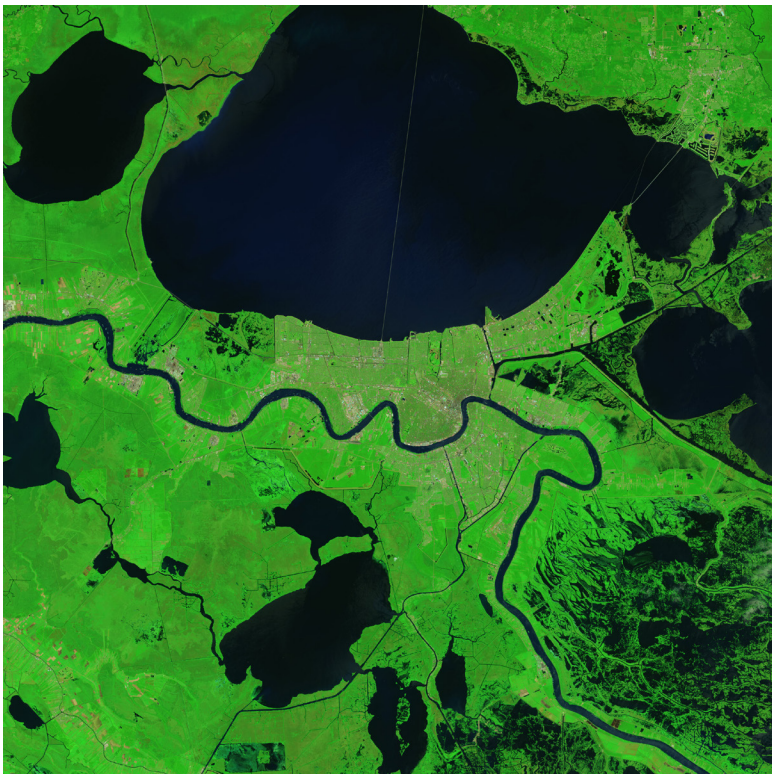
It is important to note that USGCRP leverages other agency activities not represented in the budget crosscut to accomplish its mission. For example, many of the satellite systems and observing networks that are foundational to USGCRP research were originally implemented by their sponsoring agencies for operational purposes, and thus typically are not included in the research 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 are essential to delivering on the goals of the 2012-2021 Strategic Plan. By leveraging capacity and cooperation, agencies make vital contributions towards USGCRP's goal of supplying the knowledge base needed to respond to global change.

## FY 2015 - FY 2017 USGCRP Budget Crosscut by Agency

Funding amounts are shown in millions of dollars ($M) and are rounded to the nearest millions (totals reflect the rounded sum of the unrounded agency amounts). DOD does not report activities or funding through the USGCRP budget crosscut. 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, and DOS and USAID are considered "Non-Add Agencies."

| Agency | FY 2015 Budget Enacted ($M) | FY 2016 Budget Enacted ($M) | FY 2017 Budget Requested ($M) |
|---|---|---|---|
| Department of Agriculture (USDA) | 96 | 98 | 124 |
| Department of Commerce (DOC) | 312 | 283 | 342 |
| Department of Energy (DOE) | 214 | 238 | 242 |
| Department of Health and Human Services (HHS) | 8 | 8 | 8 |
| Department of the Interior (DOI) | 58 | 57 | 63 |
| Department of Transportation (DOT) | 1 | 1 | 1 |
| Environmental Protection Agency (EPA) | 16 | 19 | 22 |
| National Aeronautics and Space Administration (NASA) | 1,432 | 1,549 | 1,632 |
| National Science Foundation (NSF) | 331 | 339 | 348 |
| Smithsonian Institution (SI) | 8 | 8 | 9 |
| **TOTAL** | **2,474** | **2,599** | **2,790** |
| **Non-Add Agencies*** | **FY 2015 Budget Enacted ($M)** | **FY 2016 Budget Enacted ($M)** | **FY 2017 Budget Requested ($M)** |
| U.S. Agency for International Development (USAID) | 6 | 9 | 10 |

* Department of State (DOS) has been included as a non-add agency in the past, but reported no USGCRP funding during this time period.



# 6 APPENDICES

# Appendix I: About USGCRP

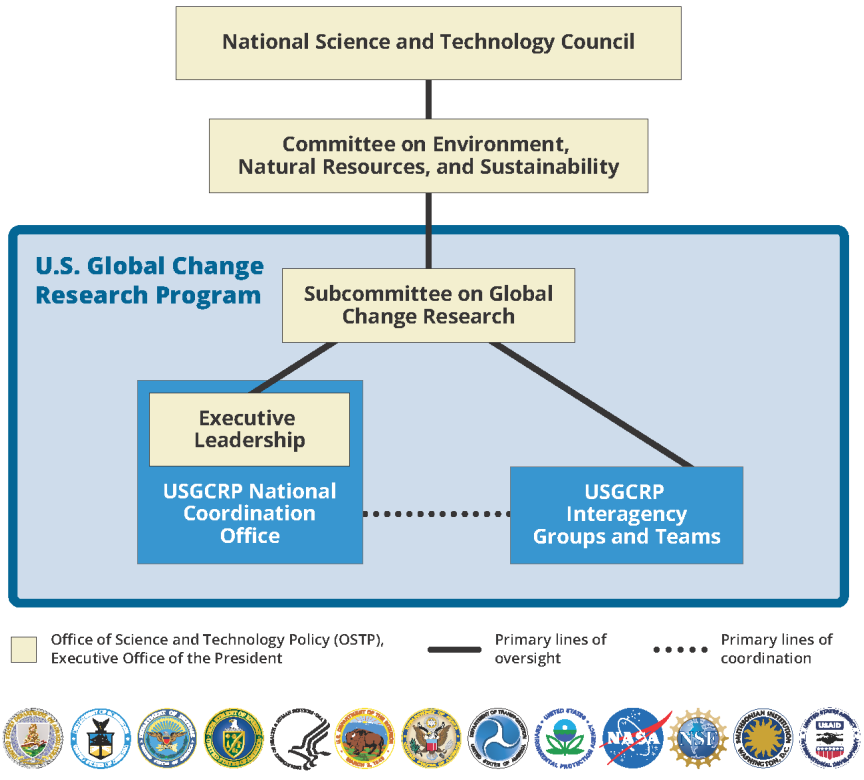
The U.S. Global Change Research Program (USGCRP) was established by Presidential Initiative in 1989 and mandated by Congress in the Global Change Research Act (GCRA) of 1990 to develop and coordinate "a comprehensive and integrated United States research program which will assist the Nation and the world 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 Figure 1: USGCRP Member Agencies)* 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 understanding of how global change is impacting society, both today and into the future.

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 through an integrated, end-to-end program.

The Program is directed and overseen by the Subcommittee on Global Change Research (SGCR), which is chartered under the Committee on Environment, Natural Resources and Sustainability (CENRS), a part of the National Science and Technology Council (NSTC). The SGCR oversees interagency activities through the interagency working groups (IWGs) and the USGCRP National Coordination Office *(Figure 4: USGCRP Lines of Oversight and Coordination)*.

