U.S. Global Change Research Program

OUR CHANGING PLANET

The U.S. Global Change Research Program for Fiscal Year 2021

A Report by the U.S. Global Change Research Program
and the Subcomittee on Global Change Research,
National Science and Technology Council

A Supplement to the President's Budget for Fiscal Year 2021

OUR CHANGING PLANET

The U.S. Global Change Research Program for Fiscal Year 2021

A Report by the U.S. Global Change Research Program
and the Subcomittee on Global Change Research,
National Science and Technology Council

A Supplement to the President's Budget for Fiscal Year 2021

This material was developed with Federal support through the U.S. Global Change Research Program under National Aeronautics and Space Administration Award No. 80HQTR21D0004.

The official and complete version of this report is the PDF, available at: https://www.globalchange.gov/browse/reports/our-changing-planet-FY-2021

Suggested citation:

U.S. Global Change Research Program. 2021. *Our Changing Planet: The U.S. Global Change Research Program for Fiscal Year* 2021. Washington, DC, USA. doi: 10.7930/ocpfy2021

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 2021 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.

Front Cover: An algal bloom in Lake St. Clair captured by the Operational Land Imager on the Landsat 8 satellite, July 28, 2015. Credit: NASA Earth Observatory image by Joshua Stevens, using Landsat data from the U.S. Geological Survey.

Our Changing Planet Editorial and Production Team

Charles A. Brodine – Engagement and Communications Specialist, USGCRP National Coordination Office
Alexa Jay – Senior Science Writer/Editor, USGCRP National Coordination Office
Katie Reeves – Engagement and Communications Lead, USGCRP National Coordination Office

Subcommittee on Global Change Research

Leadership

Mike Kuperberg - Executive Director, USGCRP
Wayne Higgins – Chair, Department of Commerce
Allison Crimmins – Director, National Climate Assessment

Principals

John Balbus - Department of Health and Human Services
Ben DeAngelo - Department of Commerce (National Oceanic and Atmospheric Administration)
Gerald Geernaert - Department of Energy
Noel Gurwick - U.S. Agency for International Development
William Hohenstein - Department of Agriculture
Kirk Johnson - Smithsonian Institution
Jack Kaye - National Aeronautics and Space Administration
April Marchese - Department of Transportation (acting)
Andy Miller - Environmental Protection Agency
Ben Petro - Department of Defense
Geoffrey Plumlee - Department of the Interior
Trigg Talley - Department of State
Maria Uhle - National Science Foundation

Executive Office of the President Liaisons

Grace Diana - Acting Executive Director, National Science and Technology Council
Kimberly Miller – Office of Management and Budget

TABLE OF CONTENTS

THE U.S. GLOBAL CHANGE RESEARCH PROGRAM **2**

IMPLEMENTING THE NATIONAL GLOBAL CHANGE RESEARCH PLAN **2**

Advancing Science 3

Informing Decisions 5

Conducting Sustained Assessments 8

Supporting International Global Change Research 9

BUDGETARY INFORMATION **11**

APPENDIX I. USGCRP MEMBER AGENCIES **12**

REFERENCES **19**

THE U.S. GLOBAL CHANGE RESEARCH PROGRAM

The U.S. Global Change Research Program (USGCRP) was mandated by Congress in the Global Change Research Act of 1990 (GCRA) to "assist the Nation and the world to understand, assess, predict, and respond" to processes of global change—including changes in climate, land productivity, oceans and other water resources, and ecological systems—that may alter Earth's capacity to sustain life.[1] USGCRP coordinates research across 13 Federal agencies (Figure 1) to improve understanding of human-induced and natural processes of change that influence the total Earth system: the atmosphere, land, water, ecosystems, and people.

USGCRP's membership includes agencies that produce global change science, agencies that use it to carry out their missions, and some that do both (see Appendix I. USGCRP Member Agencies). Through USGCRP, agencies work together to advance global change research that addresses national needs, inform decisions to build resilience to the impacts of global change, and deliver products mandated by the GCRA, including the National Climate Assessment. As directed by the GCRA, USGCRP also promotes international coordination on global change research, which includes providing support for activities relating to U.S. participation in international scientific assessments (see Supporting International Global Change Research).

The Fiscal Year (FY) 2021 edition of USGCRP's annual report to Congress, *Our Changing Planet*, presents highlights of the Program's achievements in 2019, as well as a summary of agency expenditures under USGCRP's budget crosscut (see Budgetary Information), as required by the GCRA. USGCRP's scope includes but is not limited to the range of agency programs implemented with funds included in the budget crosscut, and the efforts described in this document represent a subset of the overall accomplishments of the Program. The highlighted activities represent interagency collaborations that rely on coordinated investments of two or more member agencies. Note that single agency investments, including many that enable interagency accomplishments, are not typically covered in this annual report. See Appendix I. USGCRP Member Agencies for more detail on the principal focus areas related to global change research for each 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 the Interior**
- **Department of State**
- **Department of Transportation**
- **Environmental Protection Agency**
- **National Aeronautics and Space Administration**
- **National Science Foundation**
- **Smithsonian Institution**
- **U.S. Agency for International Development**

IMPLEMENTING THE NATIONAL GLOBAL CHANGE RESEARCH PLAN

USGCRP's National Global Change Research Plan and its 2017 update provide a framework for advancing scientific understanding of the Earth system while strengthening capacity to answer questions critical to decision-making in a changing environment. The Program's four strategic goals, which respond to its mandate under the GCRA, are to advance global change science, inform decisions, conduct sustained assessments, and engage key stakeholders and audiences in support of these goals, including internationally. This section highlights achievements in 2019 that support implementation of USGCRP's goals and illustrate ongoing advances in the science of global change. Highlights are organized by overall science goals and program area. Activities undertaken in previous years are available at globalchange.gov/explore.

