U.S. Global Change Research Program

OUR CHANGING PLANET

The U.S. Global Change Research Program for Fiscal Years 2018-2019

A Supplement to the President's Budget

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The U.S. Global Change Research Program for Fiscal Years 2018-2019

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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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 2018-19 edition of *Our Changing Planet* provides a summary of programmatic achievements, recent progress, 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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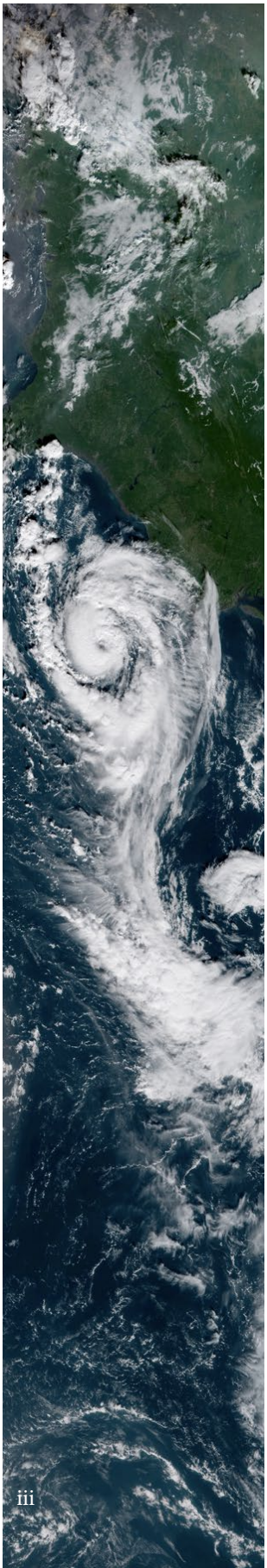

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INTRODUCTION

In the late 1980s, the U.S. Government recognized the critical role of Federally-coordinated research in understanding global change and its impacts and informing responses to it. The U.S. Global Change Research Program (USGCRP) was established by a Presidential Initiative in 1989 as a confederation of 13 Federal agencies that conduct or use research on climate and global change (Figure 1). USGCRP was codified by Congress in the Global Change Research Act (GCRA) of 1990[1] with a mandate to:

"assist the Nation and the world to understand, assess, predict, and respond to human-induced and natural processes of global change."

Research conducted by USGCRP agencies covers a range of topics in global change science and provides the basis for scientific assessment and decision support activities that help people and organizations across the country manage their assets and resources under conditions of global change. Each of the USGCRP's member agencies has its own mission, mandate, and capabilities; USGCRP facilitates collaboration and cooperation among these agencies and works to maximize efficiencies in Federal global change research. Together, the USGCRP member agencies, with participation from another 20 Federal agencies, deliver products and conduct activities mandated by the GCRA.

As part of its mandate, USGCRP provides communities, businesses, and the public sector with access to authoritative data and information resources needed to evaluate and respond to the risks and opportunities presented by global change. For example, many organizations use observations of precipitation and soil moisture collected by USGCRP member agencies to help manage water resources, agricultural operations, and wildfire risk. Others use observations and projections of storm surge and sea level rise for infrastructure and emergency response planning in coastal regions. Combining observations and modeling capabilities from several USGCRP member agencies leads to improvements in projections of future climate conditions used for long-term planning and risk management in areas such as defense, reinsurance, and infrastructure design.

USGCRP's mandate includes leveraging U.S. and international observations, modeling, research, and assessment capabilities to accomplish Program goals and priorities (see Supporting International Global Change Science). As part of this mandate, USGCRP supports activities related to international assessments, including assisting in the coordination of government reviews of reports produced by the Intergovernmental Panel on Climate Change, the Intergovernmental Platform on Biodiversity and Economic Services, the Arctic Council's Arctic Monitoring and Assessment Program, and the Montreal Protocol's Scientific Assessment Panel. These activities are done in close collaboration with the State Department, which typically serves as the focal point for the Federal government's engagement with these international organizations.

The FY2018–19 edition of USGCRP's annual report to Congress, *Our Changing Planet*, responds to the GCRA mandate to provide an overview of the Program's progress in delivering on its strategic goals (as outlined in USGCRP's Strategic Plan and its 2017 update) as well as a summary of agency expenditures under USGCRP's budget crosscut (see Budgetary Information). USGCRP's scope is defined as the range of agency programs implemented with funds included in the budget crosscut, and the efforts described in this document represent only a small subset of the overall accomplishments of the Program. The highlighted efforts represent interagency collaborations in FY2018–19 that rely on coordinated investments of two or more member agencies. Results from single agency investments that underpin interagency accomplishments are not typically covered in this annual report. Appendix I. USGCRP Member Agencies summarizes the principal focus areas related to global change research for each USGCRP member agency.

Figure 1. U.S. Global Change Research Program Member Agencies

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

DELIVERING ON THE 2012-2021 NATIONAL GLOBAL CHANGE RESEARCH PLAN

USGCRP's Strategic Plan and its 2017 update provide the framework for advancing fundamental understanding of the Earth system while further developing capacity to support scientific assessments, decision support tools, and the accompanying engagement processes. This section summarizes achievements during FY 2018–19 that support implementation of USGCRP's strategic goals: advance global change science, inform decisions, sustain scientific assessment, and engage the public on the science of global change and its use in society, including internationally. Additional activities undertaken in FY2018–19 and in previous years are highlighted at globalchange.gov/explore.

ADVANCING SCIENCE

Earth system science brings together data and understanding about the atmosphere, oceans, land and sea ice, ecosystems, land surface, and social systems to form a picture of our planet as a whole, including its changing climate. USGCRP uses Earth system observations, modeling, process understanding, and insights from the social sciences to advance scientific knowledge of the human and natural components of the Earth system, project possible future conditions, and provide the foundation for scientific assessment and decision support capabilities.

IN THIS SECTION:

ADVANCING SCIENCE
EARTH SYSTEM OBSERVATIONS

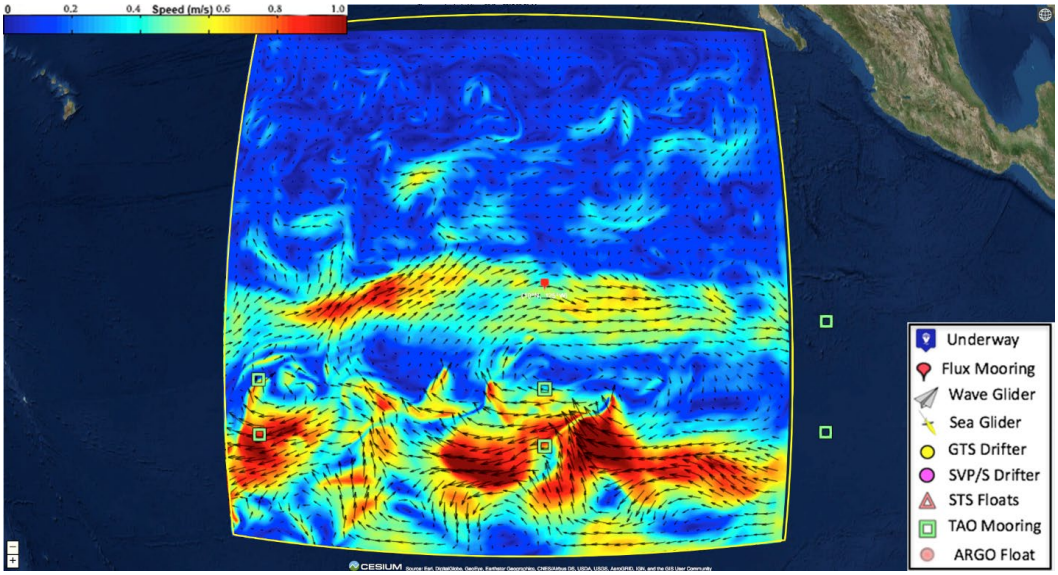
USGCRP agencies develop and maintain Earth observations systems that monitor the state of the planet over time and provide critical information used for planning related to agriculture, water resources, wildfire, air quality, severe weather, and other areas. Short-term observing campaigns are also used to target specific new areas of understanding and can complement longer term efforts or measurements made by different platforms. Satellite, aerial, *in-situ*, and field-based methods inform understanding of processes of change, both natural and human-caused, and support development and evaluation of Earth system models that provide insight into future changes. Observations efforts highlighted in this report span from pole to pole and capture processes of change across a range of timescales. In addition, a selection of USGCRP observational systems and campaigns scheduled for launch or completion during FY2017–2019 can be found at https://www.globalchange.gov/about/iwgs/obsiwg/compendium.

HIGHLIGHT 1
Strengthening critical observations of the tropical ocean and atmosphere

Upgrades to an observing network in the equatorial Pacific Ocean support valuable forecasts of global shifts in climate and extreme weather.

The El Niño Southern Oscillation (ENSO) is a natural climate phenomenon driven in part by the variability of ocean surface temperatures, atmospheric pressure, and trade winds in the tropical Pacific Ocean. ENSO events, occurring every two to seven years on average, cause widespread shifts in precipitation patterns and weather and climate extremes that impact agriculture, marine ecosystems, human health, disaster preparedness, and other sectors across the world. Using observations of ocean temperature and surface winds in the tropical Pacific, scientists are able to predict the ENSO cycle up to 12 months in advance and can provide forewarning of potentially damaging weather and climate conditions in many parts of the world. Real-time monitoring of ocean and atmospheric conditions through the **Tropical Pacific Observing System (TPOS)** supports this capability, but recent deterioration of a moored buoy network has put ENSO predictions and associated services at risk. The **TPOS 2020 Project**, running from 2014 to 2020, will oversee the transition to a more resilient observing system to meet research and forecasting needs of today and the future, including ocean temperature measurements that contribute to ENSO predictions. The First Report of TPOS 2020 proposed a network redesign that incorporates advances in observing technologies, process understanding, and modeling to improve the capability to monitor and predict ENSO and its impacts[2].

The U.S. contribution to TPOS 2020 is supported by NOAA and NASA, with scientific input from the U.S. Climate Variability and Predictability Program. NOAA recently made a significant investment to advance observing technologies in the tropical Pacific region to enhance ENSO research and predictions[3]. In addition, new technologies are being tested in conjunction with NASA's Salinity Processes in the Upper Ocean Regional Study 2 (SPURS-2) in the eastern tropical Pacific to improve understanding of interactions between the ocean and the atmosphere in these rain-dominated ocean regions, key to improving ENSO predictions (see figure)[4].



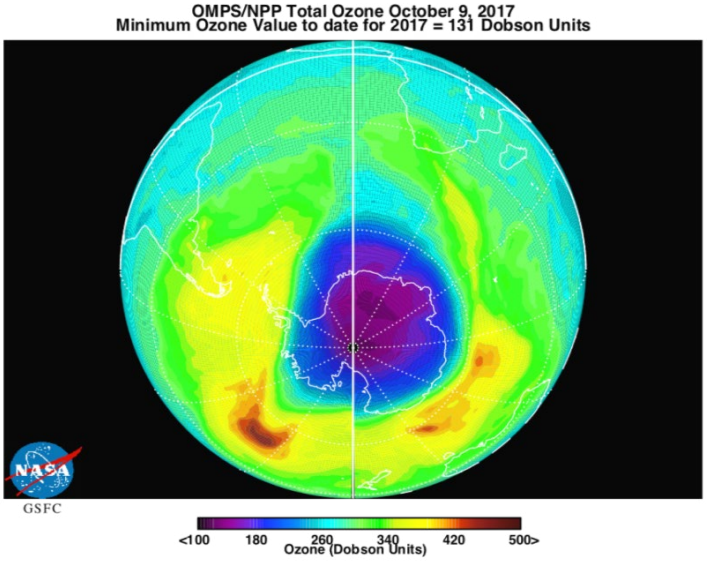
Forecasts of ocean surface current velocity in the Pacific Ocean off of Baja California generated in part using in-situ observations from NOAA's Tropical Atmosphere Ocean (TAO) moored buoy array (green squares), which is part of the Tropical Pacific Observing System (TPOS), and from measurements collected during the SPURS-2 satellite deployment over the tropical Pacific Ocean (red square). Depicted is a strong westward-flowing South Equatorial Current driven by the trade winds that blow from east to west across the equatorial Pacific. Changes to the easterly trade winds influence the progression of ENSO events. Forecasting these changes is integral to improving predictive capabilities. Source: NASA/Jet Propulsion Laboratory.

HIGHLIGHT 2
Monitoring recovery of the ozone layer

Interagency collaboration sustains long-term measurements that track the health of the ozone layer.