Figure 4:
USGCRP Lines of Oversight and Coordination




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's current working groups are the following:

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

# Appendix II: USGCRP 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) Climate Change Research Program empowers land managers, policy makers, and its agencies with science-based knowledge to manage the risks and opportunities posed by climate change, reduce greenhouse gas emissions, and enhance carbon sequestration. USDA's Climate 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). In addition to these agencies, programmatic and operational support for adaptation preparedness and resilience, greenhouse gas mitigation, and outreach and education are contributed by the Risk Management Agency (RMA) and Rural Development (RD), the Animal and Plant Health Inspection Service (APHIS), the Farm Service Agency (FSA), the Office of the Chief Economist (OCE), and Departmental Management Offices (DM). USDA has established Regional Climate Hubs for Risk Adaptation and Mitigation. Together the many USDA research and programmatic entities help ensure sustained food security for the Nation and the World. They maintain and enhance the health of U.S. forests, rangelands and natural resources while identifying ways to manage the risks and vulnerabilities ranging from temperature and precipitation extremes to the changing biology of pests, invasive species, increased wildfire intensity and extent, and diseases.

USDA develops greenhouse gas inventories and conducts assessments and projections of climate-change impacts on the natural and economic systems associated with agricultural production and forest and forest products. USDA also develops cultivars, cropping systems, and management practices to improve drought tolerance and build resilience to climate variability. The USDA Building Blocks for Climate Smart Agriculture and Forestry framework spans a range of technologies and conservation practices to reduce greenhouse gas emissions, increase carbon storage, and generate renewable energy. USDA both conducts research and 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 through its Regional Climate Hubs network and delivers science-based region-specific information and technology. 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 Analysis (FIA). Finally, USDA engages in communication, outreach, and education through multiple forums, including its vast network of agricultural extension services, its field offices, and its Regional Climate Hubs.

## Department of Commerce

The National Oceanic and Atmospheric 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
- 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 greenhouse gas 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.

## 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 greenhouse gas 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 greenhouse gas 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 greenhouse gas flux in the Nation's ecosystems.

USGS also leads the regional DOI Climate Science Centers (CSCs) that provide science and technical support to other bureaus as well as region-based partners, such as Landscape Conservation Cooperatives (LCCs), that are dealing with the impacts of climate change on fish, wildlife, and ecological processes. The LCCs complement and work closely with the CSCs, focusing on convening partners, developing shared plans, and delivering applied tools for addressing climate change and other landscape-scale stressors.

## 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, metropolitan, and local agencies. DOT has requested funding in FY 2017 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. These tools will help transportation agencies to consider improved resiliency and reliability of the transportation system in transportation planning, asset management and project development.

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 policy makers, stakeholders, 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 defining adaptation options to effectively prepare for and 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 and human health impacts of greenhouse gas emissions reduction technologies and approaches to inform mitigation solutions. EPA Program Offices and Regions leverage this research to support mitigation and adaptation decisions and to inform communication with external stakeholders and the public.

EPA relies on USGCRP to develop high-quality scientific models, data, and assessments to advance understanding about physical, chemical, and biological changes to the global environment and their relation to drivers of global climate change. Satellite and other observational efforts conducted by USGCRP agencies are crucial to supporting EPA's efforts to understand how land-use change, population change, climate change, and other global changes are affecting ecosystems, and the services they provide. EPA's global-change research applies and extends these results using regional and local air quality, hydrology, and sea-level rise models to better understand the impacts of climate change to specific human health and ecosystem 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 and understanding about the connections between global change and impacts at local, regional, and national scales, as well as how mitigation and adaptation actions may influence global changes.

EPA's research informs approaches to prepare for, adapt to, and minimize the impacts of climate change, including extreme weather events, wildfire, and rising sea levels, and their impacts on human health and well-being and social and economic systems. Other EPA program activities include the development and application of economic and biophysical models to generate projections of potential future greenhouse gas emissions trajectories and mitigation scenarios. EPA also applies long-term datasets and analytical tools to communicate observed climate change indicators and conduct economic and risk modeling to examine and project analyze impacts and economic damages associated with global mitigation scenarios. EPA collaborates with other agencies and numerous stakeholders to develop the Inventory of U.S. Greenhouse Gas Emissions and Sinks, which is submitted to the United Nations in accordance with the Framework Convention on Climate Change. Lastly, EPA efforts include technical evaluation of biogenic emissions fluxes associated with biomass use for energy.

## 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 22 on-orbit satellite missions (as of July 2016) measure numerous variables required to enhance understanding of Earth interactions. NASA is now routinely providing data from satellites launched in the 12-month period from February 2014 to January 2015: including precipitation data from the Global Precipitation Measurement (GPM), carbon dioxide data from the Orbiting Carbon Observatory-2 (OCO-2), and soil moisture data from the Soil Moisture Active Passive (SMAP), as well as wind and aerosol/cloud data from two payloads aboard the International Space Station (ISS), RapidScat and Cloud-Aerosol Transport System, respectively. NASA is also contributing to ocean and atmosphere observations with satellites launched by interagency partners (Jason-3, Deep Space Climate Observatory). NASA has delivered two payloads for planned late 2016 launch to the ISS: the Lightning Imaging Sensor, and the Stratospheric Aerosol and Gas Experiment-III. In November 2016, NASA will launch the Cyclone Global Navigation Satellite System constellation of eight nanosatellites to study winds associated with tropical storms and severe weather systems. In 2016, NASA selected two additional satellite missions as part of its Earth Venture–Instrument series of missions: 1) the Multi-Angle Imager for Aerosols, which will provide observations of small atmospheric aerosol particles to be combined with health information to determine the toxicity of different particulate matter types in airborne pollutants over the world's major cities; and 2) Time-Resolved Observations of Precipitation structure and storm intensity with a Constellation of Smallsats, which will develop and launch a constellation of CubeSats to study the development of tropical cyclones through rapid-revisit sampling.

The Administration's FY 2017 budget also enables NASA to continue its program in sustainable land imaging (in coordination with the U.S. Geological Survey) and in 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-in-

duced 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. Six significant new multi-year airborne campaigns initiated in 2015 began deployment in 2016. They 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 overlying atmosphere. 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, and are focused on such areas as water resources, health/air quality, and ecological forecasting. 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. During the FY 2016/FY 2017 timeframe it will launch several small satellites as part of its InSpace Validation of Earth Science Technologies.

## 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 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.

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, Smithsonian Design Museum 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.

# Appendix III: Observations to Support Global-Change Research

USGRP science—including fundamental research, modeling, assessments, and science for decision support—has its foundation in sustained and experimental 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 necessary for understanding and responding to global change. As an illustration of the breadth and depth of the Program's observational capabilities, this table lists examples of observational efforts that have begun or will begin and those that have ended or will end in 2015 or 2016. It does not include existing longer-term observations systems.