Advancing Science

Global change science brings together many disciplines to form a picture of our planet as a whole, including its changing climate. Integration across different approaches and areas of study, supported by interagency coordination through USGCRP, drives advances in our ability to observe, understand, and predict processes of change in the Earth system. Coordination across agencies with different missions facilitates the efficient use of Federal assets and resources to address high-priority science questions, contributing to ambitious research outcomes that require broad, sustained collaboration.

The research efforts highlighted in this section, drawn from diverse disciplines and methods within global change science, showcase advances in Earth system observations, modeling, and process understanding that provide the foundation for assessment and decision-support capabilities within and across agencies and beyond. Activities highlighted this year include an observing network that is providing insights into a changing Arctic (Highlight 1); complementary data analyses that confirm ongoing global surface temperature rise (Highlight 2); the development of a consistent framework for measuring greenhouse gas emissions at scales useful to policy decisions (Highlight 3); a campaign to investigate the impact of fire on air quality, human health, and climate (Highlight 4); and interagency modeling activities that support long-running efforts to project future climate change and inform major national and international climate assessments (Highlight 5).

Highlight 1. An observing network tracks changes in Arctic sea ice cover

Satellite observations show significant declines in Arctic sea ice cover in recent decades as the climate has warmed,[2] with impacts on fish and wildlife habitats that are important for subsistence, recreation, and tourist activities in the region. Retreating sea ice also contributes to increased storm surge, coastal flooding, and coastal erosion.[3] Arctic sea ice plays a key role in moderating climate within and beyond the region, and understanding sea ice change is critical to projections of future climate change. Complementary ground and remote sensing observations provide measurements of critical components of the Arctic sea ice system at the necessary range of spatial and temporal scales.

DoD's Cold Regions Research and Engineering Laboratory (CRREL) established a network of sensors installed in floating sea ice that provides near real-time access to data on ice thickness, temperature, and drift, as well as measurements from the surrounding ocean and atmosphere. The continuing 20-year record of quality-controlled observations offers valuable insight into the relationships among the air, ice, and sea, and can help attribute ice loss to specific causes.

The results of this NOAA-funded effort are delivered to publicly accessible archives at the National Snow and Ice Data Center and NSF's Arctic Data Center. These data provide a resource for understanding change in the Arctic and for validating remote measurements of sea ice cover, including satellite-based observations of ice thickness, depth of snow cover, and timing of ice melt and freeze-up. They also help improve understanding of the role of Arctic sea ice cover in the global climate system and contribute to improved projections of future ice conditions.

The use of observations from space, aircraft, and ground-based sensors allows scientists to monitor the Arctic system at different spatial and temporal scales. Efforts that make use of these complementary data enable improvements in understanding of sea ice processes and how they vary across scales, in remote sensing algorithms that detect change, and subsequently, in how models represent sea ice processes and future projections of how climate change will impact Arctic ice cover.

Highlight 2. Independent analyses provide a consistent picture of global surface temperature change

According to independent analyses by NASA and NOAA, Earth's average global surface temperature in 2019 was the second warmest since modern record-keeping began in 1880. Globally, 2019's average temperature was second only to that of 2016 and continued the planet's long-term warming trend. Rising temperatures are contributing to glacier melt, disappearing snow cover, shrinking sea ice, rising sea level, and changes in rainfall patterns.[4]

NOAA and NASA take slightly different, complementary approaches to interpreting global surface temperature, and work together to produce and communicate an annual update. NASA's temperature analyses incorporate surface temperature measurements from more than 20,000 weather stations, ship- and buoy-based observations of sea surface temperatures, and temperature measurements from Antarctic research stations. NOAA scientists incorporate much of the same temperature data as NASA, but use a different method of interpreting data from Earth's poles and other data-poor regions to translate the raw measurements into a global picture of temperature change. Together, the analyses provide a consistent picture of a warming planet.

A 2019 assessment of NASA's record of global surface temperatures found that improved uncertainty analysis, based on source data, suggests that the agency's estimate of Earth's long-term temperature rise in recent decades is accurate to within less than a tenth of a degree Fahrenheit. This finding provides greater confidence that past and future research is correctly capturing rising surface temperatures. The assessment of this data product, known as GISTEMP, shows that the resulting annual values (within the 95% confidence interval) are likely accurate to within 0.09°F (0.05°C) in recent decades, and 0.27°F (0.15°C) at the beginning of the nearly 140-year record.

Highlight 3. An international observing system sets a global framework for measuring greenhouse gas emissions

Long-term measurements of Earth's atmosphere show rapidly rising concentrations of greenhouse gases linked to human activities.[5] Existing observing networks provide information on atmospheric concentrations of greenhouse gases at the global scale, but this spatial scale is not sufficient to help nations, regions, and other entities quantify and manage greenhouse gas emissions. To improve the relevance of emissions information for decision-making, an international initiative is promoting scientific methods that combine atmospheric concentration and emissions inventory data with simulations of atmospheric motions, forming a framework for more accurate and consistent emissions estimates over a range of spatial and temporal scales useful in informing policies, their implementation, and outcomes.

NASA, NOAA, and the National Institute of Standards and Technology have provided leadership and support for the development of the World Meteorological Organization Integrated Global Greenhouse Gas Information System (IG^{3}IS) initiative. The IG^{3}IS initiative seeks to enhance the capacity of nations, states, cities, and industries to target emissions reduction opportunities and track progress towards their goals. Success depends on the availability of atmospheric measurements in key greenhouse gas source regions, and relies on a multi-tiered observing strategy involving satellite, aircraft, mobile, and tower-based surface measurements.

Since gaining approval of its Science Implementation Plan in June 2018, IG^{3}IS has supported the creation of new projects under its national, subnational, and industrial foci, and has won endorsement for the use of its framework and methods by international organizations such as the United Nations Framework Convention on Climate Change, the Intergovernmental Panel on Climate Change (IPCC), and the Committee on Earth Observing Satellites. A key outcome from these efforts is that the IPCC Task Force on National Greenhouse Gas Inventories has published new guidelines for all countries detailing the value and use of atmospheric measurements-based information in their 2019 *Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*.