Ozone gas in the upper atmosphere protects the planet's surface from harmful solar radiation. The Antarctic ozone hole was discovered in 1985, increasing concerns about human emissions of gases that destroy ozone and the negative consequences for life on Earth. Two years later, the international community signed the Montreal Protocol, an international treaty designed to protect the ozone layer through regulation of ozone-depleting compounds. Later amendments completely phased out production of widely-used chemicals known as chlorofluorocarbons that destroy ozone. As a result of these controls, the ozone layer is expected to recover over the next few decades. The minimum ozone concentration in the Antarctic ozone hole—a good indicator of the overall health of the ozone layer—is higher than it has been since the 1980s, which may be a sign of ozone recovery (see figure).

Since 1990, NASA and NOAA have worked together to monitor global ozone using a series of NASA and NOAA Solar Backscatter Ultraviolet Radiometer (SBUV and SBUV/2) instruments. This program of almost 30 years of sustained effort demonstrates robust cooperation between these two agencies.



The 2017 annual minimum ozone detection of 131 Dobson Units over Antarctica was observed on October 9, 2017, about a week later than usual, indicating that ozone levels may be starting to recover. Source: NASA.

ADVANCING SCIENCE
CARBON CYCLE SCIENCE

Carbon cycle science integrates observations, modeling, and process studies to advance understanding of the flow of carbon through the Earth system. The addition of carbon-based greenhouse gases (such as carbon dioxide and methane) to the atmosphere, primarily through the burning of fossil fuels, deforestation, and land use change, is driving an increase in global average temperature and other linked changes[5]. These changes are altering the flow of carbon through different parts of the Earth system, affecting ocean and atmospheric chemistry, ecosystems on land and in the ocean, and the ability of these systems to remove and store carbon from the atmosphere[6]. Understanding the dynamics of these flows and their implications for future climate change is an ongoing challenge for carbon cycle researchers. Interagency field and modeling efforts are seeking to better understand how carbon-rich ecosystems such as tropical forests, coastal wetlands, and permafrost soils will respond to a warming climate over the 21st century and improve our ability to predict future climate change.

HIGHLIGHT 3
Predicting the future of tropical forests

Field research provides new data advancing our ability to project how tropical forests will respond to a changing climate.

Tropical forests store vast amounts of carbon and play a key role in regulating Earth's climate. As climate changes, these ecosystems have the potential to become a net contributor to global warming if they shift to releasing more carbon to the atmosphere than they absorb[7]. However, how these forests will be affected by a warming climate and changing atmosphere is still uncertain—and is critical for improving model projections of future climate change[8]. In the first experiment of its kind, researchers are testing how an intact tropical forest ecosystem responds to levels of warming expected over this century, including potential feedbacks to global climate. The **Tropical Responses to Altered Climate Experiment (TRACE)** is a multi-university project funded by a collaboration among the USDA-Forest Service, U.S. Geological Survey, and DOE. TRACE, initiated in September 2016 in El Yunque National Forest, Puerto Rico, is using heaters to warm plants and soils 7°F above surrounding temperatures—consistent with the projected range for the region by 2100. This temperature increase is also used in several higher-latitude warming experiments, enabling improved cross-site comparison of results. Initial measurements demonstrate the experiment's ability to consistently warm soil at depth to targeted temperatures.

While the 2017 hurricane season dramatically impacted the TRACE site, the project is continuing and will have a unique opportunity to explore how the ecosystem responds to a major natural disturbance. Over the next phase, researchers will measure temperature effects on a wide range of biological processes important to carbon cycling. Results will help reduce the uncertainties surrounding tropical forest responses to increasing temperatures, including whether these ecosystems will become net sources of carbon to the atmosphere rather than carbon sinks.

A warmed TRACE plot in the USDA-Forest Service Luquillo Experimental Forest in Puerto Rico. Three 15-foot diameter areas are warmed 7°F above surrounding temperatures with an array of six infrared heaters; three areas of the same size receive the same infrastructure but are not warmed. Source: Tana E. Wood, USDA.

HIGHLIGHT 4
Understanding carbon flows in vulnerable coastal wetlands

A new research network aims to accelerate discoveries in the science of these important natural carbon sources and sinks.

Coastal wetlands provide protection from wind and waves, support habitats and fisheries, and store large amounts of atmospheric carbon dioxide for centuries to millennia. These ecosystems can also be sources of greenhouse gas emissions to the atmosphere; wetlands that do not have the capacity to keep pace with sea-level rise, for example, can erode and release soil carbon rapidly to the atmosphere. Freshwater and brackish wetlands also emit methane, a more potent greenhouse gas over its atmospheric lifetime than carbon dioxide. High uncertainty surrounding the spatial extent and vulnerability of coastal wetland carbon stocks, as well as the dynamics of carbon storage and release, limits our ability to project future behavior of these ecosystems.

The NSF-funded **Coastal Carbon Research Coordination Network (CCRCN)** was established in 2017 with the goal of building a global community of scientists, policy makers, and non-governmental organizations working to reduce uncertainties and accelerates advances in carbon cycle science in tidal wetlands. CCRCN engages multiple agencies associated with USGCRP's Carbon Cycle Interagency Working Group. A steering committee comprising Federal and non-Federal organizations—including the Smithsonian Environmental Research Center, U.S. Geological Survey, Woods Hole Marine Biological Lab, and Conservation International—supervises and directs CCRCN priorities. Current activities, guided by community input, include the development and release of two online resources related to carbon in coastal wetlands: a literature review and open workflow supporting the EPA National Greenhouse Gas Inventory, released in December 2017, and a database of 1,500 publicly-available tidal soil carbon depth profiles from the contiguous United States, released in June 2018 as a companion to a journal article[9].

Mangrove forests store large amounts of carbon, protect the coastline from erosion, and provide shelter for many species. The image shows Landsat-based mapping of change in mangrove forests in the Florida Everglades, 2000–2016. Orange indicates areas of loss and degradation in mangroves; blue indicates areas of mangrove gains and regrowth. A) highlights areas of mangrove recovery; B) highlights areas of coastal erosion and mangrove loss; and C) highlights areas of inland mangrove degradation, with areas of inland degradation and resulting collapse of carbon-rich peat soils from saltwater intrusion shown in the inset. Source: NASA/Goddard Space Flight Center.

ADVANCING SCIENCE
EARTH SYSTEM MODELING

Earth system models simulate the state of the Earth system by incorporating the behavior of its many interacting components, both human and natural. These include the land surface, oceans, land and sea ice, atmospheric composition, clouds, and external influences on Earth's climate such as the sun's output and volcanic aerosols, as well as human influences such as greenhouse gas emissions. Models estimate the total influence of human and natural factors on the Earth system, and how the global climate might evolve over time depending on a range of future conditions. Earth system models rely on high-quality observations and detailed understanding of Earth system dynamics. Coordinated experiments across leading Earth system models are driving improvements in model ability to project future change and its associated impacts. Other research frontiers include modeling future climate conditions at higher resolution (i.e., at the regional scale) to support decisions and using economic impact models to assess how climate information can help managers in sectors such as agriculture plan for the future.

HIGHLIGHT 5
Modeling the impacts of climate variability and change on agriculture

Researchers are improving understanding of how shifts in climate conditions affect agricultural production, as well as the value of providing advance climate information to producers.

Climate variability and change affect agricultural yields and livelihoods[10]. Improving our understanding of how the interaction of climate variability and change affects agricultural production, particularly on regional scales that are more relevant to decision making, is an important research frontier. As part of the joint NSF-USDA National Institute for Food and Agriculture program on **Decadal and Regional Climate Variability Using Earth System Models**, researchers modeled the impacts of climate variability on water resources and agriculture in the Missouri River Basin. Simulated climate data and observed yields from a large variety of crops were provided as inputs to an economic impacts model along with various other choices that producers might make about their operations, including purchasing crop insurance. Using modeled decadal and regional climate predictions to optimize management decisions, researchers found that successful climate predictions for up to a year in advance could provide producers for that region alone with as much as $30 million in economic value, and for longer periods of up to five years, as much as $80 million[11]. Successful predictions, based largely on phases of the Pacific Decadal Oscillation—a long-lived pattern of climate variability that influences temperature and precipitation in the United States—could also inform adaptation decisions for producers.

HIGHLIGHT 6
Enhancing coordination among U.S. modeling centers

Collaboration across the modeling community supports critical experiments and scientific advancement.

U.S. climate modeling centers play a central role in understanding and predicting global change on seasonal to centennial timescales. They are engaged in the Coupled Model Intercomparison Project (CMIP), which produces climate projections underpinning the assessments conducted by the Intergovernmental Panel on Climate Change and the U.S. National Climate Assessment. Models developed by these centers are designed for different purposes, from providing operational forecast information to anticipating longer-term changes and improving scientific understanding of how different elements of the Earth system interact and change. The **U.S. Climate Modeling Summit (USCMS)**, convened annually since 2015, provides a venue for communication, collaboration, and coordination of these modeling activities. The Fourth USCMS, held in April 2018, featured discussions of the newest generation of climate models (CMIP6). An outcome of the meeting was a plan for comparison of model skill in simulating climate variability and an investigation of differences across models. During the summit, a workshop on "Land-Atmosphere Interactions and Extremes," involving discussion of modeling approaches and priorities across centers, allowed researchers to learn from one another's experiences in this rapidly evolving area of research and model development. The USCMS is convened by the USGCRP Interagency Group for Integrative Modeling, comprising agencies that sponsor U.S. climate modeling activities (including DOE, NOAA, NASA, and NSF) and those that are interested in model output application such as the USDA.

ADVANCING SCIENCE
SOCIAL SCIENCE PERSPECTIVES

Humans both drive and respond to change in the Earth system and can act to reduce risks arising from natural and human-caused changes and their interaction. The social and behavioral sciences are a key component of understanding the impacts of global change on human welfare, vulnerabilities in critical systems, and decision making in response to change. Improving integration of social science insights on climate change impacts, vulnerabilities, and the social processes of responses into USGCRP research and activities is an ongoing goal for the Program.

HIGHLIGHT 7
Learning from social science perspectives

Social science methods and insights can enhance Federal global change research, assessments, and programs.

In March 2017, USGCRP's Social Science Coordinating Committee convened a three-day workshop, "**Social Science Perspectives on Climate Change**." The workshop brought together over 80 participants, including scientists and program managers from 13 Federal agencies, representatives from non-governmental organizations, and academic social scientists from four disciplines: anthropology, archaeology, geography, and sociology. Participants focused on identifying how social science perspectives, methods, and data can improve our understanding of global climate change as well as new opportunities and avenues for incorporating social science research into Federal climate research, assessments, and programs. To facilitate discussion, three white papers were developed by academic and Federal social scientists that focused on three themes: (1) characterizing differences between and within communities that affect *vulnerability* to climate change; (2) providing social science perspectives on on *drivers* of and *responses* to global climate change; and (3) identifying innovative *tools*, *methods*, and *analyses* to improve understanding of the interactions among human and natural systems under climate change. The workshop participants reviewed the white papers and provided input. The three white papers are now finalized and published and are available at https://www.globalchange.gov/content/social-science-perspectives-climate-change-workshop.

ADVANCING SCIENCE
INTEGRATIVE SCIENCE TOPICS

These selected topics illustrate how long-term, coordinated investments in scientific research into natural and human-caused processes of change can lead to tangible applications, including partnerships and science-based tools supporting rapid responses to and recovery from extreme events, forecasting of sea ice conditions for operational use, and building longer-term resilience to forces of global change.

Integrative Science Topics: Extreme Events

HIGHLIGHT 8
Supporting recovery from the 2017 hurricane season

Interagency collaboration supported recovery efforts after Hurricanes Irma and Maria.

During the 2017 hurricane season, hurricanes Irma and Maria, two of the most significant storms to affect Florida and the U.S. Caribbean in recent history, caused catastrophic damage that affected ecosystems, livelihoods, and economic stability throughout the region. USGCRP provided one venue for facilitating interagency efforts—involving USDA, DOE, NASA, NSF, DOI, and FEMA—that are tracking storm damage and recovery in forests and the agricultural sector and supporting recovery and resilience-building efforts in affected communities.

The USDA Forest Service (USDA-FS) and the USDA Caribbean Climate Hub, headquartered in San Juan, Puerto Rico, began post-hurricane work within days of the storms, initiating research activities to aid in recovery efforts and develop lessons learned from the storm impacts and recovery that can inform future responses. Damage assessments of rural and urban forests are being conducted to obtain information on management and reforestation needs, including salvage opportunities for downed trees. To better understand how and why some landscapes are more vulnerable to hurricane damage than others, scientists are assessing how land characteristics such as topography affected vegetation damage. USDA is also evaluating the vulnerability of agricultural operations in Puerto Rico to hurricanes, as well as the vulnerability of sectors such as communications, energy, and transportation that support agribusinesses; these assessments are being used to improve the delivery of information and programs to reduce risks from future extreme events. USDA, NSF, and university partners are also supporting hurricane recovery and resilience-building efforts in urban communities, including opportunities for governmental and community leaders, practitioners, and academics to reflect on lessons learned from these storms and to identify innovative solutions to promote resilience—such as community hubs that use data and visualization technologies to support and connect communities in addressing local issues.