## A. Projects completed in 2015 or 2016

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| ***Airborne Microwave Observatory of Subcanopy and Subsurface (AirMOSS) Experiment*** | **Description:** AirMOSS collects and uses airborne radar to collect soil moisture data from nine climatic habitats in North America to estimate how much carbon the continent is taking in or releasing to the atmosphere.<br>**Sponsoring agencies:** NASA (EVS-1)<br>**Observation type:** field campaign<br>**Location:** Continental United States and Alaska<br>**Timeline**: March 2012 – August 2016<br>**More Information**: https://airmoss.jpl.nasa.gov |
| ***Airborne Tropical Tropopause Experiment (ATTREX)*** | **Description:** ATTREX used measurements onboard the NASA Global Hawk to investigate: the role of stratospheric water vapor in Earth's energy budget and climate; dehydration of tropospheric air entering the stratosphere; and the physical processes and chemical composition of the Tropical Tropopause Layer (TTL) to better understand the controls on the composition of the stratosphere.<br>**Sponsoring agencies:** NASA (EVS-1)<br>**Observation type:** field campaign<br>**Location:** Flights from Palmdale, CA (Oct-Nov 2011, Jan-Feb 2013, Feb-Mar 2015) and Guam (Jan-Mar 2014)<br>**Timeline**: November 2011 – November 2015<br>**More Information**: https://espo.nasa.gov/missions/attrex |
| ***Aquarius*** | **Description:** Aquarius was a focused satellite mission to measure sea surface salinity that provided the global view of salinity variability needed for climate studies.<br>**Sponsoring agencies**: NASA, CONAE (Argentina)<br>**Observation type:** satellite<br>**Location:** global<br>**Timeline:** June 2011 to June 2015.<br>**More Information**: http://aquarius.nasa.gov/ |
| ***Carbon in Arctic Reservoirs Vulnerability Experiment (CARVE)*** | **Description:** CARVE is a five-year mission to measure carbon dioxide and methane fluxes from Alaska, using sensors aboard a NASA aircraft to deliver the first simultaneous measurements of surface parameters that control gas emissions and total atmospheric columns of carbon dioxide, methane, and carbon monoxide. Continuous ground-based measurements provide temporal and regional context as well as calibration for airborne measurements. Contributions of tower and aircraft observations were provided by NOAA as well as a tower near Fairbanks with continuous measurements of methane.<br>**Sponsoring agencies:** NASA (EVS-1), NOAA<br>**Observation type:** field campaign<br>**Location:** Alaska<br>**Timeline:** November 2010 – November 2015<br>**More information:** http://science.nasa.gov/missions/carve/ |

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| ***Deriving Information on Surface Conditions from Column and Vertically Resolved Observations Relevant to Air Quality (DISCOVER-AQ)*** | **Description:** DISCOVER-AQ is a five-year mission to improve the interpretation of satellite observations to diagnose near-surface conditions relating to air quality. This campaign utilized an systematic and concurrent observation strategy which included: in situ vertical profiles on the NASA P-3B; remote sensing mapping of trace gas and aerosol columns on the UC-12; surface lidar and balloon soundings; and continuous monitoring of trace gases and aerosols at surface sites (including both in situ and column-integrated quantities.<br>**Sponsoring agencies:** NASA (EVS-1)<br>**Observation type:** field campaign<br>**Location:** Baltimore-Washington (2011), Houston (2013), San Joaquin Valley (2013), Denver (2014)<br>**Timeline:** November 2010 – November 2015<br>**More information:** http://discover-aq.larc.nasa.gov |
| ***Hurricane and Severe Storm Sentinel (HS3)*** | **Description:** HS3 is a five-year mission specifically targeted to investigate the processes that underlie hurricane formation and intensity change in the Atlantic Ocean basin. HS3 is motivated by hypotheses related to the relative roles of the large-scale environment and storm-scale internal processes. HS3 addresses the role of the Saharan Air Layer in tropical storm formation and intensification as well as the role of deep convection in the inner-core region of storms.<br>**Sponsoring agencies:** NASA (EVS-1)<br>**Observation type:** field campaign<br>**Location:** 2011 (Pacific Atm River), 2012 (Hurr. Leslie, TS and Hurr Nadine), 2013 (Ex-TS Erin, TS Gabrielle, Hurr. Ingrid, TS Humberto), 2014 (Hurr. Cristobal, TS Dolly, TS and Hurr. Edouard, Hurr. Gonzalo)<br>**Timeline:** November 2010 – November 2015<br>**More information:** https://espo.nasa.gov/hs3/ |
| ***Tropical Rainfall Measurement Mission (TRMM)*** | **Description:** TRMM studied rainfall for weather and climate research. It delivered a unique 17-year dataset of global tropical rainfall and lightning. The TRMM dataset became the space standard for measuring precipitation, and led to research that improved understanding of tropical cyclone structure and evolution, convective system properties, lightning-storm relationships, climate and weather modeling, and human impacts on rainfall.<br>**Sponsoring Agencies**: NASA, JAXA<br>**Observation type**: satellite<br>**Location**: Global tropics (32°N to 32°S).<br>**Timeline**: November 1997 to April 2016.<br>**More information**: http://trmm.gsfc.nasa.gov/ |
| ***Twin Otter Projects Defining Oil/gas Well emissioNs (TOPDOWN)*** | **Description:** TOPDOWN aims to understand the atmospheric impact of rapidly expanding oil and gas operations in the Bakken play in North Dakota through downwind cross-section flights of the active field, quantifying key atmospheric trace gases (carbon dioxide, carbon monoxide, methane, ethane, ozone, and more), and black carbon using airborne in situ sensors and complementary airborne remote sensing instrumentation. Subsequent flights examined the Denver-Julesburg basin in northeast Colorado, and the San Juan basin in New Mexico.<br>**Sponsoring agencies:** NOAA, NASA, NSF, DOE<br>**Observation type:** field campaign<br>**Location:** North Dakota, Colorado, New Mexico, United States<br>**Timeline:** May–June 2014, April 2015<br>**More information:** http://www.esrl.noaa.gov/csd/groups/csd7/measurements/2014topdown/ |
| ***Solar Forecast Improvement Project (SFIP)*** | **Description:** two mobile Surface Radiation Network (SURFRAD) platforms were deployed in support of SFIP. Scientific goals are: model verification using SURFRAD and Integrated Surface Irradiance Study (ISIS) site measurements, provision of high-quality solar radiation measurements for 14 ISIS and SURFRAD sites, analysis of this data for comparison to satellite and model products, and high quality diffuse and direct solar irradiance.<br>**Sponsoring agencies:** NOAA, DOE<br>**Observation type:** field campaign<br>**Location:** Vermont, Colorado<br>**Timeline:** Vermont (October 2014–~October 2015); Colorado (July 2014–~December 2015)<br>**More information:** http://www.esrl.noaa.gov/gmd/grad/surfrad/; http://www.esrl.noaa.gov/gmd/grad/isis/; http://energy.gov/eere/sunshot/solar-forecast-improvement-project |