Highlight 4. An observing campaign investigates the impact of fires on air quality and climate

Fire risks to human health and property have increased in recent decades due to the impacts of a warmer, drier climate on ecosystems as well as historic land use and management practices. Smoke from wildfires in the western United States and agricultural fires in crop-producing regions such as the southeastern United States increasingly impacts air quality, with expected negative effects on human health.[6]

The impacts of smoke on atmospheric conditions depend on many factors: the kind of fuel being burned, weather and climate conditions at ignition, and how smoke moves through the atmosphere. To help improve understanding of how these conditions influence air quality, the summer 2019 FIREX-AQ (Fire Influence on Regional to Global Environments and Air Quality) field campaign brought together hundreds of scientists from NOAA, NASA, USDA Forest Service, and more than 40 additional partners to sample fire emissions in the northwestern and southeastern United States. Over two months, researchers used aircraft, satellite, and ground-based instrumentation to investigate the chemistry and fate of trace gases

A natural color image of the Williams Flats fire approaching the north bank of the Columbia River in eastern Washington, August 7, 2019, captured by the Operational Land Imager on the USGS/NASA Landsat 8 satellite. On August 8, FIREX-AQ researchers aboard NASA's DC-8 research plane sampled the composition and chemistry of the fire's smoke plume. Source: NASA Earth Observatory image by Joshua Stevens, using Landsat data from the USGS.

and aerosols in smoke from wildfires and agricultural fires. To investigate fires in more detail than any previous study—from the fuels on the ground to long-term climate impacts and everything in between—the multi-agency collaboration leveraged assets and resources from all partners involved in FIREX-AQ.

Data from the campaign will be used to improve satellite-based estimates of emissions from wildfires and agricultural burns as well as understanding of the atmospheric impacts of fires. These advances will in turn improve climate and air quality models and help provide better information to public health and land management officials

Highlight 5. Modeling efforts drive advances in projections of future climate change

The U.S. research centers that develop climate and Earth system models and the U.S. scientific community are key participants in long-running collaborative efforts to improve knowledge on climate change. A number of major interagency activities supporting improvements in climate modeling took place in 2019.

Most prominently, the World Climate Research Programme Coupled Model Intercomparison Project (CMIP) is currently in its sixth phase (CMIP6). The earlier phases of CMIP experiments have provided the research community with large, detailed model-generated datasets that allow them to evaluate and improve various aspects of model performance and develop projections of future climate change. CMIP6 is the largest such modeling experiment so far, with a number of intercomparison projects that examine specific Earth system components and processes, including aerosol chemistry, detection and attribution of climate change, and the evaluation of and potential risks related to geoengineering, among many others.

Model output from CMIP6 and prior CMIPs will continue to be analyzed, validated, and used by the research community to improve future predictive models, allowing scientists and practitioners to develop and deliver much higher resolution climate projections at a global scale, and to better understand how the climate system functions and how it can be simulated with greater accuracy. The outcomes of analyses of CMIP6 model output will inform the next Intergovernmental Panel on Climate Change assessment report and the Fifth National Climate Assessment. Many U.S. modeling centers are participating in the CMIP6 effort, including the National Center for Atmospheric Research (NCAR; primarily sponsored by NSF, with some additional support from NOAA, NASA, DOE, DoD, and the Federal Aviation Administration), DOE's Energy Exascale Earth System Model effort, NOAA's Geophysical Fluid Dynamics Laboratory, and NASA's Goddard Institute for Space Studies.

CMIP6 datasets are already being used in a collaboration among NOAA, DOE, NSF, and other agencies to develop process-oriented diagnostics that help scientists understand and address model errors. Software was developed through a collaboration among scientists at NCAR, NOAA, DOE, and NASA laboratories, as well as academic institutions.

Collaboration on model development has also continued in the interagency space. One such activity initiated in 2019 involves scientists from NOAA, NASA, NCAR, and DOE, who are collaborating with the academic community on new Climate Process Team (CPT) efforts. These activities represent coordinated efforts by observational scientists, process theoreticians, and modelers to improve the representation of land surface and ocean processes in climate models. This CPT method of improving climate models was originally pioneered by NSF and has since expanded to a multi-agency consortium. CPT efforts have yielded significant advances in climate models through collaboration among Federal agencies and with the non-Federal scientific community. This work is also supportive of the U.S. Global Energy and Water Exchanges (GEWEX) effort coordinated through USGCRP.

Informing Decisions

USGCRP provides a venue for coordination and integration of efforts across the Federal Government to provide access to datasets, tools, and assessments that inform decisions related to all aspects of global change. Interagency science contributes to the development of authoritative, freely available information tools for responding to climate-related risks and opportunities, including the provision of information at scales that are useful for decision-making. Efforts highlighted this year include research and applications to support management of risks from harmful algal blooms (Highlight 6), the use of satellite data to track crop production (Highlight 7), information tools to support climate-resilient agriculture in the Midwest (Highlight 8), and activities focused on improving U.S. capacity to predict and communicate changes in risks of climate-sensitive diseases (Highlight 9).

Highlight 6. Research and decision tools support management of harmful algal blooms

Harmful algal blooms, or HABs, occur when colonies of cyanobacteria grow to a much greater size and density than normal, resulting in negative effects on water quality, ecosystem health, and the health of humans and animals. Climate-related factors contribute to HABs, including water temperatures and the frequency and intensity of extreme events such as intense storms, both of which are affected by climate change. The impacts of climate change are expected to further increase risks from HABs in recreational and drinking water sources in the coming decades.[7]

While researchers have identified many factors that contribute to HABs, how these factors come together to create a bloom of algae is not well understood. Interagency research efforts

An algal bloom in western Lake Erie, September 26, 2017, captured by the USGS/NASA Landsat 8 satellite. Brighter shades of green indicate a higher concentration of algae. Source: USGS/NASA.

seek to advance understanding of how and why HABs form to improve detection and forecasting of these seasonal events. Other efforts are using currently available data to provide communities with advance warning of events so they can prepare for the adverse environmental, economic, and health impacts of HABs.