In addition to direct effects on livelihoods, extreme events can degrade important ecosystem services. Mangrove forests in both Puerto Rico and Florida affected by Hurricanes Irma and Maria serve as protective barriers to storm surge. Tropical forests and mangrove forests damaged by the storms also have high rates of carbon exchange with the atmosphere and very high carbon sequestration potential that can be affected by ecosystem disruptions. The hurricanes affected areas that had recently been surveyed via NASA Goddard's Lidar, Hyperspectral, and Thermal Airborne Imager (**G-LiHT**), which creates 3-D high-resolution maps of forested areas—allowing for direct observation of the effects of storm damage on these ecosystems and their recovery. Pre-hurricane flights, conducted in spring 2017 by NASA Goddard through an award from DOE and NGEE-Tropics, collected data over about 12% of the is-

land. After the storms, researchers conducted repeat flights between November 2017 and May 2018, with support from DOI and FEMA, based on interactions initiated through USGCRP's Carbon Cycle Interagency Working Group. USDA National Institute of Food and Agriculture, NASA, and DOE provided support for work on the ground, field validation of remote sensing observations, and analysis of results.

Preliminary evidence shows that five months after Hurricane Maria, more than half of the trees in Puerto Rican rainforests are damaged or were downed and 60% of protective coastal mangroves in Florida were destroyed[12]. Some areas and species are recovering faster than others; for instance, palm trees in Puerto Rico's El Yunque National Forest are taking advantage of sunlight provided by an open canopy[13]. When fully analyzed, observations from this multi-agency effort will provide an unprecedented picture of the damage and initial recovery from these two events and help improve understanding of how hurricanes change forest ecosystems. Such assessments can inform planning for recovery and rehabilitation of affected lands and preparation for future events.

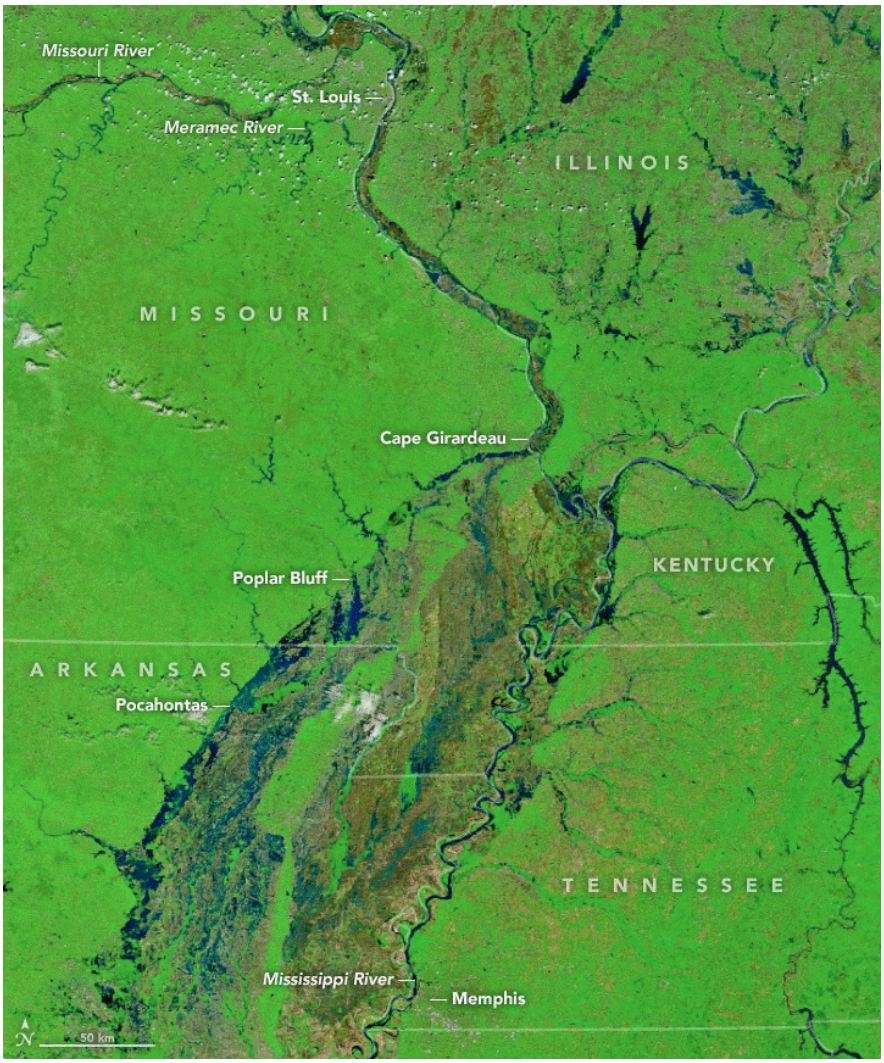
The Ten Thousand Islands mangrove ecosystem in the Florida Everglades pictured before (top, March 28, 2017) and after (bottom, December 1, 2017) Hurricane Irma, as captured by the NASA G-LiHT team. The greener vegetation in the top image is indicative of a healthier ecosystem; the bottom image shows significant damage to foliage and trees. Source: NASA.

HIGHLIGHT 9
Responding to the 2017 Midwestern floods

Interagency collaboration supported rapid response efforts.

Periods of heavy rainfall caused extensive flooding across much of the Midwestern United States and Mississippi River Basin in spring 2017, including widespread accumulation of 7–10 inches of rain, flash floods, and long-term river flooding. In response, NASA's Earth Science Disasters Program assembled a team of scientists at NASA's Marshall Space Flight Center in Huntsville, Alabama, other NASA centers, and NASA-affiliated partners to assist the U.S. Federal Emergency Management Agency (FEMA) and the U.S. National Guard in their emergency operations.

The Disasters Response Team created flood extent maps and assisted with the integration of remote sensing products for FEMA and the National Guard. The flood extent maps primarily relied on data from synthetic aperture radar, which has great value for flood monitoring because it can "see" through cloud cover that blocks other types of satellite imagery[14]. Maps were processed with help from collaborators at the University of Alaska Fairbanks. The team also used Landsat 8 visible/infrared sensors and data provided by the U.S. Geological Survey Hazards Data Distribution System to track flood waters and assist in overall emergency response.



Imagery captured by the Moderate Resolution Imaging Spectroradiometer (MODIS) aboard NASA's Terra satellite on May 2, 2017 showing flooding along several tributaries of the Mississippi River. The false-color image highlights vegetation (greens, browns), river, and flood waters (blues) from St. Louis to Memphis, along with several other affected towns and cities in Missouri, Kentucky, Arkansas, and Tennessee. Credit: NASA Earth Observatory.

HIGHLIGHT 10
Monitoring change in Alaska and the Arctic

By monitoring trends such as permafrost thaw, shifts in wildfire, and changing wildlife habitats, a multi-year field campaign seeks to provide the scientific basis for informed decision-making in response to change.

Climate change in the Arctic and Boreal Region is unfolding faster than anywhere else on Earth. Observations reveal reduced Arctic sea ice, widespread changes to coastlines and waterways, thawing of permafrost soils and decomposition of long-frozen organic matter, and shifts in ecosystem structure and function. These changes have far-reaching impacts in the region as well as implications for global climate[15]. As part of a broader effort to improve understanding of the vulnerability and resilience of ecosystems and society to a changing environment, NASA and its partners have begun a multi-year field campaign to investigate the ecological impacts of a rapidly changing climate in Alaska and northwestern Canada. The **Arctic-Boreal Vulnerability Experiment (ABoVE)** will build upon ongoing research sponsored by multiple Federal agencies, bringing together on-the-ground research with data collected by NASA airborne instruments, satellites, and other agency programs.

In the summer of 2017, an ABoVE airborne remote sensing campaign collected an extensive data set over study sites in Alaska and northwestern Canada. The campaign was coordinated with multiple U.S. agencies, including NASA, DOE, NSF, NOAA, USDA-Forest Service, U.S Geological Survey, U.S. Fish and Wildlife Service, Bureau of Land Management, National Park Service, and U.S. Army Corps of Engineers, as well as Canadian partners. Flights were coordinated across multiple field sites in Alaska and northwestern Canada during the growing season to link remote sensing data with key environmental and societal processes. ABoVE will continue the cooperative remote sensing campaign during the summers of 2018–2020 using the Airborne Visual Imaging Infrared Spectrometer, L-Band Radar, and possibly the Land, Vegetation, and Ice Sensor.

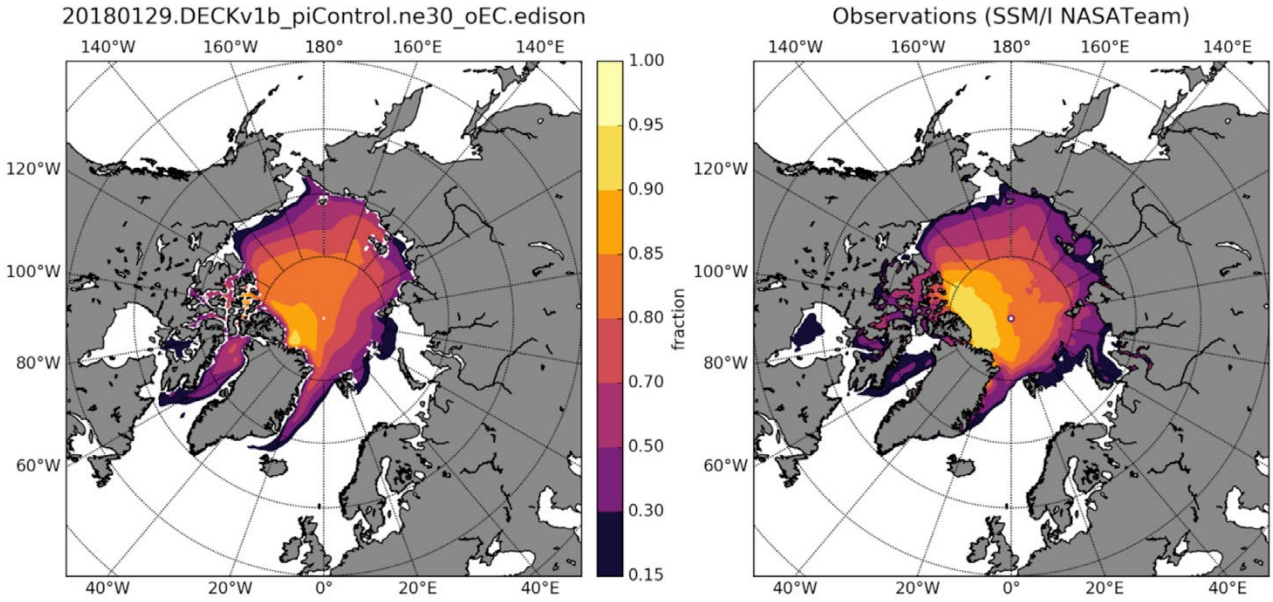
A lake near Fairbanks, Alaska shows signs of thawing permafrost below the surface—including "drunken trees" that tip over as soil shifts around their roots. Through the ABoVE campaign, scientists are investigating the impacts of warming temperatures on northern lakes like this one. Credit: Kate Ramsayer, NASA.

HIGHLIGHT 11
Predicting Arctic sea ice change

Interagency collaboration supports predictions of Arctic sea cover used by the U.S. Navy and other operational and research organizations.

Summer sea ice cover in the Arctic Ocean shrunk significantly since the early 1980s, with particularly rapid declines in recent years[16]. Arctic sea ice plays a key role in regulating weather and climate in and beyond the region[17], and projections of how sea ice cover will change in the coming years are critical for predicting climate change in the region and its influence on global climate. Several modeling centers that study such changes use the **CICE sea ice model**, first developed by scientists at DOE's Los Alamos National Laboratory, as a component of Earth system models that can predict future changes across weather and climate timescales. CICE simulates sea ice extent, thickness, and movement over seasonal to decadal timescales (see figure), offering a number of research and operational uses. One noteworthy application of CICE is in the U.S. Navy's sea ice prediction capability. The Navy disseminates daily sea ice forecast products to NOAA and to the multi-agency National Ice Center (NOAA, U.S. Navy, U.S. Coast Guard), while also using the model for special missions. CICE has also been adopted by research and operational organizations in more than twenty countries, including numerous climate modeling groups (including NOAA's Geophysical Fluid Dynamics Laboratory, NSF's Community Earth System Model, and DOE's Energy Exascale Earth System Model) as well as forecast centers operated by the National Weather Service, United Kingdom Meteorological Office, Environment Canada, and the Danish Meteorological Service.

In 2016, a group of CICE users and primary developers founded the international CICE Consortium as a vehicle for collaboration as the community continues to use and improve the model. The Consortium formalizes an existing collaborative alliance among a large group of participating universities, government agencies, and affiliated institutions. By coordinating innovations in both model code and analysis tools and allowing a greater number of modeling groups and agencies to use and contribute to this scientific resource, the Consortium serves to accelerate the transfer of innovations in sea ice modeling research and operational applications.