## B. Projects initiated in 2015 or 2016

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| ***Arctic-Boreal Vulnerability Experiment (ABoVE)*** | **Description:** ABoVE is a large-scale investigation of the impact of environmental change on ecosystem function, ecosystem services, and its implications for social-ecological systems in Alaska and northwestern Canada. ABoVE research links field-based, process-level studies with geospatial data products derived from airborne and satellite sensors, providing a foundation for improving analysis and modeling capabilities for northern ecosystems.<br>**Sponsoring agencies:** NASA in partnership with DOE, DOI, US Forest Service, State of Alaska as well as several federal and provincial agencies in Canada.<br>**Observation type:** field campaign<br>**Location:** Alaska and western Canada<br>**Timeline:** September, 2015 – September 2023<br>**More information**: http://above.nasa.gov/index.html |
| ***Atmospheric Radiation Measurement (ARM) Cloud Aerosol Precipitation Experiment (ACAPEX)/ CalWater2*** | **Description:** ACAPEX/CalWater2 is a joint campaign to improve understanding and modeling of large-scale dynamics and cloud and precipitation processes associated with atmospheric rivers and aerosol-cloud interactions that influence precipitation variability and extremes in the western United States.<br>**Sponsoring agencies:** NOAA, DOE, NASA<br>**Observation type:** field campaign<br>**Location:** western United States<br>**Timeline:** January–May 2015<br>**More information:**<br>ACAPEX: http://www.arm.gov/sites/amf/acx<br>CalWater2: http://www.esrl.noaa.gov/psd/calwater/overview/ |
| ***Atmospheric Carbon and Transport (ACT-America)*** | **Description:** ACT-America involves five six-week airborne campaigns to quantify anomalies in atmospheric carbon. The campaign will enable and demonstrate a new generation of atmospheric inversion systems for quantifying carbon dioxide and methane sources and sinks.<br>**Sponsoring agencies:** NASA (EVS-2), NOAA<br>**Observation type:** field campaign<br>**Location:** Eastern United States<br>**Timeline:** July 2016 – May 2018 (est.)<br>**More information:** http://act-america.larc.nasa.gov |
| ***ARM Airborne Carbon Measurements (ACME)*** | **Description:** ACME conducts airborne observations and analysis of atmospheric trace gases, designed to improve fundamental understanding of the carbon cycle. The project coordinates with the NASA Carbon in Arctic Reservoirs Vulnerability Experiment campaign.<br>**Sponsoring agencies:** DOE, NASA<br>**Observation type:** field campaign<br>**Location:** DOE Atmospheric Radiation Measurement Southern Great Plains (SGP) and North Slope of Alaska (NSA) sites<br>**Timeline**: FY 2009 – FY 2016 (SGP); June – August 2015 (NSA)<br>**More information:** https://www.arm.gov/campaigns/aaf2014armacmev |
| ***Atmospheric Tomography Mission (ATom)*** | **Description:** ATom is a global-scale aircraft sampling of the atmosphere to study the impact of air pollution on greenhouse gases and chemically-reactive gases in the atmosphere, to improve the representation of chemically-reactive gases and short-lived climate forcers in global models of atmospheric chemistry and climate. Profiles of the reactive gases will also provide critical information for validation of satellite data, particularly in remote areas where *in situ* data is lacking. Flights will occur in each of 4 seasons over a 4-year period.<br>**Sponsoring agencies:** NASA (EVS-2)<br>**Observation type:** field campaign<br>**Location:** global<br>**Timeline:** April 2015 – April 2019<br>**More information:** http://science.nasa.gov/missions/atom/ |

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| ***ARM West Antarctic Radiation Experiment (AWARE)*** | **Description:** AWARE deploys the DOE Atmospheric Radiation Measurement Mobile Facility to Antarctica to study the role of clouds and aerosols on the surface energy budget in this rapidly warming region, and improve fundamental understanding of the surface energy budget, and the cloud and aerosol processes that impact it, in an under-observed region.<br>**Sponsoring agencies:** NSF, DOE<br>**Observation type:** field campaign<br>**Location:** Antarctica<br>**Timeline:** November 2015 – November 2016<br>**More information:** http://www.arm.gov/campaigns/amf2015aware |
| ***Airborne Visible-Infrared Imaging Spectrometer-Next Generation (AVIRIS-NG) - India*** | **Description:** AVIRIS-NG was a three-month airborne campaign in India collecting imaging spectroscopy measurements for 57 sites.<br>**Sponsoring agencies:** NASA, ISRO<br>**Observation type:** field campaign<br>**Location:** India<br>**Timeline:** March-April 2016<br>**More information:** http://aviris-ng.jpl.nasa.gov/ |
| **Coral Reef Airborne Laboratory (CORAL)** | **Description:** CORAL will provide the most extensive picture to date of the condition of a large portion of the world's coral reefs from a uniform data set. CORAL acquires airborne spectral image data using the Portable Remote Imaging Spectrometer (PRISM) instrument.<br>**Sponsoring Agencies**: NASA (EVS-2)<br>**Observation Type**: field campaign<br>**Location:** Hawaii (June 2016, Feb 2017), Great Barrier Reef (Sept-October 2016), April - May (Paulau and Mariana Islands)<br>**Timeline**: June 2016 – December 2017<br>**More Information**: http://airbornescience.jpl.nasa.gov/campaign/coral |
| ***DamWatch*** | **Description:** DamWatch is a tool to help watershed project sponsors monitor and manage dams that were built with assistance from USDA National Resources Conservation Service. It provides real-time monitoring of rainfall, snowmelt, stream flow, and seismic events that could pose potential threats to dam safety. In its first year of service, it has monitored 12,000 dams across the country.<br>**Sponsoring agencies:** USDA<br>**Observation type:** surface measurement network<br>**Location:** United States<br>**Timeline:** June 2015 – present<br>**More information:** http://www.usengineeringsolutions.com/dam-watch/; http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/newsroom/releases/?cid=NRCSEPRD366417 |
| ***Earth Polychromatic Imaging Camera (EPIC)*** | **Description:** EPIC is a 10-channel spectroradiometer (317 – 780 nm) onboard NOAA's DSCOVR (Deep Space Climate Observatory) spacecraft that provides 10 narrow band spectral images of the entire sunlit face of Earth. The DSCOVR spacecraft is located at the Earth-Sun Lagrange-1 (L-1) point giving EPIC a unique perspective that will be used in science applications to measure ozone, aerosols, cloud reflectivity, cloud height, vegetation properties, and UV radiation estimates at Earth's surface.<br>**Sponsoring agencies:** NASA/NOAA<br>**Observation type:** satellite<br>**Location:** global<br>**Timeline:** February 2015–present<br>**More information:** http://epic.gsfc.nasa.gov |
| ***Evaluation of Routine Measurements using Unmanned Aerial Systems (ERASMUS)*** | **Description:** ERASMUS collects atmospheric measurements using a small unmanned aerial system, geared toward improved understanding of Arctic moisture and radiation budgets designed to complement those concurrently obtained by the third DOE ARM Mobile Facility. The second stage of ERASMUS in spring 2016 focused on aerosol measurements.<br>**Sponsoring agencies:** DOE<br>**Observation type:** field campaign<br>**Location:** Alaska<br>**Timeline:** August 2015 – April 2016<br>**More information:** https://www.arm.gov/campaigns/amf2015erasmus |

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| ***Hyperspectral Infrared Imager (HyspIRI) Airborne Campaign*** | **Description:** NASA is conducting preparatory airborne campaigns for the potential Hyperspectral Infrared Imager (HyspIRI) mission, using the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) and the MODIS/ASTER Airborne Simulator (MASTER) instruments on a NASA ER-2 aircraft to collect precursor datasets in advance of the HyspIRI satellite observations, and demonstrate the science and applications research enabled by HyspIRI-type data (continuous spectral measurements in the visible to short-wavelength infrared).<br>**Sponsoring agencies:** NASA<br>**Observation type:** field campaign<br>**Location:** California<br>**Timeline:** 2013 – 2016<br>**More information:** https://hyspiri.jpl.nasa.gov, http://aviris.jpl.nasa.gov, http://master.jpl.nasa.gov |
| ***KORUS-AQ/OC*** | **Description:** Joint field study between NASA and the Republic of Korea to assess air quality across urban, rural and coastal South Korea using observations from aircraft, ground sites, ships and satellites to test air quality models and remote sensing methods. Findings will help develop observing systems using models and data to improve air quality assessments for decision makers.<br>**Sponsoring agencies:** NASA<br>**Observation type:** field campaign<br>**Location:** South Korea<br>**Timeline:** May – June 2016<br>**More information:** http://www-air.larc.nasa.gov/missions/korus-aq/ |
| ***Layered Atlantic Smoke Interactions with Clouds (LASIC)*** | **Description:** LASIC is a deployment of the DOE Atmospheric Radiation Measurement Mobile Facility and Mobile Aerosol Observing System to Ascension Island to study how smoke from biomass burning in Southern Africa is transported across the Atlantic, how the aerosol properties change during transport and aging, and the aerosol effects on low clouds. LASIC will advance fundamental understanding of the physical and chemical processes associated with biomass burning aerosols, their interactions with clouds, and their impact on the Earth's energy budget.<br>**Sponsoring agencies:** DOE<br>**Observation type:** field campaign<br>**Location:** Ascension Island<br>**Timeline:** June 2016 – October 2017<br>**More information:** http://www.arm.gov/campaigns/amf2016lasic |
| ***Megacities Carbon Project*** | **Description:** the Megacities Carbon Project aims to demonstrate a scientifically robust capability to measure multi-year emission trends of carbon dioxide, methane, and carbon monoxide attributed to individual megacities and selected major sectors. Studies over Los Angeles and Paris, as well as planning for a study over São Paulo, are underway.<br>**Sponsoring agencies:** NASA, National Institute of Standards and Technology, Keck Institute for Space Studies<br>**Observation type:** surface measurement network<br>**Location:** Los Angeles, Paris<br>**Timeline:** August 2015 (current network installation complete) – present<br>**More information:** https://megacities.jpl.nasa.gov/portal/ |
| ***North Atlantic Aerosols and Marine Ecosystems Study (NAAMES)*** | **Description:** NAAMES is a five-year investigation to resolve key processes controlling ocean system function, their influences on atmospheric aerosols and clouds, and their implications for climate. Observations obtained during four targeted ship and aircraft measurement campaigns, combined with the continuous satellite and *in situ* ocean sensor records, will enable improved predictive capabilities of Earth system processes and will inform ocean management and assessment of ecosystem change.<br>**Sponsoring agencies:** NASA<br>**Observation type:** field campaign, satellite, *in situ* ocean sensors<br>**Location:** North Atlantic Ocean<br>**Timeline:** January 2015 – January 2020<br>**More information:** http://naames.larc.nasa.gov |