Nutrient runoff from fertilizer applied to agricultural fields is one source of risk for HABs. USDA's Agricultural Research Service (ARS) is conducting a series of pond-scale experiments to evaluate how excess nitrogen and phosphorous affects the development of algal blooms at the ecosystem scale. ARS is also conducting field work to understand seasonal variability in environmental factors that influence algal blooms in agricultural water bodies. These efforts are critical to closing research gaps between understanding of the biological factors and the environmental conditions that influence algal growth rates, and will help resource managers predict and manage risk within agricultural water bodies. This research is conducted jointly with EPA and the USGS.

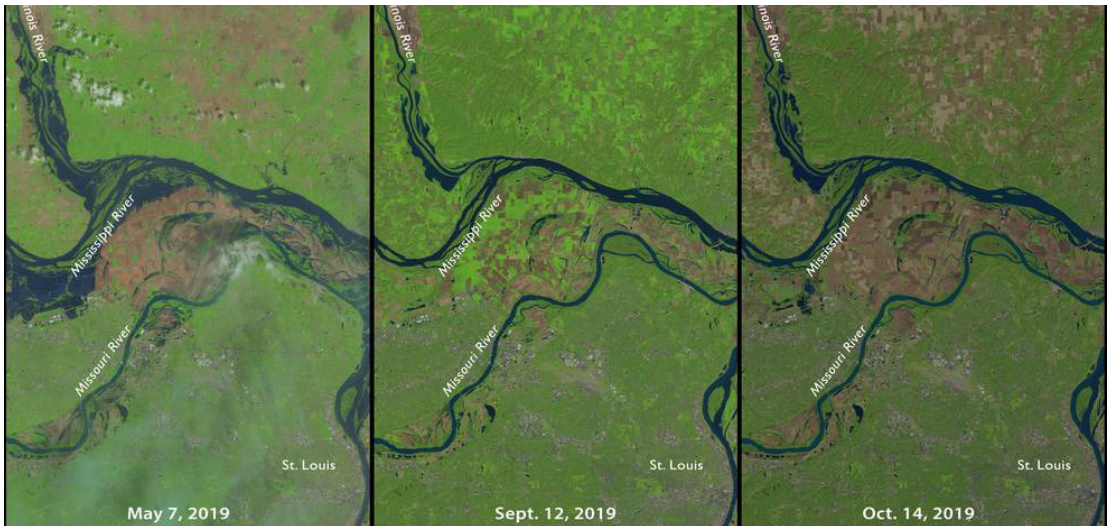
In a separate project, a regional network of agricultural fields and small watersheds is serving as an outdoor laboratory for ARS units in West Lafayette, Indiana and Columbus, Ohio, allowing researchers to quantify the impacts of human-caused and natural climate changes on nutrient runoff that fuels HAB formation in Lake Erie.[8 9 10] Assessment of long-term trends in precipitation, discharge, and water quality identified associated changes in rainfall patterns and land management practices that influence algal blooms. Research evaluating the uptake of nutrients by crops and the transport of water through the system, coupled with field-scale testing of novel conservation practices, has resulted in new strategies and recommendations for decreasing nutrient loss under current and future climatic conditions.[11] This research is conducted jointly with EPA and the USGS.

Like a weather forecast, an HAB forecast provides advance warning of conditions that could lead to potentially harmful algal blooms. EPA's Cyanobacteria Assessment Network Mobile Application (CyAN app) alerts officials and members of the public when an HAB may be forming, based on satellite observations of changes in water color. The app provides access to satellite algal bloom data for over 2,000 of the largest lakes and reservoirs across the United States.

The CyAN app is a product of the multi-agency Cyanobacteria Assessment Network, a collaboration among EPA, NASA, NOAA, and the USGS to develop an early warning indicator system using historical and current satellite data to detect algal blooms in U.S. freshwater systems.

Highlight 7. Satellite and ground data track status of the nation's food supply

USDA's National Agricultural Statistics Service (NASS) and Economic Research Service (ERS) track U.S. crop production each year, relying in large part on producer surveys and ground observations to estimate acreage and yields at state and county levels. During the growing season, production data inform estimates of crop acreage and yields that help farmers and traders set prices. Satellite data offer a useful method for validating statistics collected on the ground, and can help fill in gaps in ground observations, particularly in years where planting is delayed or disrupted due to weather or climate extremes.



Three moments in a year of farming north of St. Louis, Missouri, as seen in USGS/NASA Landsat 8 data. On the left is May 7, 2019, as heavy rains delayed planting for many farms. September 12, in the middle, shows bright green signifying growing vegetation, although with a fair amount of brown, bare fields. On the right, October 14, the light brown indicates harvested fields, while darker brown indicates fields that had not been seeded or were fallow all summer. Source: USGS/NASA.

NASS uses data from the USGS/NASA Landsat 8 and the European Union Copernicus Sentinel 2 A/B satellites, which provide data at a fine enough scale to distinguish individual fields, to identify where particular crops are growing. Sensors aboard NASA's Aqua and Terra satellites also monitor daily vegetation health and growth stage, which are indicators of crop yield. For example, in 2019, heavy spring rains flooded millions of acres of cropland around the Mississippi, Wisconsin, and Missouri Rivers, delaying planting for many farmers. Landsat 8 and Sentinel 2 data helped NASS state officials observe which fields and areas were most impacted by the floods and determine which fields had planted crops.

NASS's Cropland Data Layer datasets are released to the public at the end of each year. The site's historic data are used by disaster managers to evaluate crop damage from floods and other natural disasters. Resource managers also use historic data to monitor crop rotation, study land-use change and crop migration, and monitor water use.

Highlight 8. An ongoing partnership provides climate information to agricultural producers

The U.S. Midwest is a major producer of a wide range of food and animal feed for national consumption and international trade. Higher humidity, precipitation, and temperatures associated with a changing climate increasingly impact agriculture in the region, and projected climate changes are expected to pose growing challenges to agricultural productivity in the coming decades.[12]

Weather and climate information targeted to the needs of agricultural producers can help producers increase the resilience of their operations to climate variability and change. USDA's Midwest Climate Hub works closely with NOAA's National Weather Service to collect and supply weather and climate-related information that is useful and usable for agricultural producers in the region. Together, USDA and NOAA continuously assess current conditions and upcoming situations, including weather-related disasters, and communicate tailored information to help producers prepare for and recover from climate-related events.