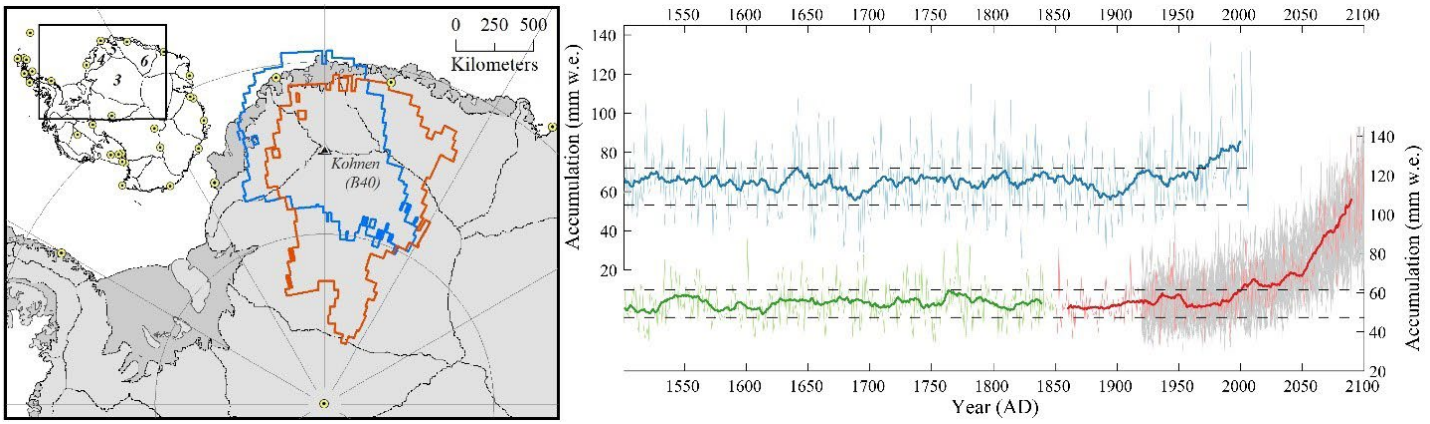


The figure shows long-term averages of Arctic summer sea ice concentration simulated by an adaptation of CICE/Icepack in the DOE's Energy Exascale Earth System Model (left panel) compared with observational estimates derived from measurements by the Special Sensor Microwave Imager satellite instrument (right panel). Source: DOE Los Alamos National Laboratory.

HIGHLIGHT 12
Modeling ice sheet change in Antarctica

Modeling efforts provide new data on the effects of climate change in Antarctica.

Between 1998 and 2016, warming in Antarctica has been rapid and significant. Recent observations also reveal increases in snowfall in western Queen Maud Land, East Antarctica that are unprecedented over the past two millennia. To investigate these changes, a team of NSF-sponsored researchers and NASA scientists merged observation-based NSF-funded research with global modeling efforts that benefited from NASA satellite and airborne-based data[18]. Researchers determined that models were underestimating snow accumulation and temperature increases in this region, with implications for sea level rise estimates based on contributions from the East Antarctic Ice Sheet. Updated climate model projections suggest that additional snowfall over Antarctica, largely due to atmospheric warming, is expected to partly offset dynamic ice losses by the end of the 21st century[19]. However, even small variations in the modeled snowfall accumulation rates created great uncertainty about the balance of ice loss and accumulation in Antarctica. The mitigating impact of higher snowfall rates is therefore not fully resolved, indicating a need for improved evaluation of global atmospheric model performance in Antarctica.



Left: *In the study area in Queen Maud Land, eastern Antarctica, the blue area experienced increased snowfall related to warming temperatures[20].* ***Right:*** *Until recently, annual snowfall, as recorded in the historical ice core record (blue), remained within preindustrial averages (dashed grey lines). Data modeled by the Community Earth System Model includes an artificially-controlled run (green) and an ensemble data run (red), showing the potential projected snowfall increases based on the NSF data recorded at Queen Maud Land. The grey area around the ensemble data is the margin for error. Source: NASA.*

INFORMING DECISIONS

USGCRP coordinates and integrates many efforts across the Federal government to provide access to authoritative, freely-available assessments, datasets, and tools that inform decisions under changing environmental conditions. Interagency science contributes to the development of information tools for managing climate-related risks and opportunities in sectors such as agriculture, transportation, and water resources, including the provision of information at regional scales useful for decision making.

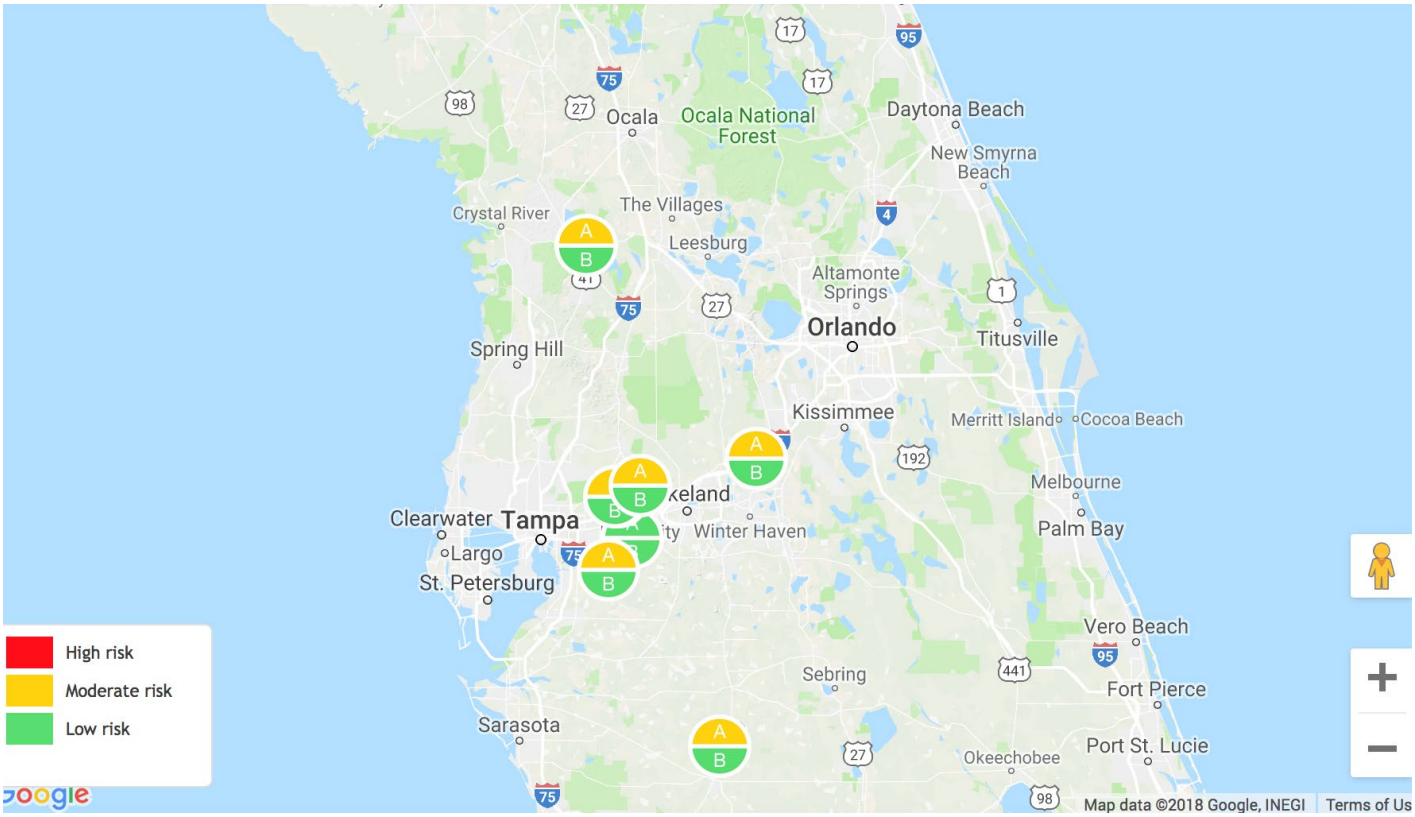
HIGHLIGHT 13
Providing climate information tools to agricultural communities

Interagency efforts develop and deliver science-based information and technologies to help agricultural producers and natural resource managers make optimal management decisions.

Farmers, ranchers, and land managers across the country rely on weather and climate information in their management decisions. To help producers and managers better understand the risks and opportunities that extreme weather events and climate change present for their operations, interagency efforts produce and deliver a range of information tools and resources that help guide climate risk management in agriculture now and in the future.

USDA's ten regional **Climate Hubs**, hosted across the country in partnership with the Agricultural Research Service, the USDA-Forest Service, and the Natural Resources Conservation Service, deliver science-based knowledge, tools, and technical support to farmers, ranchers, forest landowners, and resource managers to inform decision-making related to changing climate conditions and risks. Key partners in this effort include NOAA, DOI, public and land grant universities, cooperative extension services, and non-profits providing assistance to landowners. The Climate Hubs offer a variety of information resources that help translate climate change projections into potential impacts on the agriculture and forestry sectors and can inform actions to prepare for changing conditions, including a number of recent examples. The Southern Plains Hub, in collaboration with the Cheyenne and Arapaho Tribes and USDA's Natural Resource Conservation Service, facilitated a new demonstration farm on Tribal lands to showcase the effectiveness of soil health practices in increasing land productivity, reducing environmental impacts, and building resiliency to droughts and floods. The Southeast Hub's Lately Identified Geospatial Hazard Tracking System (SERCH LIGHTS) email alert service, drawn from NOAA datasets, notifies subscribers in the contiguous United States when climate-related conditions of potential concern arise in their area and provides links to supporting resources and management information. Monthly Drought and Cattle Heat Stress alerts are available for the contiguous United States; alerts for the Emerald Ash Borer pest and for fire weather conditions are under development. Finally, the Northeast Hub and its partners have developed a series of Adaptation Factsheets on cover cropping, managed grazing, and managing dairies in a changing climate.

The **AgroClimate** web resource, established with funding from USDA, NOAA, and state and regional partners, provides a range of customizable weather and climate decision tools and resources for agricultural producers to support management of climate risks in both day-to-day decisions and longer-term planning. For example, the Strawberry Advisory System decision-support tool has been used by Florida strawberry growers assess the risk of epidemics from anthracnose and Botrytis fruit rot on their farms[21], which are influenced by weather and climate conditions and can reduce yields and profits (see figure). Using the advisories, farmers are able to target fungicide application to periods when conditions are more likely to generate disease, reducing production costs and avoiding unnecessary applications. A number of tools were implemented and revised during the last year, including rainfall and temperature monitoring, a climatology tool, a growing degree-day calculator and monitoring tool, and a chill hours calculator and monitoring tool. In addition the AgroClimate Workbook provides an introduction to the effects of climate on agriculture and is designed to be used in conjunction with decision-support tools and information hosted on AgroClimate.org.



The Strawberry Advisory System tool, which shows risk levels for climate-related disease in strawberry crops, helps growers make decisions about fungicide application. The tool is available at http://agroclimate.org/tools/sas/. Source: AgroClimate

The **Useful to Usable (U2U)** research and extension project (funded 2011–2017) focused on improving the usability of climate information for agricultural production in the Midwestern United States. With core funding from USDA-National Institute of Food and Agriculture (NIFA) and by leveraging NOAA datasets and expertise from the NOAA Midwestern and High Plains Regional Climate Centers, an interdisciplinary team from nine universities developed a series of climate-based tools and resources that have supported farm management and planning decisions on millions of acres across the U.S. Corn Belt. A recent evaluation found that farm advisors used U2U tools to assist clients with seed purchases, crop choices, and timing of fertilizer application. Farmers reported using the U2U tools to aid in planting and harvest scheduling, fertilizer management, and improvement of crop yields. U2U decision tools and related user guides continue to be accessible through the Midwestern and High Plains Regional Climate Centers and allow users to customize data for a variety of uses and locations, including historical climate and crop yield data (*AgClimate Viewer*), real-time corn growing degree day accumulations and climate risks for corn development (*Corn Growing Degree Day*), and the connections between global climate conditions and local climate impacts (*Climate Patterns Viewer*). Tools for determining the feasibility and profitability of using in-season nitrogen application for corn production (*Corn Split Nitrogen Application*) and exploring the profitability of investing in irrigation equipment (*Irrigation Investment*) are also available.

The ***AgBizClimate*** farm-level management tool assesses how climate change could impact costs and returns over the next twenty to thirty years for producers of specific agricultural commodities. Using AgBizClimate, farmers can see the impact of expected climate changes on their cropping system or livestock enterprise in terms of their economic costs and returns, and how changes in farm practices such as technology changes or crop choices may influence the health of their businesses. This tool is a powerful means to help farmers understand their area's available climate information and can also serve as an assessment tool for researchers and government agencies. *AgBizClimate* is part of a suite of *AgBiz Logic™* decision tools that enable agribusiness professionals to make sustainable choices that impact their bottom line. *AgBiz Logic™* was developed through a partnership among the USDA Northwest Climate Hub, Oregon State University, Oregon Climate Change Research Institute, and USDA-NIFA. With support from the USDA Climate Change Program Office, efforts are underway to expand participation and use across the USDA Climate Hubs, specifically with the Northwest, Northeast, and Southwest regions and the NOAA RISA Climate Impacts Research Consortium at Oregon State University.