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| ***Next Generation Ecosystem Experiment (NGEE)-Tropics*** | **Description:** NGEE-Tropics is a combined observational-modeling project to increase scientific understanding of how tropical forest ecosystems will respond to climate and atmospheric change, reduce uncertainty in Earth System Model projections, and discover if tropical forests will act as net carbon sinks through the 21st century. NGEE uses will couple observations and field campaigns in tropical forest regions with development of a process-rich tropical forest ecosystem model at a resolution better than 10 km.<br>**Sponsoring agencies:** DOE, Smithsonian Tropical Research Institute, USDA Forest Service, NASA<br>**Observation type:** field campaign<br>**Location:** Puerto Rico; Manaus, Brazil<br>**Timeline:** 2016–2026<br>**More information:** http://esd1.lbl.gov/research/projects/ngee_tropics/index.html |
| ***Oceans Melting Greenland (OMG)*** | **Description:** OMG is a five-year mission using the Glacier and Ice Surface Topography Interferometer (GLISTIN) to generate high resolution, high-precision elevation measurements of Greenland's coastal glaciers during boreal spring. Annual aircraft surveys measure glacier thinning and retreat over the preceding season, and a second aircraft campaign each year deploys 250 temperature and salinity probes along the continental shelf to measure the volume and extent of warm, salty Atlantic water. This data, along with fundamental new and critical observations of airborne marine gravity and ship-based observations of the sea floor geometry will provide a revolutionary data set for modeling ocean/ice interactions and lead to improved estimates of global sea-level rise.<br>**Sponsoring agencies:** NASA<br>**Observation type:** field campaign<br>**Location:** Greenland<br>**Timeline:** July 2015 – July 2020<br>**More information:** https://omg.jpl.nasa.gov/portal/ |
| ***ObseRvations of Aerosols above CLouds and their intEractionS (ORACLES)*** | **Description:** ORACLES is a five-year investigation designed to study key processes that determine the climate impacts of aerosols from biomass burning in Africa. ORACLES provides multi-year airborne observations over the complete vertical column of the key parameters that drive aerosol-cloud interactions in the Southeast Atlantic, an area with some of the largest inter-model differences in aerosol forcing assessments on the planet.<br>**Sponsoring agencies:** NASA (EVS-2)<br>**Observation type:** field campaign<br>**Location:** Southeast Atlantic Ocean<br>**Timeline:** February 2015 – February 2020<br>**More information:** http://science.nasa.gov/missions/oracles/ |
| ***$O_2/N_2$ Ratio and $CO_2$ Airborne Southern Ocean (ORCAS)*** | **Description:** ORCAS is an airborne field campaign to advance understanding of the physical and biological controls on air-sea exchange of oxygen and carbon dioxide in the Southern Ocean, through intensive airborne surveys of atmospheric oxygen, carbon dioxide, related gases, and ocean surface properties over biogeochemical regions adjacent to the southern tip of South America and the Antarctic Peninsula.<br>**Sponsoring agencies:** NSF, NASA<br>**Observation type:** field campaign<br>**Location:** Puntas Arenas, Chile<br>**Timeline:** January – February 2016<br>**More information:** https://www.eol.ucar.edu/field_projects/orcas |
| **Olympic Mountains Experiment (OLYMPEX)** | **Description:** OLYMPEX is a ground and airborne field campaign designed to verify and validate satellite measurement of precipitation from the constellation of satellites known as the Global Precipitation Measurement (GPM). The primary goal is to validate rain and snow measurements over the Olympic Peninsula in Washington State, and to determine how remotely sensed GPM measurements can be applied to a range of hydrologic, weather forecasting, and climate data.<br>**Sponsoring agencies:** NASA<br>**Observation type:** field campaign<br>**Location:** Washington<br>**Timeline:** November 2015–February 2016<br>**More information:** http://olympex.atmos.washington.edu |

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| ***Ozone sonde Mini Campaign*** | **Description:** the Ozone sonde Mini Campaign involves dual flights in Boulder, Fiji (February 2015), and dual flights in Samoa and Fiji (August 2015) conducted to determine the vertical difference in ozone profiles when different types of chemical solution are used to prepare ozone sondes, with the intent of homogenizing ozone sonde time series at 10 NOAA-operated sites.<br>**Sponsoring agencies:** NOAA<br>**Observation type:** field campaign<br>**Location:** Fiji, Samoa<br>**Timeline:** February 2015 – August 2015<br>**More information:** http://igaco-o3.fmi.fi/VDO/files/Harris_ozone_trends_initiative.pdf |
| ***Plains Elevated Convection at Night (PECAN)*** | **Description:** PECAN is a field campaign to obtain targeted observations in critical locations before and during nighttime severe storms, with a key focus on the atmospheric layer between 500-1000 meters above the ground, in order to learn how these storms form, why some become severe, and how to better predict their characteristics in weather and climate models.<br>**Sponsoring agencies:** NSF, NASA, NOAA, DOE<br>**Observation type:** field campaign<br>**Location:** Kansas, Oklahoma, and Nebraska, United States<br>**Timeline:** June–July 2015<br>**More information:** http://www.pecan15.org/home/ |
| ***Salinity Processes in the Upper Ocean Regional Study 2 (SPURS-2)*** | **Description:** SPURS-1 and SPURS-2 are a pair of oceanographic field experiments addressing the essential role of the ocean in the global water cycle studying salinity changes that span thousands of miles together with those happening in the top centimeter of the ocean. The overall goal of SPURS-2 is to improve understanding of the physical processes that influence upper-ocean salinity and sea surface salinity in a precipitation-dominated regime with net freshwater and buoyancy fluxes into the ocean.<br>**Sponsoring agencies:** NASA, NSF, NOAA<br>**Observation type:** field campaign<br>**Location:** eastern tropical Pacific Ocean<br>**Timeline:** August 2016–August 2017<br>**More information:** http://ourocean3.jpl.nasa.gov/spurs2/index.php |
| ***Soil Moisture Active Passive (SMAP)*** | **Description:** SMAP is a satellite mission with the goal of providing a capability for global mapping of soil moisture and freeze/thaw state with unprecedented accuracy, resolution, and coverage. Science objectives are to understand processes that link the terrestrial water, energy and carbon cycles; estimate global water and energy fluxes at the land surface; quantify net carbon flux in boreal landscapes; enhance weather and climate forecast skill; and develop improved flood prediction and drought-monitoring capabilities. On July 7, 2015, SMAP's radar stopped transmitting, marking the end of soil moisture radar operations; however, the passive SMAP soil moisture radiometer continues to return data.<br>**Sponsoring agencies:** NASA<br>**Observation type:** satellite<br>**Location:** global<br>**Timeline:** January 2015–May 2018<br>**More information:** http://smap.jpl.nasa.gov |
| ***Soil Moisture Active Passive Validation Experiment 2015 (SMAPVEX15)*** | **Description:** SMAP is a satellite mission with the goal of providing a capability for global mapping of soil moisture and freeze/thaw state with unprecedented accuracy, resolution, and coverage. Science objectives are to understand processes that link the terrestrial water, energy and carbon cycles; estimate global water and energy fluxes at the land surface; quantify net carbon flux in boreal landscapes; enhance weather and climate forecast skill; and develop improved flood prediction and drought-monitoring capabilities. On July 7, 2015, SMAP's radar stopped transmitting, marking the end of soil moisture radar operations; however, the passive SMAP soil moisture radiometer continues to return data.<br>**Sponsoring agencies:** NASA<br>**Observation type:** satellite<br>**Location:** Arizona, United States<br>**Timeline:** January 2015–May 2018<br>**More information:** http://smap.jpl.nasa.gov |