In addition to regular webinars and meetings with users, recent examples of this partnership include the Extreme Cold Snap brief (January 2019), Post-Bomb Cyclone Recovery list of resources (March 2019), and a special weather event webinar on flooding and precipitation impacts on agriculture (June 2019). These communications also connect users with region-specific information and resources provided by university agricultural extension services, state and Federal disaster relief agencies, and other science-based information and tools created by regional and national partners.

Highlight 9. Interagency activities inform efforts to predict and prepare for climate-sensitive infectious diseases

Climate-sensitive infectious diseases, including vector-borne diseases (such as dengue, West Nile Virus, and Chikungunya), waterborne diseases (such as those caused by *Vibrio* species), soil- and dust-borne diseases (such as Valley Fever), and zoonotic diseases (such as plague and avian influenza) pose threats to the health of Americans living at home and abroad. These threats are anticipated to change in distribution and severity as climate change progresses in the coming decades. Improving U.S. capacity to predict and communicate changes in risks of climate-sensitive diseases, including translation of predictions into decision-support tools, is key to managing future disease risks in a changing climate.

In April 2019, USGCRP's Interagency Crosscutting Group on Climate Change and Human Health (CCHHG) published a summary report, *Predicting Climate-Sensitive Infectious Diseases to Protect Public Health and Strengthen National Security*, that represented the culmination of a series of webinars and a workshop exploring this challenge. The webinars and workshops were led by a steering committee that included members from USGCRP's Interagency Group on Integrative Modeling and the CCHHG as well as the interagency Pandemic Prediction and Forecasting Science and Technology Working Group.

The report highlights current efforts and outlines a path forward for increasing the U.S. Government's ability to predict, prevent, and prepare for climate-sensitive infectious diseases that threaten U.S. interests at home and abroad. For example, the Rift Valley Fever Monitor and related Emerging Risk Notification, produced by DoD, NASA, and USDA, provide a model for what could be done regularly to manage other emerging climate-sensitive disease risks in the future. The analysis and frameworks represented in the report informed several follow-on activities within USGCRP and its member agencies. For example, the National Institutes of Health, the Centers for Disease Control and Prevention, NOAA, and DoD have begun collaborating to develop seasonal forecasting products to inform health decision-making. In another example, the DOS partnered with experts from HHS, USAID, NOAA, State and local governments, and the non-governmental sector to deliver several international information-sharing programs focused on the use of Integrated Information Systems—a key concept in the report—in 2018 and 2019. An Integrated Information System is a framework designed to ensure that environmental, socioeconomic, health, and other variables are combined to provide useful information for early warnings and promote sound health-related risk management.

In addition, in response to the report's recommendations, and in partnership with USGCRP's International Activities Interagency Working Group, NOAA's International Research and Applications Program and the NSF supported research grants focused on predicting climate-sensitive infectious diseases. This research funding was further leveraged as part of the global Belmont Forum's Collaborative Research Action on Climate, Environment and Health.

Conducting Sustained Assessments

The Global Change Research Act directs USGCRP to produce quadrennial assessments of current scientific understanding on global change, including projections of future climate conditions and ongoing and potential impacts on society in the United States. USGCRP approaches assessment as a sustained process that enables scientists and stakeholders to address issues of emerging importance on an ongoing basis while improving the thoroughness of the quadrennial report. Focused assessment reports on topics such as the impacts of drought (Highlight 10) as well as ongoing efforts including an interagency climate-relevant indicators web platform (Highlight 11) and efforts to develop indicators of socio-environmental change (Highlight 12) provide valuable input to the National Climate Assessment, and serve individual agency and interagency constituencies.

Highlight 10. A new assessment links the latest drought science with management responses

Most regions of the United States are projected to experience a higher frequency of severe droughts and longer dry periods as a result of a warming climate.[13] In 2016, USDA Forest Service (USDA-FS) scientists and partners prepared a state-of-the-science synthesis of drought effects on the nation's forests designed to inform drought resilience and adaptation efforts. A new volume released in 2019 builds on that work, linking recent scientific evidence with regionally focused discussions of risks, vulnerabilities, and management options to minimize drought impacts, optimize forest and rangeland recovery from drought, and create forests and rangelands better adapted to future drought conditions.

Drought conditions and impacts vary across the United States, and evaluating management options requires a regionally specific approach. The new volume includes seven regional chapters (Alaska and the Pacific Northwest, California, Hawai'i and U.S.-Affiliated Pacific Islands, Interior West, Great Plains, Northeast and Midwest, and Southeast) that provide a state-of-the-science assessment of drought effects and region-specific management options to help natural resource managers anticipate and respond to current and future droughts.

The interagency effort led by USDA-FS involved researchers from the USGS, National Park Service, Bureau of Land Management, NOAA, and USDA's Agricultural Research Service. This assessment product will provide input to USGCRP's sustained assessment process, including the Fifth National Climate Assessment.