HIGHLIGHT 14
Building infrastructure resilience

Interagency efforts are supporting preparedness and safety measures for critical transportation infrastructure.

Dust storms in the Southwest can create dangerous and deadly driving conditions, reducing visibility to near zero with very little warning. Interstate 10 is especially vulnerable to dangerous dust-related driving conditions as it passes through a dry lake bed west of Lordsburg near the Arizona border. To help reduce dust-related risks, the NOAA Regional Integrated Sciences and Assessments (RISA) program and the DOT Federal Highway Administration coordinated with the National Weather Service and the New Mexico Department of Transportation on several public safety and dust mitigation projects. New infrastructure includes static and dynamic warning signs, surveillance cameras to view current conditions, shoulder repair, pavement markings, and other road improvements. Funding also supports new ad and awareness campaigns to promote driver safety and revegetation projects to mitigate dust creation.

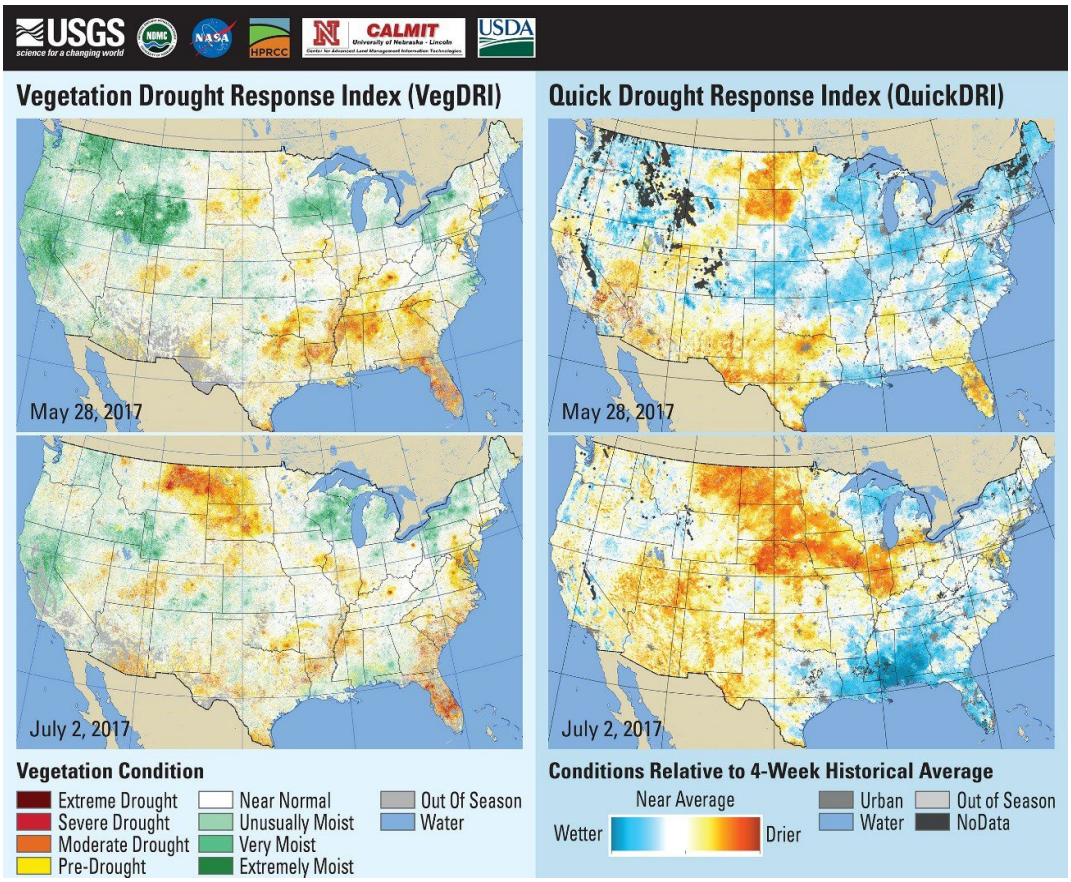
A NOAA National Weather Service (NWS) dust warning to motorists traveling along Interstate 10 near Lordsburg, New Mexico, tweeted in November 2017. Source: NOAA NWS.

HIGHLIGHT 15
Supporting informed responses to drought

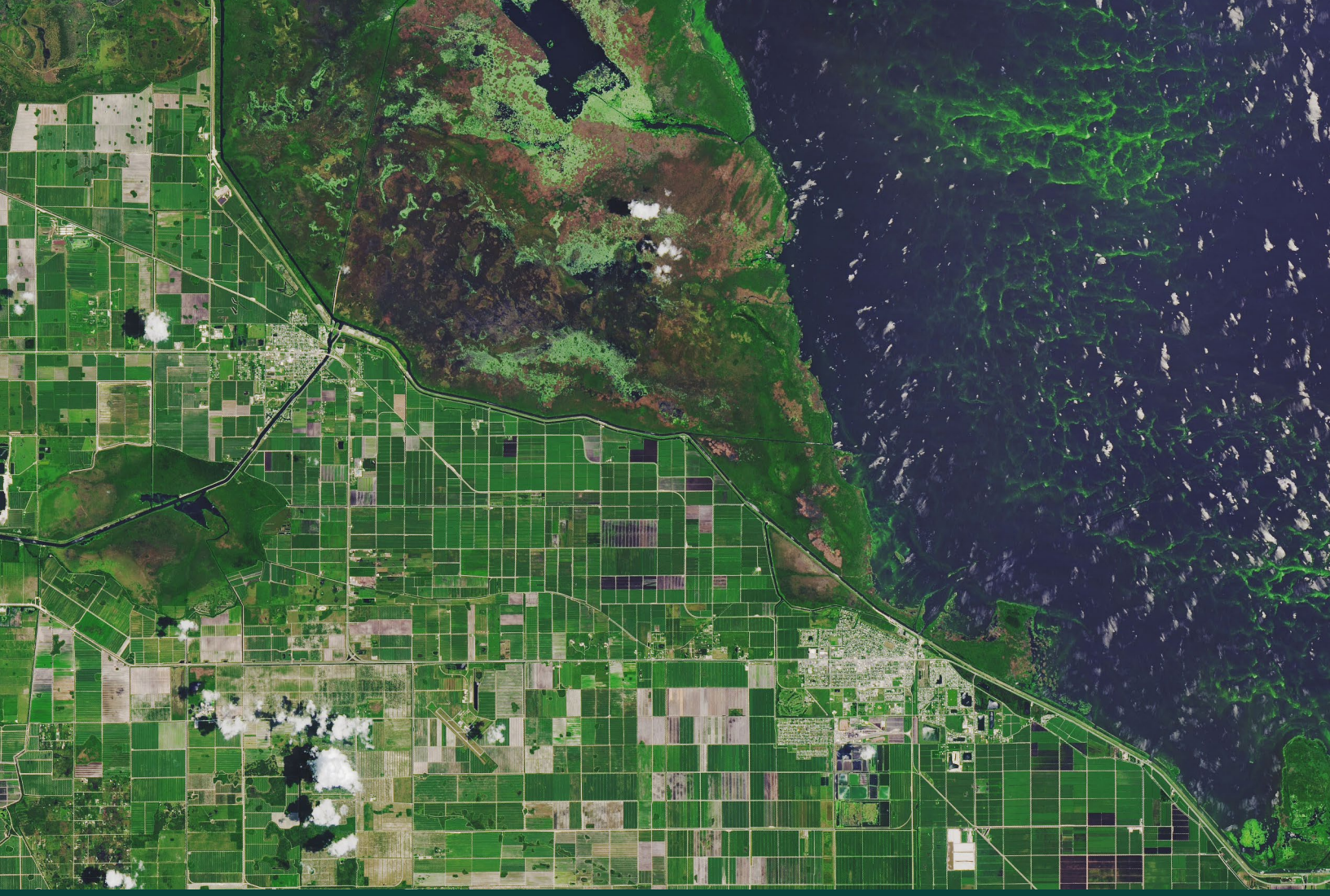
Monitoring tools help resource managers prepare for and reduce the impacts of drought.

The impacts of drought on water resources, plants and wildfire, agriculture, and the economy are complex and occur over many timescales, underscoring the value of a range of drought monitoring tools that support different types of decisions. To help meet this need, two complementary weekly drought monitoring and mapping tools—the **Vegetation Drought Response Index (VegDRI)** and the **Quick Drought Response Index (QuickDRI)**—were developed by the U.S. Geological Survey and the National Drought Mitigation Center in collaboration with NASA, USDA, and the Center for Advanced Land Management Information Technologies. VegDRI and QuickDRI both integrate satellite-based observations of vegetation and soil conditions, climate data, and other environmental parameters across the contiguous United States. VegDRI, in operation since May 2009, depicts the effects of drought on vegetation at a 1-kilometer spatial resolution over seasonal timescales[22]. VegDRI has been useful for depicting drought in the **U.S. Drought Monitor (USDM)** especially over croplands, rangelands, pastures, and natural grasslands, and is being used by the National Weather Service as part of their drought assessment reports and by various state-level drought task forces[23]. QuickDRI, which became operational in 2017, is more sensitive to emerging or rapidly changing drought events (or "flash" droughts) that can have devastating impacts on agriculture, natural resources, and the economy. QuickDRI is designed to be especially useful for crop and rangeland assessments, irrigation scheduling, and wildfire management decisions.

These products are consulted each week by the USDM map team as they assemble the national USDM map and summary narrative, which sets the standard for communicating the location and intensity of drought to a broad audience. Weekly national USDM maps are the most widely consulted gauge of drought conditions across the country, used by policy makers, state drought task forces, media, farmers, and ranchers. Since 2012, the USDM has been used to trigger aid tied to the Farm Bill that has supported ranchers and farmers impacted by drought.



VegDRI (left) and QuickDRI (right) for weeks in May and July depicting the evolution of the "flash" drought over eastern Montana, North Dakota, and South Dakota in 2017. Note: No Data in QuickDRI occurs where snow cover is present. Source: USGS.



SUSTAINING ASSESSMENT

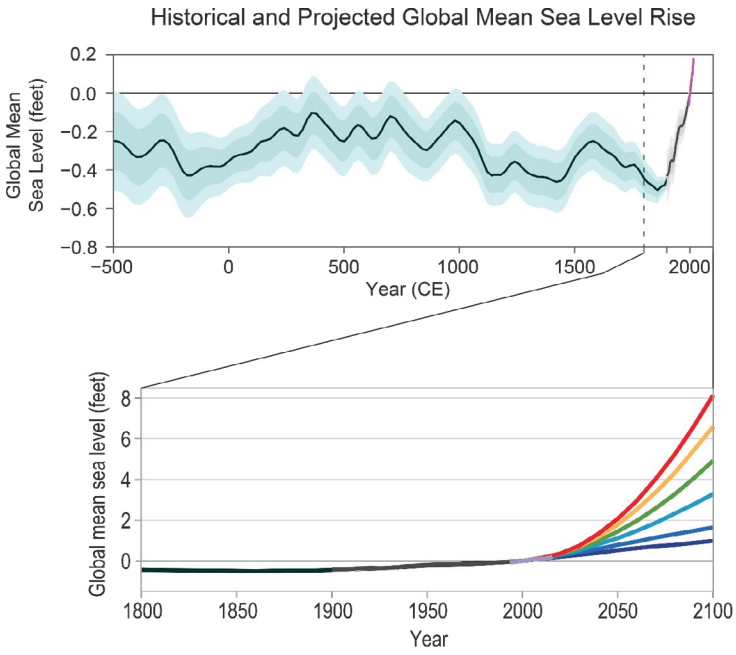
As required by the Global Change Research Act, USGCRP produces a quadrennial National Climate Assessment (NCA) that synthesizes understanding of present and future climate change processes and the ongoing and potential impacts across regions and sectors in the United States. Since the release of the NCA3 in 2014, USGCRP has transitioned towards a sustained assessment process that supports ongoing assessment and engagement processes, culminating in a quadrennial assessment. Agency and interagency assessment efforts provide technical inputs to the NCA and serve particular agency and interagency constituencies on an ongoing basis.

HIGHLIGHT 16
Providing the climate science foundation for the Fourth National Climate Assessment

An assessment of observed and projected climate trends in the United States forms the foundation for comprehensive analyses of climate-related vulnerabilities and risks.