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| ***Shale Oil and Natural Gas NEXUS (SONGNEX)*** | **Description:** the SONGEX campaign aims to quantify the emissions of trace gases, fine particles, and methane from several types of oil and shale gas basins in the western United States at different stages of development, and to study the chemical transformation of these emissions.<br>**Sponsoring agencies:** NOAA, NASA, NSF<br>**Observation type:** field campaign<br>**Location:** North Dakota, Wyoming, Utah, Colorado, Texas, and New Mexico<br>**Timeline:** March–May 2015<br>**More information:** http://www.esrl.noaa.gov/csd/projects/songnex/ |
| ***SMAP Validation Experiment 2016 (SMAPVEX 16)*** | **Description:** The SMAPVEX-16 campaign flew an L-band radar and microwave radiometer over US and Canadian agricultural areas to further evaluate SMAP satellite data products.<br>**Sponsoring agencies:** NASA, USDA, Agriculture Canada, Canadian Space Agency<br>**Observation Type:** field campaign<br>**Location:** Iowa and Manitoba.<br>**Timeline:** June-August 2016<br>**More information:** http://smap.jpl.nasa.gov/ |
| ***Spruce and Peatland Responses Under Climatic and Environmental Change (SPRUCE)*** | **Description:** the SPRUCE experiment, conducted in a black spruce peat bog in in the U.S. Forest Service Marcell Experimental Forest in northern Minnesota, tests mechanisms controlling the vulnerability of organisms, biogeochemical processes, and ecosystems to climate change. SPRUCE is focused on the combined responses to multiple levels of warming at ambient or elevated carbon dioxide levels, towards improving fundamental understanding and model representation of ecosystem processes under climate change.<br>**Sponsoring agencies:** DOE, USDA-Forest Service, EPA<br>**Observation type:** surface measurement<br>**Location:** Minnesota, United States<br>**Timeline:** 2015–2025<br>**More information:** http://mnspruce.ornl.gov |
| ***Wind Forecast Improvement Project 2 (WFIP-2)*** | **Description:** WFIP-2 records surface solar radiation budget measurements in the Columbia River Gorge in Washington state. These measurements support forecast improvements for renewable energy application in foundational numerical weather prediction models built by NOAA.<br>**Sponsoring agencies:** DOE, NOAA<br>**Observation type:** field campaign<br>**Location:** Columbia River Gorge, Washington<br>**Timeline:** October 2015–March 2017<br>**More information:** http://www.esrl.noaa.gov/psd/renewable_energy/wfip2/ |
| ***Wintertime Investigation of Transport, Emissions, and Reactivity (WINTER)*** | **Description:** WINTER evaluates the atmospheric chemical transformations and transport associated with anthropogenic emissions during winter in the mid-Atlantic region of the United States, including the Marcellus Pennsylvania shale play. Measurements will be made in large urban and industrial plumes, coal-fired power plant emission and distributed emissions from oil and gas extraction, agricultural or biofuel burning, and vegetation.<br>**Sponsoring agencies:** NSF, NOAA<br>**Observation type:** field campaign<br>**Location:** Northeastern United States<br>**Timeline:** February–March 2015<br>**More information:** http://www.atmos.washington.edu/~thornton/field-campaigns/wintertime-investigation-transport-emissions-and-reactivity |

# Appendix IV: Glossary

**Adaptation**
Adjustment in natural, human-natural, or human systems to a new or changing environment that exploits beneficial opportunities or moderates negative effects.

**Aerosol (atmospheric)**
Fine solid or liquid particles, caused by people or occurring naturally, that are suspended in the atmosphere. Depending on their composition, aerosols can cause cooling by scattering incoming radiation or by affecting cloud cover, or cause warming by absorbing radiation.

**Arctic tundra**
A biome with cold, desert-like conditions, short growing seasons, low biotic diversity, and poor nutrients, located in the northern hemisphere. A layer of permanently frozen soil called permafrost exists below the surface. Alpine tundra also exists in high altitude regions throughout the world.

**Atmospheric circulation**
The large-scale movement of air, and together with ocean circulation, the means by which heat is distributed on the surface of the Earth.

**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.

**Baseline emissions**
A measurement of greenhouse gas emissions at a given point in time, used as a basis for tracking emissions trends over time.

**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).

**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.

**Carbon cycle**
The continuous flow of carbon atoms through atmosphere, oceans, soil, and living organisms 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 dioxide**
The primary greenhouse gas emitted through human activities. See also carbon cycle.

**Carbon sequestration**
The process of capturing carbon dioxide from the atmosphere, measured as a rate of carbon uptake per year.

**Carbon stocks**
The amount of carbon stored in an ecosystem, mainly in living biomass and soil, but also in decomposing organic materials. Stocks have the capacity to accumulate or release carbon.

**Climate**
The average of weather over at least a 30-year time period.

**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.

**Climate forecast**
A probabilistic statement about future climate conditions on time scales ranging from seasons to decades, based on conditions that are known at present and assumptions about the physical processes that will determine future changes. “Climate prediction” is an equivalent term.

**Climate model**
A mathematical model for quantitatively describing, simulating, and analyzing the interactions between the atmosphere and the underlying surface (e.g., ocean, land, and ice)

**Climate prediction**
See climate forecast.

**Climate projection**
A long-term estimation of climate conditions produced by a climate model, usually forced by atmospheric greenhouse gas concentrations.

**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. Drivers of climate variability include the El Niño Southern Oscillation and other phenomena.

**Convection**
The transfer of heat through a fluid by the movement of the heated material. Convective motions in the atmosphere are responsible for the redistribution of heat from the warm equatorial regions to higher latitudes and from the Earth's surface upward.