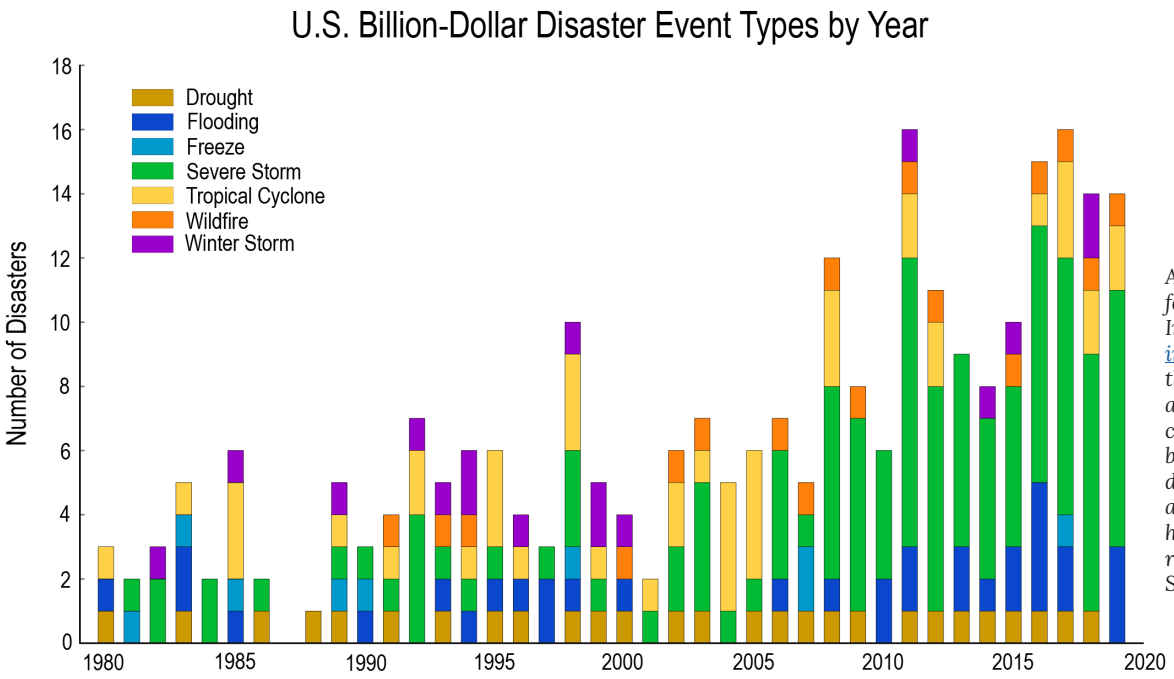
Tree mortality at Bass Lake Recreation Area, California. A five-year drought in California (2011–2016) led to western pine beetle outbreaks, which contributed to the mortality of 129 million trees. Credit: Marc Meyer, U.S. Forest Service; NCA4, Ch. 6: Forests, Figure 6.2.

Highlight 11. An interagency platform highlights important indicators of change

Climate indicators show trends over time in key aspects of our environment, such as greenhouse gas levels in the atmosphere, temperatures across land and sea, and the extent of Arctic sea ice, as well as metrics of social or economic exposure to the impacts of climate variability and change. Indicators are based on long-term, consistently collected data and can be used to assess risks and vulnerabilities from a changing climate and to inform response actions. USGCRP's Indicators Interagency Working Group (IndIWG) leverages existing agency research, data, and indicators in support of sustained assessment activities, including the National Climate Assessment.

IndIWG launched an interagency web platform for USGCRP to highlight federally supported climate-relevant indicators (see figure for example) and programs and integrate information from the Fourth National Climate Assessment (NCA4), including a figure depicting climate-relevant trends across the United States that was developed for the NCA4 Volume II Overview chapter. The platform provides readily accessible, well-documented climate information and is well positioned to support sustained assessment activities, including the addition of new indicators, routine data updates, and a range of communication activities.

The IndIWG and the indicators web platform represent an interagency collaboration with participation and input from many USGCRP member agencies, including the DOI, EPA, HHS, NASA, NOAA, NSF, and USDA, as well as USGCRP interagency working groups.



An example indicator featured on the USGCRP Indicator Platform. This indicator shows, by year, the number of weather and climate disasters causing more than one billion U.S. dollars in direct losses. These events are binned into seven hazard types, each represented by its own color. Source: USGCRP.

Highlight 12. A collaboration explores socio-environmental systems indicators for climate change adaptation and resilience

A national system of physical, ecological, and societal indicators is considered a foundational component of the sustained assessment process, serving to help users understand the changing environment, assess risks and vulnerabilities, and make informed decisions to build resilience to change. A 2019 Federal–academic workshop sought to advance the development of socio-environmental systems indicators of climate change to support adaptation and resilience decisions at various scales in the United States.

This work was supported by the National Socio-Environmental Synthesis Center (SESYNC) under funding received from NSF. Nineteen participants from Federal agencies (EPA, NOAA, USDA Forest Service), academia, State, and non-governmental organizations convened at SESYNC headquarters in Annapolis, Maryland, on May 15–17, 2019. Participants discussed strategies for integrating social and environmental data into indicators, and shared perspectives on how to build robust resilience knowledge and better address the needs of people doing resilience and adaptation projects when designing indicators for use in decision-making.

Supporting International Global Change Research

As part of its legislative mandate, 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. To advance these goals, USGCRP develops international partnerships that support the priorities and objectives of the USGCRP community, link to USGCRP's program areas, and build on existing agency investments and resources (Highlight 13).

Highlight 13. USGCRP enhances cooperation among international global change science organizations

USGCRP's International Activities Interagency Working Group (IAIWG) convened its first international and interagency workshop in December 2018, bringing together representatives from System for Analysis, Research and Training (START), Future Earth, and the World Climate Research Programme (WCRP). These three international programs receive funding through USGCRP to support their activities and to advance USGCRP's international mandate. USGCRP was represented by ten Federal agencies as well as USGCRP staff. The workshop's goals were to enhance awareness of mutual priorities, investments, and activities; and to identify areas where coordination could be most beneficial. Outcomes from this meeting include improved communications among USGCRP and the three international organizations supported by the Program.

In November 2019, the IAIWG hosted a follow-on briefing between USGCRP member agencies, START, Future Earth, WCRP, and the Inter-American Institute for Global Change Research to further strengthen coordination among these organizations and establish a foundation for the regular convening of USGCRP and the international programs it supports. Outcomes from the 2019 briefing included increased awareness of the international organizations' priorities and activities and information-gathering exercises to identify specific coordination opportunities.