USGCRP oversaw the production of the *Climate Science Special Report (CSSR)* as Volume I of the Fourth National Climate Assessment. CSSR assesses the state of knowledge on human-caused climate change, with a primary focus on the United States, including observed and future projected changes in temperatures, precipitation patterns, extreme weather events, sea-level rise, and ocean acidification. CSSR was released in November 2017 and provides the physical science foundation for a consistent assessment of climate-related risks and impacts across regions and sectors of the United States in NCA4 Volume II (*Impacts, Risks, and Adaptation in the United States*), released in late 2018. CSSR was developed as part of USGCRP's sustained assessment process, which facilitates ongoing participation of scientists and stakeholders in the integration of knowledge into assessment products and the quadrennial NCA, enabling new information and insights to be assessed as they emerge.

Following a public notice for author nominations, the CSSR Federal steering committee selected 30 scientists from Federal agencies, national laboratories, universities, and the private sector as Lead Authors. Contributing Authors were later chosen to provide input on select areas of the assessment. NOAA served as the administrative lead agency for preparation of the report. CSSR was reviewed multiple times by USGCRP agencies as well as the public and the National Academies of Sciences, Engineering, and Medicine. The report is available at https://science2017.globalchange.gov.



The top panel shows observed and reconstructed global mean (average) sea level for the last 2,500 years. The bottom panel shows projected mean sea level for six future climate change scenarios. The six scenarios—spanning a range designed to inform a variety of decisions—extend from a low scenario, consistent with continuation of the rate of sea level rise over the last quarter century, to an extreme scenario, assuming rapid mass loss from the Antarctic ice sheet. Note that the range on the vertical axis in the bottom graph is approximately ten times greater than in the top graph. Source: Climate Science Special Report Executive Summary, Figure 8, based on Figures 12.2 and 12.4 in Chapter 12 of the full report.

HIGHLIGHT 17
Engaging the public in assessing climate change impacts and risks in the United States

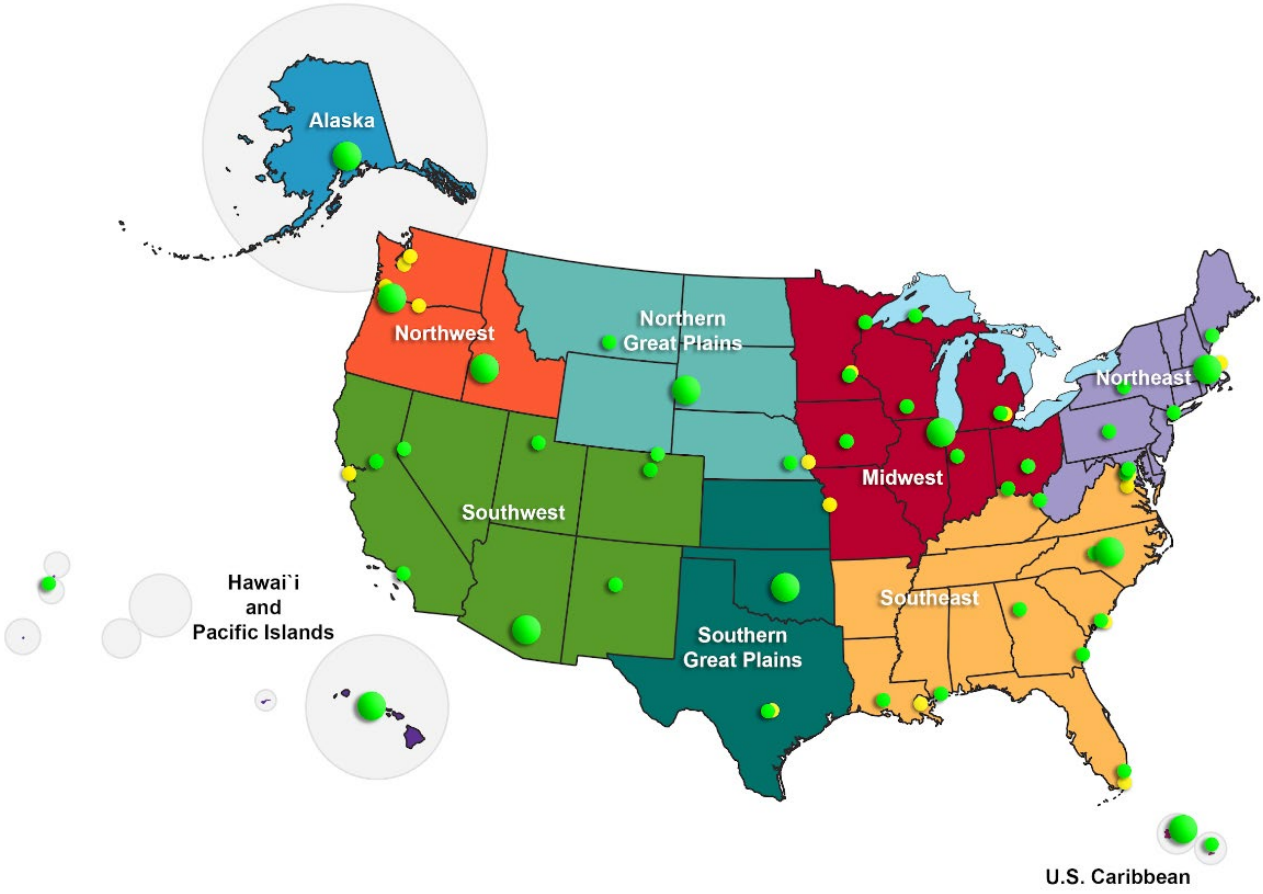
Strong engagement efforts help ensure that USGCRP assessment products are relevant and accessible to users.

USGCRP recently finalized the fourth installment of the National Climate Assessment (NCA4). Volume I (the *Climate Science Special Report*, see Highlight 16) was released in November 2017, and Volume II (*Impacts, Risks, and Adaptation in the United States*) was released in late 2018. A USGCRP Sustained Assessment Report, the *Second State of the Carbon Cycle Report* (SOCCR2), was also released in late 2018. To ensure that these assessments provide relevant, usable science for stakeholders, USGCRP agency representatives, working groups, staff, and authors implemented an extensive engagement plan to gather public feedback during the development, drafting, and review phases.

For NCA4 Volume II, these opportunities included a call for public comment on the draft prospectus in July 2016, a public call for author nominations (Sep. 2016), a call for submission of technical inputs to the assessment (Aug. 2016–Jan. 2017), a description of public engagement opportunities (ongoing), a public call for review editors (Jul.–Sep. 2017), and an opportunity for the public to review the draft report (Nov. 2017–Jan. 2018). For SOCCR2, opportunities included a call for public comment on the draft prospectus, technical inputs, and nominations for technical contributors (Feb.–Mar. 2016); a description of public engagement opportunities (ongoing); a public call for review editors (Jul. 2017); and an opportunity for the public to review the draft report (Nov. 2017–Jan. 2018). These calls led to hundreds of author nominations and technical inputs and thousands of public comments, which will be available online upon release of each report.

Unique to NCA4 Volume II, a series of regional engagement workshops allowed for the gathering of regional input to the report. In early 2017, USGCRP staff and representatives rom USGCRP member agencies worked with regional authors and collaborators to host a series of regional engagement workshops in each NCA4 region (see figure). These workshops used a hub-and-satellite model to better enable participation from individuals who may have otherwise been unable to attend. For example, the Midwest regional engagement workshop hub was held in Chicago, with nine total satellite locations in seven of the eight Midwest region's states, including two each in Ohio, Michigan, and Minnesota. In total, NCA4 author teams gathered input from more than 1000 participants in 46 cities. Each regional engagement workshop was followed by a one-day author team meeting to discuss how feedback received could inform chapter development.

Throughout the development of both NCA4 Volume II and SOCCR2, report authors, agency representatives, USGCRP staff, and stakeholders from academia, state, local, and tribal governments, as well as the non-profit and private sectors spoke at and participated in sessions at professional society meetings, web-based seminars, community meetings, and other events aimed at providing an overview of the respective assessment processes and opportunities for engagement. As the sustained assessment process moves forward, agencies, staff, and authors continue to provide the public with information about upcoming events as well as opportunities to provide feedback on the process and products, and seek venues to disseminate findings from USGCRP's assessment products.



Locations of regional engagement workshop hubs and satellites (green) and NCA4 participation at professional conferences, meetings and other events (yellow) through May 2018. Source: USGCRP.

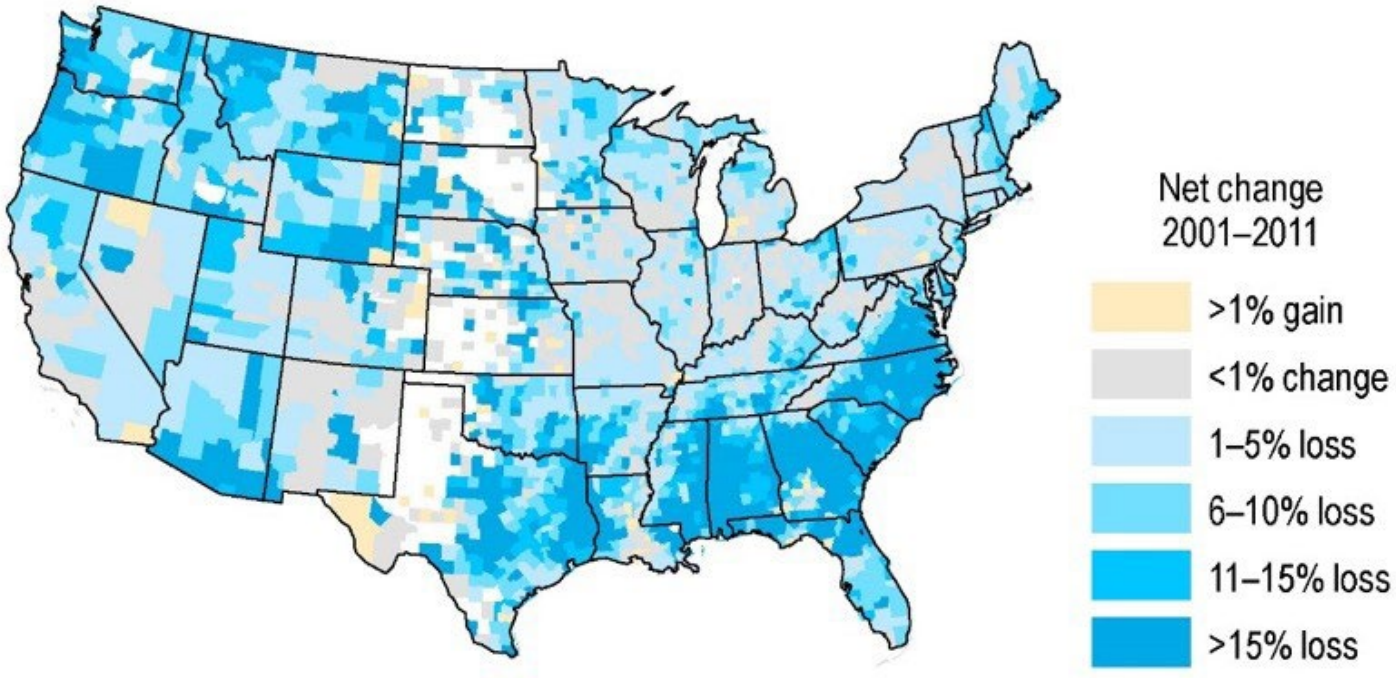
HIGHLIGHT 18
Assessing the future of America's forests and rangelands

A report on the status of America's forests and rangelands provides a baseline for monitoring future change and its effect on ecosystem services and livelihoods.

Expanding populations, increased urbanization, land use change, and climate change continue to affect American forests and rangelands. Climate change and natural disturbances will alter forest and rangeland ecosystems and affect their ability to provide ecosystem services such as water quality protection, removal of pollutants from the atmosphere, and outdoor recreation. The most recent Resources Planning Act (RPA) Assessment update, released by the USDA-Forest Service in December 2016, tracks historical trends in these ecosystems and provides a look into their future, as mandated by Congress in 1974[24]. The RPA Assessment is the product of Forest Service scientists and numerous university partners.

The report highlights key trends and projections that inform land managers and policy makers in their work to sustain important ecosystems for current and future generations. While total forest area remains relatively stable, the breakdown of large, continuous forest cover into smaller patches continued from 2001 to 2011, which can increase the risk of forest degradation from nearby human activities and alter the type and quality of ecosystem services provided (see figure). U.S. forests continue to store more carbon than they release to the atmosphere, but forests are accumulating carbon at a decreasing rate, primarily as a result of land use change and forest aging. Continued development is expected to reduce forest area in future decades. Wildlife habitats, already affected by breakdown of forest cover and conversion from native vegetation, are expected to be stressed further by the effects of climate change.

Net change in interior forest cover from 2001–2011, by county (38-acre scale)



The greatest decrease in intact forest cover 2001–2011 occurred in interior forests, which include forest cover surrounded by a 38-acre neighborhood that is at least 90 percent forested. Counties are shaded and state boundaries shown for reference; counties without color had no interior forest cover in 2001 and/or 2011. Source: USDA-Forest Service.