**Coupled models**
Climate or Earth system models that allow different components of the system to interact with and influence one another; for instance, a coupled ocean-atmosphere model.

**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.

**Earth system**
Earth's interacting physical, chemical, and biological processes.

**Earth System Models**
Numerical representations of the interactions among the atmosphere, ocean, land, ice, biosphere, and human activities to estimate the state of regional and global climate under a wide variety of conditions.

**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)**
Natural variability of sea surface temperatures and the air pressure of the overlying atmosphere in the tropical Pacific Ocean. The warm phase of ENSO, El Niño, is associated with high surface air pressure in the western tropical Pacific and warm sea surface temperatures in the eastern tropical Pacific, while the cold phase, La Niña, is associated with low surface air pressure in the western tropical Pacific and cool sea surface temperatures in the eastern tropical 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 can cause extreme weather (such as floods and droughts) in many regions of the world.

**Ensemble Forecast**
Multiple predictions from an ensemble of slightly different initial conditions and/or various versions of models. The objective is to improve the accuracy of the forecast through averaging the various forecasts, which eliminates non-predictable components, and to provide reliable information on forecast uncertainties from the diversity amongst ensemble members. Forecasters use this tool to measure the likelihood of a forecast.

**Extratropical**
In meteorology and climate science, the area north of the Tropic of Cancer and the area south of the Tropic of Capricorn. In other words, the area outside of the tropics.

**Extreme events**
A weather event that is rare at a particular place and time of the year, including, for example, heat waves, cold waves, heavy rains, periods of drought and flood-

ing, and severe storms. Extreme events are often associated with significant economic damages.

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

**Food security**
When all people at all times have both physical and economic access to sufficient food to meet their dietary needs for a productive and healthy life.

**Forcing**
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.

**Global change**
Planetary-scale changes to atmospheric circulation, ocean circulation, climate, the carbon cycle, the nitrogen cycle, the water cycle and other cycles, biological diversity, food webs, health, fish stocks, changes in sea ice and sea level, pollution, and more. Civilization is now a large driver of global change so the term includes population, the economy, resource use, energy, development, transport, communication, land use and land cover change, urbanization, and globalization.

**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.

**Global Climate Models**
Mathematical models that simulate the physics, chemistry, and biology that influence the global climate system.

**Greenhouse gases**
Gases that absorb heat in the atmosphere near the Earth's surface, preventing it from escaping into space. This 'greenhouse effect' occurs naturally; an increase in the effect in response to a higher concentration of If the atmospheric concentrations of these gases rise, the average temperature of the lower atmosphere will gradually increase, a phenomenon known as the 'enhanced greenhouse effect.' Greenhouse gases include, for example, carbon dioxide, water vapor, and methane.

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

**Hydrography**
The measurements and description of the physical features of oceans, seas, coastal areas, lakes and rivers.

**Ice sheet**
A mass of glacial ice covering surrounding terrain, also known as a continental glacier. The only current ice sheets are in Antarctica and Greenland.

**In situ**
A sensor situated in the location of the measurement it is taking, as opposed to a remote sensor, which takes measurements from a distance.

**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.

**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.

**Interannual variability**
Year-to-year variability in climate conditions.

**Intraseasonal variability**
Variability in climate conditions on timescales (ranging from a few days to more than a month) within a season.

**Irradiance**
Radiated energy emitted from a body, such as the sun.

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

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

**Methane**
A colorless, odorless greenhouse gas with a wide distribution in nature. After carbon dioxide, it is the most prevalent greenhouse gas emitted by human activities. In the first two decades after its release, its heat-trapping potential is 84 times more potent than carbon dioxide.

**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.

**Mixing ratio**
The ratio of the mass of an atmospheric constituent to the mass of dry air.

**Observations**
Systematic collection of primary source data that describes the state of a system.

**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.

**Ozone**
An inorganic molecule found in the atmosphere that is damaging to plant and animal tissue at higher concentrations. The ozone layer in the upper atmosphere prevents damaging ultraviolet light from reaching the Earth's surface. Ozone is also a greenhouse gas.

**Peatland**
An area with or without vegetation with a naturally accumulated layer of high-carbon, partially decomposed plant material that has accumulated in a water-saturated environment and in the absence of oxygen. The warmer the climate, the more quickly the plant material will decompose.

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

**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.

**Process research**
Study of the underlying mechanisms controlling the components of the Earth system.

**Remote sensing**
The science of obtaining information about objects or areas from a distance, by detecting the energy that is reflected from the Earth's surface via sensors usually mounted on satellites or aircraft.

**Representative Concentration Pathways**
Descriptions of a range of potential futures for the main drivers of climate change: greenhouse gas emissions and land use, spanning high emissions scenarios to a low scenario consistent with the aim of limiting the increase of global mean temperature to less than 2 degrees Celsius.

**Resilience**
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.

**Risk**
Threats to life, health and safety, the environment, economic well-being, and other things of value. Risks are often evaluated in terms of how likely they are to occur (probability) and the damages that would result if they did happen (consequences).

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

**Salinity**
Salt content of a liquid. Salinity impacts the density of water masses, and has a significant impact on ocean circulation.

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

**Shared Socioeconomic Pathways**
Quantitative and qualitative descriptions of plausible alternative solutions of society at the global level, to be combined with assumptions about climate change and policy responses to evaluate climate change impacts, adaptation, and mitigation.

**Sink**
A natural or technological reservoir that stores carbon from the atmosphere and stores it.

**Spectroscopy**
The study of the interaction between matter and electromagnetic radiation.

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

**Stressor**
Something that has an effect on people and on natural, managed, and socio-economic systems.

**Teleconnections**
Large-scale climate anomalies that influence the variability of the atmospheric circulation, and have impacts on weather and climate patterns in different parts of the globe. For example, there appears to be a teleconnection between the tropics and North America during El Niño events.

**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.

**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.

**Validate**
To establish or verify accuracy. In reference to remote sensing, validation involves using ground-based measurements to determine the accuracy of satellite data.

**Vector**
An organism, such as a mosquito, capable of transmitting disease.

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

# Appendix V: Acronyms

| | |
|---|---|
| **ABoVE** | Arctic-Boreal Vulnerability Experiment |
| **ACAPEX/CalWater 2** | Cloud Aerosol Precipitation Experiment |
| **ACME** | ARM Airborne Carbon Measurements |
| **ACT-America** | Atmospheric Carbon and Transport America |
| **AFOSR** | Air Force Office of Scientific Research |
| **ARM** | Atmospheric Radiation Measurement |
| **ARO** | Army Research Office |
| **ARS** | Agricultural Research Service |
| **ASTC** | Association of Science-Technology Centers |
| **ASTER** | Advanced Spaceborne Thermal Emission and Reflection Radiometer |
| **ASTC** | Association of Science-Technology Centers |
| **ATom** | Atmospheric Tomography Mission |
| **AVIRIS** | Airborne Visible/Infrared Imaging Spectrometer |
| **AWARE** | ARM West Antarctic Radiation Experiment |
| **CAAFI** | Commercial Aviation Alternative Fuels Initiative |
| **CARVE** | Carbon in Arctic Reservoirs Vulnerability Experiment |
| **CATS** | Cloud-Aerosol Transport System |
| **CDC** | Centers for Disease Control and Prevention |
| **CDI** | Climate Data Initiative |
| **CENRS** | Committee on Environment, Natural Resources, and Sustainability |
| **CLEEN** | Continuous Lower Energy, Emissions, and Noise program |
| **CLIVAR** | Climate Variability and Predictability |
| **CMIP** | Coupled Model Intercomparison Project |
| **CMIP5** | Coupled Model Intercomparison Project Phase 5 |
| **COP** | Conference of Parties to the United Nations Framework Convention on Climate Change |
| **COP21** | 21st Conference of Parties to the United Nations Framework Convention on Climate Change |
| **CRREL** | Cold Regions Research and Engineering Laboratory |
| **CRT** | Climate Resilience Toolkit |
| **CYGNSS** | Cyclone Global Navigation Satellite System |
| **DARPA** | Defense Advanced Research Projects Agency |
| **DEWS** | Drought Early Warning System |
| **DOC** | Department of Commerce |
| **DOD** | Department of Defense |
| **DOE** | Department of Energy |
| **DOS** | Department of State |
| **DOT** | Department of Transportation |