Open data initiatives were highlighted as potential areas for future cross-collaboration, including preparations for a data assimilation network and a Tropospheric Ozone Assessment Report coordinated by WCRP, NOAA, and NASA. The group also agreed to establish an understanding of the current programming and activity landscape through development of a cross-organizational list of current and planned activities. This activity is ongoing.

BUDGETARY INFORMATION

The budget crosscut represents the funds self-identified by USGCRP agencies as their expenditures in support of 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 surface-based 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.

FY 2021 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	FY 2019 Enacted (M$)	FY 2020 Enacted ($M)	FY 2021 President's Budget ($M)**
Department of Agriculture (USDA)	107	111	101
Department of Commerce (DOC)	293	306	191
Department of Energy (DOE)	259	256	128
Department of Health and Human Services (HHS)	10	10	9
Department of the Interior (DOI)	25	38	10
Department of Transportation (DOT)	0	0	0
Environmental Protection Agency (EPA)	19	18	0
National Aeronautics and Space Administration (NASA)	1,484	1,469	1,252
National Science Foundation (NSF)	246	246	217
Smithsonian Institution (SI)	8	8	8
TOTAL (USGCRP)	2,451	2,461	1,915

***Please note that FY 2021 enacted appropriations differ significantly from the FY 2021 President's Budget provided above. FY 2021 enacted figures will be provided in the FY 2022 edition of this report.*

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

Global change research is fully integrated across the Department of Agriculture, involving multiple mission areas and including 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 ranging from temperature and precipitation extremes to the changing infestation ranges and intensities of pests, invasive species, and diseases that result from shifting climatic conditions.

USDA assesses climate change effects on the natural and economic systems associated with productive lands. 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 through the development of information products and decision-support tools.

USDA observes and monitors natural resource conditions on-the-ground. USDA assessments of natural resource conditions include the Long-Term Agro-ecosystem Research (LTAR) Network, the Snowpack Telemetry (SNOTEL) network, the Experimental Forests and Ranges, the Soil Climate Analysis Network (SCAN), the National Resources Inventory (NRI), and the Forest Inventory and Analysis (FIA) Program, which are utilized by multiple scientific and programmatic efforts across the Department and the U.S. Government to improve land management efforts.

USDA's ten Regional Climate Hubs deliver timely and authoritative tools and information to natural resource management professionals, ensuring that the latest science is available to support decision-making. To that end, USDA engages in many communication, outreach, education, and extension efforts across multiple forums to ensure that decision-makers, natural resource managers, and stakeholders have access to the most up-to-date scientific information for management decisions. The Hubs are an example of close interagency collaboration on climate change at the regional level, delivering tools, strategies, management, and technical solutions to farmers, ranchers, forestland owners, and resource managers to inform better decision-making in a changing climate.

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 mission is to understand and predict changes in climate, weather, oceans and coasts, to share that knowledge and information with others, and to conserve and manage coastal and marine ecosystems and resources. From supercomputers and state-of-the-art models to observations and outlooks, NOAA provides data, tools, and information to help people understand and prepare for climate variability and change. NOAA's current priorities are (1) to reduce the impact of extreme weather and water events (Weather Act of 2017) and (2) to increase the sustainable economic contributions of our fishery and ocean resources (Blue Economy). NOAA aims to advance its goals and priorities through the following research and development vision areas:

- Reduced societal impacts from severe weather and other environmental phenomena;
- Sustainable use of coastal and ocean resources;
- A robust and effective research, development, and transition enterprise.

NIST's measurement science research supports enhanced, internationally accepted, and traceable measurement standards, methodologies, and technologies that provide accurate greenhouse gas emissions and uptake data and analyses to support mitigation management and the advancement of climate science research. NIST provides measurements and standards for consistent, comparable, and reliable climate observations and provides calibrations and special tests to improve the accuracy of a wide range of instruments and techniques used in climate research and monitoring.

Department of Defense

The Department of Defense (DoD) recognizes that global changes in the environment, such as climate change, impact DoD operations and installations. In alignment with the National Defense Strategy (NDS), the DoD Directive 4715.21 Climate Change Adaptation and Resilience, and the Department's 2019 Arctic Strategy, DoD seeks to understand, prepare, and respond to the impact of global environmental changes. DoD's research, development, test, and evaluation (RDT&E) activities as well as interagency and international collaboration through the USGCRP play a critical role in DoD's efforts to address global environmental change. DoD manages and executes RDT&E activities across the Services that respond to specific national security requirements and may also be leveraged to address the strategic goals of the USGCRP. DoD's global change RDT&E efforts focus on building awareness of the changing operational physical environment through observations and predictive models and enhancing operations in those changing environments via mitigation, adaptation, and resilience.

The Navy is exploring new platforms for sustained observational capability in the Arctic as well as developing global weather, ocean, and sea ice prediction models at the seasonal (months) timescale. The Navy and the Air Force collaborate with U.S. interagency partners on the National Earth System Prediction Capability, the next generation of predictive models for the entire Earth system. The Air Force leverages National and allied partners' seasonal and climate model projections to provide value-added products for DoD and the Intelligence Community. DoD is expanding and modifying an Army tool for installations to assess exposure to climate and weather impacts. The Army continues to focus on addressing Arctic mobility and infrastructure challenges. The Strategic Environmental Research and Development Program (SERDP), the Department's joint environmental science and technology program, invests in research to enhance DoD's overall resilience to environmental threats and climate change impacts. Finally, the Department more broadly sponsors basic research in a number of potentially relevant areas such as marine meteorology, physical oceanography, polar science and engineering, biogeochemical sciences, and terrestrial science and phenomenology.

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, cryospheric, oceanic, and human-energy components of the Earth system. DOE's research strives to understand and anticipate how environmental and compounding stressors can influence the pattern and magnitude of weather and other extremes, and how these in turn influence the robustness and resilience of U.S. energy infrastructures. Supporting its major role in Earth system prediction, DOE supports long-term field experiments to advance process and systems level understanding; scale-aware parameterizations that can be incorporated into multi-scale models; and advanced software tailored to models that can be ported to DOE's fastest supercomputers. DOE also invests novel machine learning and uncertainty quantification methodologies that allow model products to be more useful to DOE stakeholders. To assist the scientific community in carrying out research, DOE commits significant resources to archiving and management of extensive observed and model-generated datasets for easy retrieval and processing.