SUPPORTING INTERNATIONAL GLOBAL CHANGE SCIENCE

As directed by the Global Change Research Act, USGCRP works to improve coordination of U.S. activities with the programs of other nations and international organizations in order to promote international cooperation on global change research and build global change research capacity in developing countries. USGCRP advances these goals by developing international partnerships that (1) advance the priorities and objectives of the USGCRP community, (2) effectively link to USGCRP's program areas, and (3) leverage existing agency investments and resources. The partnerships and related activities highlighted this year support partner activities that align with USGCRP's strategic goals and help to maintain U.S. influence and leadership in the international research community.

HIGHLIGHT 19
Developing international support for research on climate, environment, and human health

USGCRP co-led an international group of funders and implementers in initiating development of a collaborative research action.

The **Belmont Forum** is an international partnership between national research funding agencies and international science organizations focused on advancing transdisciplinary global change science and accelerating its application. Its Collaborative Research Actions (CRAs) combine natural science, social science, and stakeholder perspectives to produce knowledge for understanding and responding to global environmental change. In November 2017, the Belmont Forum approved a proposed CRA focused on the linkages among climate, environment, and health. An international steering group, co-led by representatives from USGCRP member agencies (including NOAA, NIH, and NSF), was formed to develop the initial proposal into a final CRA and to organize a scoping workshop, hosted by USGCRP in April 2018. USGCRP's engagement with the Belmont Forum is coordinated through the International Activities Interagency Working Group (IAIWG). The Program's inputs into the scoping process for the Climate, Environment, and Health CRA took place through an interagency consultative process managed by the Interagency Cross-cutting Group on Climate Change and Human Health (CCHHG).

The scoping workshop brought together a diverse group of international funding organizations and Federal agencies including NIH, NOAA, NSF, USGS, USDA, NASA, and USAID, with the goal of developing a shared set of funding priorities for the Climate, Environment, and Health CRA. Steering group discussions and the scoping workshop identified a number of interconnected research priorities that reflect a "systems" approach, including climate change and health; disasters, extreme weather, and climate events; heat and health; oceans and health; and climate-sensitive infectious diseases and land use change. Following input and deliberations at the workshop, the steering committee developed a roadmap for a multi-year international call for proposals to begin in 2019. This CRA aims to fund research that will advance understanding of risks and vulnerabilities across multiple time scales; develop robust modeling, prediction, and early warning systems for climate-related health threats; and provide information useful to decision makers.

HIGHLIGHT 20
Promoting international research on global change

USGCRP efforts support building global change research capacity in developing countries.

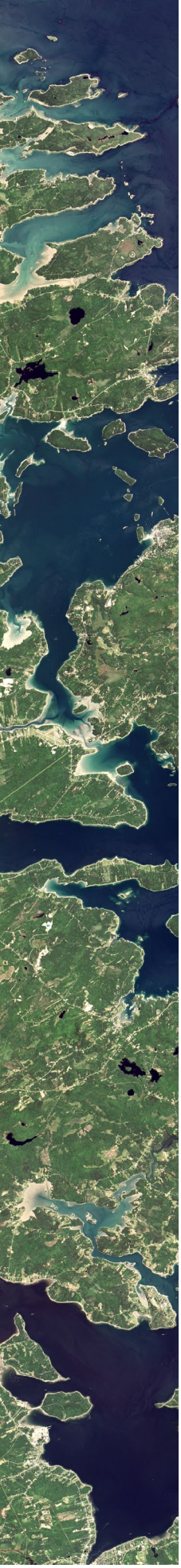
USGCRP provides support to help sustain the core operations of three international science organizations: the **World Climate Research Program (WCRP)**, which is the primary coordination mechanism for international research on the climate system; **System for Analysis, Research and Training (START)**, which provides opportunities for research, education, and training to scientists, policymakers, and practitioners in developing countries; and **Future Earth**, which builds interdisciplinary, cross-sectoral relationships to advance global sustainability science. Through NSF, USGCRP provides a U.S. contribution to these collaborators to help advance the fundamental understanding of the natural and human components of the Earth system, thereby extending the reach of USGCRP's own programs in observations, process research and modeling. With USGCRP's support, these collaborators also organize conferences, workshops, and trainings for scientists and policy makers from around the world, including those in their early career stages, in accordance with USGCRP's mandate under the Global Change Research Act to assist in building global change research capacity in the developing world.

HIGHLIGHT 21
Supporting responses to climate-sensitive diseases

Interagency efforts are engaging citizens in forecasting and observation of mosquito threats.

Global Learning and Observations to Benefit the Environment (GLOBE) is an international science and education program that provides students and the public worldwide with the opportunity to participate in data collection and the scientific process and contribute meaningfully to our understanding of the Earth system and global environment. In 2017, the U.S. Department of State (DOS) partnered with NASA to leverage GLOBE in engaging hard-to-reach populations in targeted Zika-affected countries to better track and control mosquitoes, combat Zika transmission, eliminate breeding sites, and make crowd-sourced data available to global partners. GLOBE program participants use a mobile phone app, low-cost lens attachments, and the scientific training they receive in the program to identify the types of mosquitoes in their communities, safely collect samples, and upload photos and data via a global map tracker to a centralized NASA database. The project currently runs through September 2019 and aims to build sustainable networks of schools, organizations, and public health officials in each Zika-affected region to improve disease tracking and control in focus countries and make the crowdsourced data available for use by international partners.

A participant using the GLOBE Observer app on their mobile device examines a magnified mosquito larva to determine if it is a disease-carrying species. Source: Department of State.



BUDGETARY INFORMATION

The budget crosscut represents the funds self-identified by USGCRP agencies as their contributions to USGCRP research activities. In addition, 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. By leveraging capacity and cooperation, agencies make vital contributions towards USGCRP's goal of supplying the knowledge base needed to respond to global change.

FY2017–2019
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).

Agency	FY2017 Enacted ($M)	FY2018 Enacted ($M)	FY2019 President's Budget ($M)
Department of Agriculture (USDA)	142	175	84
Department of Commerce (DOC)	293	320	206
Department of Energy (DOE)	229	239	129
Department of Health and Human Services (HHS)	6	7	6
Department of the Interior (DOI)	54	25	13
Department of Transportation (DOT)	0	0	-
Environmental Protection Agency (EPA)	19	18	-
National Aeronautics and Space Administration (NASA)	1,555	1,499	1,329
National Science Foundation (NSF)	280	254	238
Smithsonian Institution (SI)	8	8	8
TOTAL	2,585	2,546	2,013

APPENDIX I.

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) global change research program includes contributions from the Agricultural Research Service (ARS), the National Institute of Food and Agriculture (NIFA), the Forest Service (USDA-FS), Natural Resources Conservation Service (NRCS), National Agricultural Statistics Service (NASS), and Economic Research Service (ERS). These USDA entities ensure sustained food security for the Nation and the world. They maintain and enhance the health of U.S. forests and natural resources while identifying risks to agricultural production ranging from temperature and precipitation changes to the changing biology of pests, invasive species, and diseases.

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

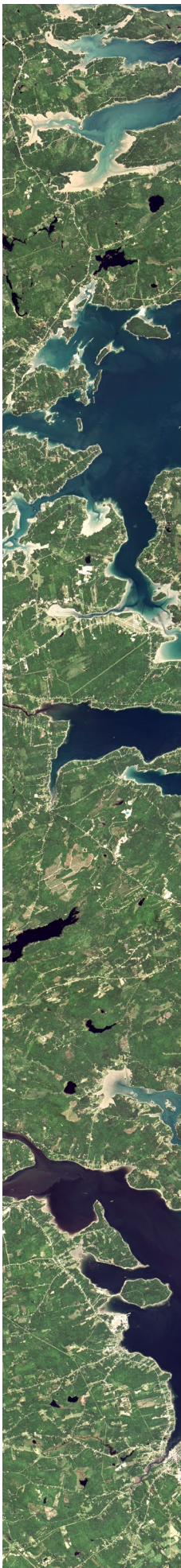
DEPARTMENT OF COMMERCE

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

NIST works with other Federal agencies to develop or extend internationally accepted traceable measurement standards, methodologies, and technologies that enhance measurement capabilities for greenhouse gas emission inventories and measurements critical to advancing climate science research. NIST provides measurements and standards that support accurate, comparable, and reliable climate observ-



-ations 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

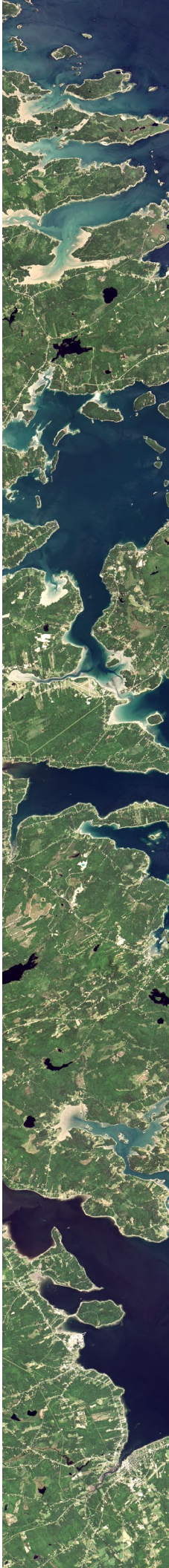
The Department of Defense (DOD)—while not supporting a formal mission dedicated to global change research—is developing policies and plans to manage and respond to the effects of climate change on DOD missions, assets, and the operational environment. Various research agencies within DOD sponsor and 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 United States 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 address key uncertainties in regional to global-scale Earth system change arising from the interactions and interdependencies of the atmospheric, terrestrial, subsurface, cryospheric, oceanic, and human-energy components of the Earth system. DOE's research strives to understand and anticipate how environmental and compounding stressors behave within a non-linear system and how these stressors, in turn, can influence the robustness and resilience of U.S. energy infrastructure. Particular emphasis also is placed on understanding how natural and human-derived factors contribute to variabilities and trends spanning local to global scales and extending from seasonal to multi-decadal time horizons. Supporting its major role in Earth system prediction, DOE advances long-term field experiments and best-in-class computing, exploiting major user facilities; develops modeling and simulation tools; conducts process and systems level research; incorporates model and data analytics and uncertainty characterization; and carries out archiving and management of extensive observed and model-generated data sets for use by the research community.

There are three areas of DOE research that contribute to the Department's efforts to advance the science of Earth system change: (a) Atmospheric System Research (science of aerosols, clouds, and radiative transfer); (b) Terrestrial Ecosystem Science (role of terrestrial ecosystems and coupled biogeochemical cycles); and (c) advanced modeling that combines development, simulation and analysis. DOE maintains its own suite of advanced modeling platforms, including the Energy Exascale Earth System Model (E3SM), which uses DOE's advanced high performance computers; DOE also collaborates with NSF to support the widely-used Community Earth System Model. DOE supports methods to obtain, evaluate, and analyze



regional climate information; explores and simulates multi-scale, multisector dynamics in context of global and regional changes and influences; and analyzes and distributes large Earth System Model output through the Program for Climate Model Diagnosis and Intercomparison (PCMDI) and the Earth System Grid. The Department supports the Atmospheric Radiation Measurement Climate Research Facility, a scientific user facility based on three permanent observatories and four mobile platforms 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.

DOE also conducts related applied research through its policy and energy offices. The research and analyses undertaken by these offices often requires the development and application of companion models to those used in Office of Science, e.g. models of energy systems and infrastructures; economics; technology impact; and risk-assessment. The applied offices also maintain and update data sets to explore such topics as electric grid stability, water availability for energy production, and siting of energy infrastructures.

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 air contaminants affected by climate change, changes in transmission of infectious diseases, and impacts in the aftermath of severe weather events, among many others. Research efforts also seek to assess the effectiveness of various public health adaptation strategies to reduce climate vulnerability, as well as the potential health effects of interventions to reduce GHG emissions.

Specifically, HHS supports USGCRP by conducting fundamental and applied research on linkages between climate variability and 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.

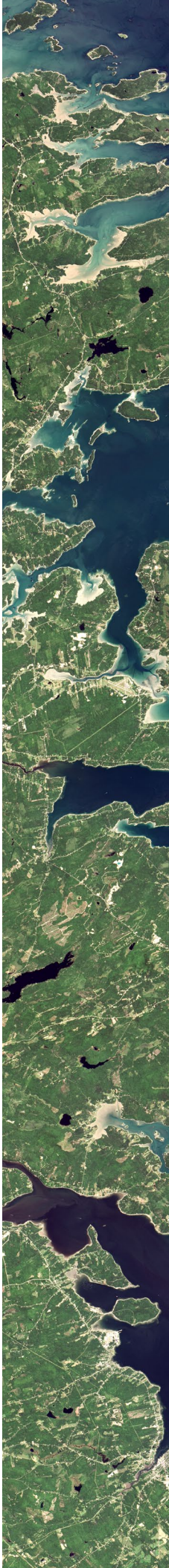
DEPARTMENT OF INTERIOR

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 an understanding of global change and its impacts with the ultimate goal of helping the Nation understand, adapt to, and mitigate global change.