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|---|---|
| **ECOSTRESS** | ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station |
| **ENSO** | El Niño/Southern Oscillation |
| **EPA** | Environmental Protection Agency |
| **ERASMUS** | Evaluation of Routine Measurements using Unmanned Aerial Systems |
| **ERDC** | U.S. Army Corps of Engineers Engineer Research and Development Center |
| **ERS** | Economic Research Service |
| **ESM** | Earth System Models |
| **FAA** | Federal Aviation Administration |
| **FAC** | Federal Advisory Committee |
| **FEMA** | Federal Emergency Management Agency |
| **FHWA** | Federal Highway Administration |
| **FIA** | Forest Inventory and Assessment |
| **ForestGEO** | Smithsonian's Global Earth Observatories examining forests (formerly SIGEO) |
| **FTA** | Federal Transit Administration |
| **GCB** | Global Carbon Budget |
| **GCIS** | Global Change Information System |
| **GCP** | Global Carbon Project |
| **GCRA** | Global Change Research Act of 1990 |
| **GEDI** | Global Ecosystem Dynamics Investigation Lidar |
| **GEOSS** | Group on Earth Observation System of Systems |
| **GFDL-CM3** | Geophysical Fluid Dynamics Laboratory Model Code 3 |
| **GLISTIN** | Glacier and Ice Surface Topography Interferometer |
| **GMB** | Global Methane Budget |
| **GO-SHIP** | Global Ocean Ship-Based Hydrographic Investigations Program |
| **GOFC-GOLD** | Global Observation of Forest and Land Cover Dynamics |
| **GPM** | Global Precipitation Measurement |
| **HHS** | Department of Health and Human Services |
| **HMT** | Hydrometeorology Testbed |
| **HyspIRI** | Hyperspectral Infrared Imager |
| **ICLUS** | Integrated Climate and Land-Use Scenarios |
| **InFlux** | Indianapolis Flux Experiment |
| **IPC** | World Meteorological Organization International Pyrheliometer Comparison |
| **IPCC** | Intergovernmental Panel on Climate Change |
| **IRI** | International Research Institute for Climate and Society |
| **IWG** | Interagency Working Group |
| **JMS** | Jamaican Meteorological Service |
| **KORUS-AQ/OC** | Korea-United States joint field study on Air Quality/Ocean Color |
| **LASIC** | Layered Atlantic Smoke Interactions with Clouds |
| **LTAR** | Long-Term Agroecosystem Research |

| | |
|---|---|
| **MarineGEO** | Smithsonian's Global Earth Observatories examining coastal marine habitats |
| **MASTER** | Moderate Resolution Imaging Spectroradiometer (MODIS)/ Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Airborne Simulator |
| **MIROC5** | Fifth Model on Interdisciplinary Research on Climate |
| **MODIS** | Moderate Resolution Imaging Spectroradiometer |
| **NAAMES** | North Atlantic Aerosols and Marine Ecosystems Study |
| **NASA** | National Aeronautics and Space Administration |
| **NASA ER-2** | NASA Earth Resources 2 |
| **NASA-JPL** | NASA Jet Propulsion Laboratory |
| **NASS** | National Agricultural Statistics Service |
| **NCA** | National Climate Assessment |
| **NCA3** | Third National Climate Assessment |
| **NCA4** | Fourth National Climate Assessment |
| **NCAnet** | National Climate Assessment network of networks |
| **NCAR** | National Center for Atmospheric Research |
| **NGEE Arctic** | Next-Generation Ecosystem Experiments-Arctic |
| **NIDIS** | National Integrated Drought Information System |
| **NIFA** | National Institute of Food and Agriculture |
| **NIH** | National Institutes of Health |
| **NIHHIS** | National Integrated Heat Health Information System |
| **NIST** | National Institute of Standards and Technology |
| **NMME** | North American Multi-Model Ensemble |
| **NOAA** | National Oceanic and Atmospheric Administration |
| **NRCS** | Natural Resources Conservation Service |
| **NRI** | National Resources Inventory |
| **NSA** | North Slope of Alaska |
| **NSF** | National Science Foundation |
| **NWS** | National Weather Service |
| **OCO-2** | Orbiting Carbon Observatory 2 |
| **OLYMPEX** | Olympic Mountains Experiment |
| **OMG** | Oceans Melting Greenland |
| **ONR** | Office of Naval Research |
| **ORACLES** | ObseRvations of Aerosols above CLouds and their intEractionS |
| **ORCAS** | Oxygen/Nitrogen Ratio and Carbon Dioxide Airborne Southern Ocean Study |
| **OSHA** | Occupational Safety and Health Administration |
| **OSTP** | White House Office of Science and Technology Policy |
| **PCAP** | President's Climate Action Plan |
| **PCN** | Permafrost Carbon Network |
| **PECAN** | Plains Elevated Convection at Night |
| **RADEX** | Radar Definition Experiment |
| **RCP** | Representative Concentration Pathway |

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|---|---|
| **SCAN** | Soil Climate Analysis Network |
| **SERDP** | Strategic Environmental Research and Development Program |
| **SFIP** | Solar Forecast Improvement Project |
| **SGCR** | Subcommittee for Global Change Research |
| **SGP** | Southern Great Plains |
| **SI** | Smithsonian Institute |
| **SMAP** | Soil Moisture Active Passive |
| **SMAPVEX15** | Soil Moisture Active Passive Validation Experiment 2015 |
| **SNOTEL** | Snowpack Telemetry |
| **SONGNEX 2015** | Shale Oil and Natural Gas Nexus |
| **SPRUCE** | Spruce and Peatland Responses Under Climatic and Environmental Change |
| **SPURS-1** | Salinity Processes in the Upper Ocean Regional Study 1 |
| **SPURS-2** | Salinity Processes in the Upper Ocean Regional Study 2 |
| **SSCC** | Social Sciences Coordinating Committee |
| **SSWSF** | Snow Survey and Water Supply Forecasting program |
| **START** | global change SysTem for Analysis, Research, and Training |
| **SURFRAD** | Surface Radiation Network |
| **TFCC** | the Navy's Task Force Climate Change |
| **TOPDOWN** | Twin Otter Projects Defining Oil/gas Well emissioNs |
| **UN** | United Nations |
| **UNFCCC** | United Nations Framework Convention on Climate Change |
| **USACE** | United States Army Corps of Engineers |
| **USAID** | United States Agency for International Development |
| **USDA** | United States Department of Agriculture |
| **USDA-FS** | United States Department of Agriculture-Forest Service |
| **USGCRP** | United States Global Change Research Program |
| **USGS** | United States Geological Survey |
| **WFIP-2** | Wind Forecast Improvement Project 2 |
| **WINTER** | Wintertime Investigation of Transport, Emissions, and Reactivity |
| **WMO** | World Meteorological Organization |

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