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

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



DEPARTMENT OF STATE

The Department of State (DOS) contributes to the Intergovernmental Panel on Climate Change (IPCC), which assesses scientific, technical, and socioeconomic information relevant to the understanding of climate change, its potential impacts, and options for adaptation and mitigation. DOS, with the assistance of USGCRP, coordinates U.S. reviews of IPCC reports and U.S. author nominations and represents the U.S. at Panel meetings. DOS also works with other agencies in promoting international cooperation in a range of bilateral and multilateral science 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.

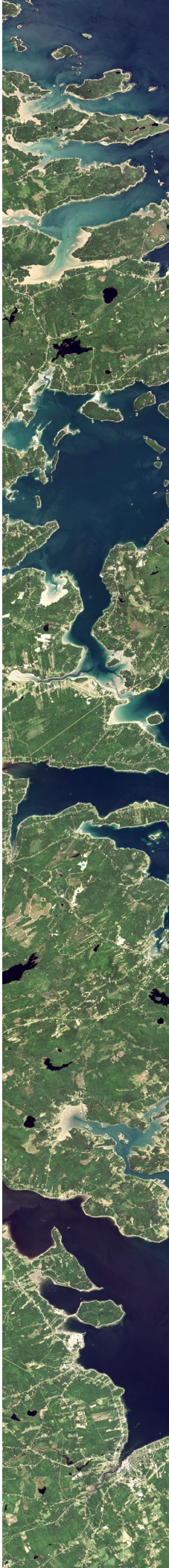
DOT works closely with USGCRP and its participating agencies to identify and address key scientific gaps regarding aviation climate impacts and to inform mitigation solutions. Other DOT initiatives to address climate change and improve the sustainability of the U.S. transportation sector follow:

- The Federal Highway Administration (FHWA) and other DOT agencies are undertaking climate impact and adaptation studies (including vulnerability and risk assessments), working with science agencies to develop regional climate data and projections, conducting methodological research, supporting pilot programs, and providing assistance to transportation stakeholders including state and local agencies.

- The Federal Aviation Administration (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 GHG emission reduction technologies and approaches to inform sustainable 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.



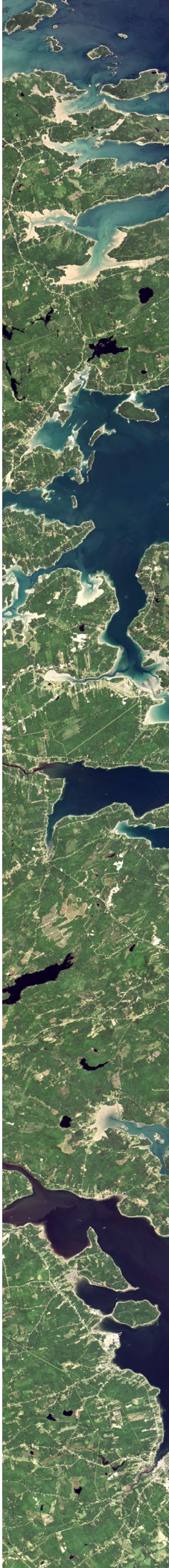
EPA relies on USGCRP to develop high-quality scientific models, data, and assessments to advance understanding about physical, chemical, and biological changes to the global environment and their relation to drivers of global climate change. Satellite and other observational efforts conducted by USGCRP 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 activities apply long-term datasets, analytical tools, and models to examine and communicate observed climate change indicators and project impacts and economic damages associated with global mitigation scenarios.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA's global change activities have four integrated foci: satellite observations, research and analysis, applications, and technology development. Satellites provide critical global atmosphere, ocean, land, sea ice, and ecosystem measurements. NASA's 21 on-orbit missions (as of September 2018) measure numerous variables required to enhance understanding of Earth interactions. In 2018, NASA launched the Gravity Recovery and Climate Experiment Follow On (GRACE-FO) dual-satellite mission with its German partner GFZ (German Research Centre for Geosciences) to restart the record from the 2002–2017 GRACE satellite mission. GRACE-FO will continue the work of tracking Earth's water movement to monitor changes in underground water storage, the amount of water in large lakes and rivers, soil moisture, ice sheets and glaciers, and sea level caused by the addition of water to the ocean. NASA also launched the ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS) instrument to the International Space Station (ISS) in 2018, which will measure the temperature of plants and use that information to better understand how much water plants need and how they respond to stress. Additional launches planned in 2018 are the Ice, Cloud, and land Elevation Satellite (ICESat-2), which will allow scientists to measure the elevation of ice sheets, glaciers, and sea ice in unprecedented detail, and the Global Ecosystem Dynamics Investigation (GEDI) to the ISS, which will measure the structure of Earth's tropical and temperate forests in high resolution and three dimensions. NASA's Earth Science Technology program also deployed several small (U-Class) satellites (also known as CubeSats) from the International Space Station in 2018 as part of its InSpace Validation of Earth Science Technologies program. In 2018, NASA selected two additional missions as part of its Earth Venture–Instrument series: 1) the Polar Radiant Energy in the Far Infrared Experiment (PREFIRE), which will fly a pair of small CubeSat satellites to probe a little-studied portion of the radiant energy emitted by Earth for clues about Arctic warming, sea ice loss, and ice-sheet melting ; and 2) the Earth Surface Mineral Dust Source Investigation (EMIT), which is a sensor that will be mounted to the exterior of the ISS to determine the mineral composition of natural sources that produce dust aerosols around the world.

NASA's program advances observing technology and leads to new and enhanced space-based observation and information systems. The Earth science research program explores interactions among the major components of the Earth system—continents, oceans, atmosphere, ice, and life—to distinguish natural from human-induced causes of change and to understand and predict the consequences of change. NASA makes significant investments to assure the quality and integration of data



through calibration and validation efforts that include satellite, surface, and airborne measurements, as well as data intercomparisons. NASA also carries out observationally driven modeling projects that include data assimilation, reanalysis, process representation, initialization, and verification. Significant airborne and shipborne campaigns took place during 2018, including the combined NASA-NSF Export Processes in the Ocean from Remote Sensing (EXPORTS) ship-based campaign in the Pacific Ocean and continued observations in Northwest Canada and Alaska through the Arctic-Boreal Vulnerability Experiment (ABoVE) campaign. 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 funds, develops and demonstrates a broad range of cutting-edge technologies – from new instruments and components to advanced modeling and information systems- to enable new capabilities, and reduces the cost, risk, and/or development times for Earth science instruments.

NATIONAL SCIENCE FOUNDATION

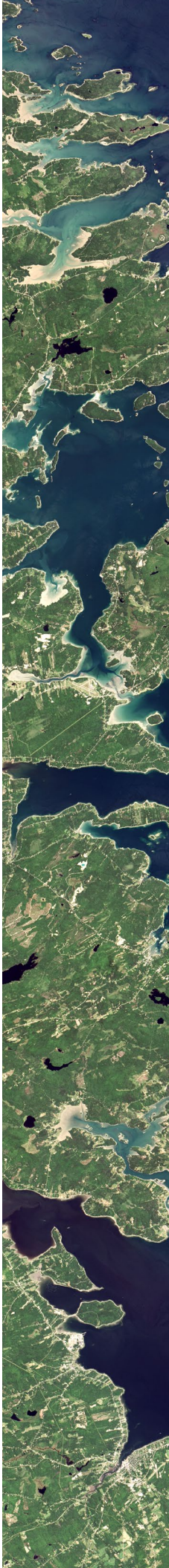
The National Science Foundation (NSF) addresses global change issues through investments that advance frontiers of knowledge, provide state-of-the-art instrumentation and facilities, develop new analytical methods, and enable cross-disciplinary collaborations while also cultivating a diverse, highly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

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

SMITHSONIAN INSTITUTE

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, observ¬ing 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 also 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 hu¬mans. 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, the Anacostia Community Museum, and the Cooper Hewitt Museum of Design to examine human responses to global change, within communities, reflected in art and culture, food, and music. Finally, Smithsonian outreach and education expands our scientific and social understanding of processes of change and represents them in exhibits and programs, including at the history and art museums of the Smithsonian. USGCRP funding enables the Smithsonian to leverage private funds for additional research and education programs on these topics.

U.S. AGENCY FOR INTERNATIONAL DEVELOPMENT

The U.S. Agency for International Development (USAID) carries out climate change and development work in four main areas: energy, sustainable landscapes, climate resilience, and climate risk management. USAID supports global research and analysis and partners bilaterally with dozens of countries to build capacity, address governance, and create the legal and regulatory environment needed to address climate change and development. This work is integral to helping countries pursue economic growth, stability, and self-reliance.

Energy: USAID helps partner countries build strong energy sectors that can attract private investment and power global economic and social development. USAID's efforts support least-cost modern energy solutions. In many countries, renewable energy is now the least-cost solution that maximizes development impact.

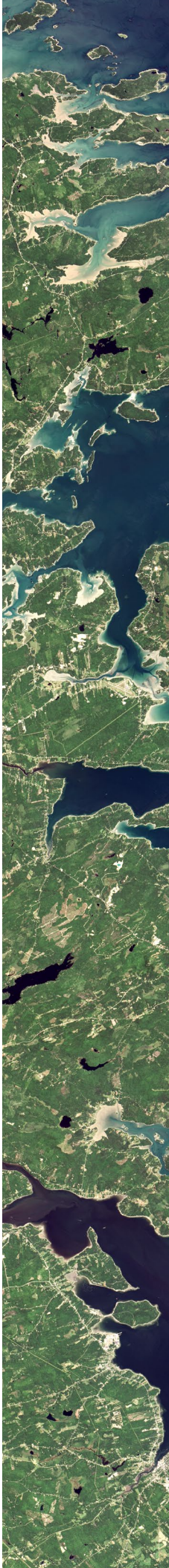
Sustainable landscapes: USAID supports research on estimating and accounting for land-based carbon stocks and greenhouse gas fluxes, and on governance and finance in the land sector, all with a focus on developing countries. USAID also supports partner countries in meeting their commitments to reduce land-based greenhouse gas emissions, often through activities that promote conservation, restoration, and sustainable use of forests, agriculture, and other lands. By improving landscape management, USAID helps to curb destruction and degradation, improve livelihoods, and increase resilience.

Climate resilience: USAID works with partner countries to build climate resilience and disaster preparedness to weather and climate-related shocks and stresses such as droughts, floods, and shifting rainfall patterns. Improved weather and climate information, informed land use planning, and smart infrastructure design are some ways communities can prepare for these risks and avoid setbacks. Thinking ahead and proactively managing risks help sustain livelihoods and maintain critical services, reducing the need for costly disaster response.

Climate risk management (CRM): CRM is an internal USAID practice to assess, address and manage climate risk in new strategies, projects, and activities across USAID's development portfolio, safeguarding U.S. investments through informed decision-making.

With over seventy overseas missions, USAID enables decision makers to apply high-quality climate information to their decision making and enables countries to accelerate their transition to climate resilient, sustainable economic development. USAID achieves these objectives through direct programming and integration of climate change adaptation and mitigation activities into the broader development portfolio.

USAID leverages scientific and technical resources from across the U.S. Government, private sector partners, and nongovernmental organizations and science institutes to develop and implement low-emissions development strategies, creating policy frameworks for market-based approaches to emission reduction and energy sector reform, promoting sustainable management of agricultural lands and forests, protecting biodiversity, and mainstreaming adaptation into development activities in countries most at risk to advance resilient and sustainable development.



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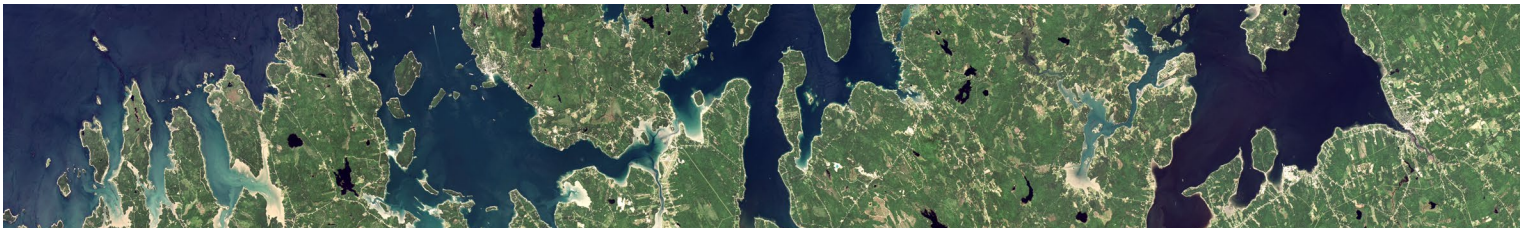

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