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, precipitation, 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 currently uses DOE's advanced high performance pre-exascale computers; DOE also collaborates with NSF to support the widely used Community Earth System Model. Using the DOE-supported Program for Climate Model Diagnosis and Intercomparison (PCMDI) and the DOE- and NASA-supported Earth System Grid Federation, DOE analyzes and distributes large Earth System Model output, with data analytics capabilities available to researchers. The Department also supports the Atmospheric Radiation Measurement (ARM) Research Facility, a scientific user facility based on three permanent observatories and three mobile observatories that in turn provides the research community with unmatched measurements permitting the most detailed high-resolution, three-dimensional documentation of evolving cloud, aerosol, precipitation, and radiative transfer characteristics in climate-sensitive sites around the world.

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

Department of Health and Human Services

The U.S. Department of Health and Human Services (HHS) supports a broad portfolio of research and decision support initiatives related to environmental health and the health effects of global climate change, primarily through the National Institutes of Health (NIH) and the Centers for Disease Control and Prevention (CDC). Research focuses on the need to better understand the vulnerabilities of individuals and communities to climate-related changes in health risks such as heat-related morbidity and mortality, respiratory effects of 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 the Interior

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

USGS scientists work with other agencies to provide policy makers and resource managers with scientifically valid information and 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 supports research to understand the physical, chemical, and biological components of the Earth system, the causes and consequences of climate and land use change, and the vulnerability and resilience of the Earth system to such changes. 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 are used to assess changes in land use, land cover, ecosystems, and water resources resulting from the interactions between human activities and natural systems.

USGS also leads the regional DOI Climate Adaptation Science Centers, which deliver science to help fish, wildlife, water, land, and people adapt to a changing climate.

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 to ensure that the reports are a comprehensive, objective, and balanced assessment of the subject matter; nominates U.S. scientists to serve as authors; and represents the United States at IPCC 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) coordinates with USGCRP and its participating agencies to inform transportation system mitigation and resilience solutions. DOT initiatives to improve the resilience of the U.S. transportation sector include:

- The Federal Highway Administration (FHWA) and the Federal Transit Administration (FTA) are working with States, public transportation agencies, and metropolitan areas to increase the health and longevity of the Nation's Highways and public transportation systems, respectively, through an ongoing program of assessing vulnerabilities; considering resilience in the transportation planning process; incorporating resilience in asset management plans; addressing resilience in project development and design; and optimizing operations and maintenance practices.
- The Maritime Administration (MARAD) Ports Team is scoping a framework for a proposed asset management tool called the "Waterfront Asset Management Tool" (WFAM) for domestic port planning. This proposed asset management tool would assist public and private ports with tools to establish risk-based asset management plans to prioritize maintenance dollars and provide justification for spending scarce funding for maintenance and/or resiliency priorities.
- The Office of the Assistant Secretary for Research and Technology (OST-R) is working in partnership with FHWA and DOT's Office of Intelligence, Security, and Emergency Response to ensure that the costs and benefits of resilience are incorporated into the transportation infrastructure planning process. The goal is to develop nationally replicable modelling tools capable of estimating the regional-scale impacts of natural and man-made disasters on the transportation system. These tools will enhance pre-event planning and disaster recovery capabilities.

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, as well as 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. These connections 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 include applying 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. EPA's technical assistance and analytical expertise supports state and local decision-makers seeking to identify, prioritize, and implement adaptation work within their environmental programs.

National Aeronautics and Space Administration

NASA's global change activities span the entire Earth Science Division, from satellite observations and technology development to research and analysis that help inform real-life applications of our science. These program elements advance our capacity to observe and explore the interactions among the major components of the Earth system—including the atmosphere, ocean, land, ice, and ecosystems—and to distinguish between natural and human-induced causes and consequences of change.

As of April 2020, NASA's portfolio included 21 on-orbit missions, whose combined measurements enhanced our understanding of our changing planet. These included new satellite missions and recently launched or newly selected instruments aboard the International Space Station. Several of these came through NASA's Earth Venture portfolio, which consists of science-driven, competitively selected, cost-capped missions. In addition, NASA has made significant use of its airborne platforms and sensors together with surface-based measurements in targeted campaigns.

In tandem with these missions and measurements, NASA supports applications projects to extend the societal benefits of its research, technology, and spaceflight programs to the broader public. These include the development and transition of user-defined tools for decision support for water resources, health and air quality, ecological forecasting, disasters, food security, and more. Moreover, NASA's Earth Science Technology Office funds, develops, and demonstrates a broad range of cutting-edge technologies to enable new capabilities and reduce costs, risks, and development times for new Earth science instruments. NASA Earth science satellite data are made widely and freely available through the Earth Science Data System.

To help us understand Earth's changing atmosphere, NASA recently launched the Orbiting Carbon Observatory 3 (OCO-3) aboard the ISS, as well as the Hyper-Angular Rainbow Polarimeter (HARP) and the Compact Infrared Radiometer in Space (CIRiS), small U-Class satellites (also known as CubeSats). OCO-3 uses the vantage point of the ISS to focus on regional sources and sinks of carbon dioxide (CO_2), contributing to the global CO_2 measurements taken by its predecessor, OCO-2. The HARP CubeSat collects information about atmospheric aerosols around which cloud nuclei can form, and the CIRiS CubeSat will help measure the optical and physical properties of clouds, land, and sea surface temperatures, as well as Earth's radiation budget.

In addition to these space-based projects, NASA also recently completed two suborbital airborne campaigns to help study our atmosphere: the Cloud, Aerosol and Monsoon Processes Philippines Experiment ($CAMP^2Ex$), and the Fire Influence on Regional to Global Environments Experiment - Air Quality (FIREX-AQ). $CAMP^2Ex$ and FIREX-AQ focused on regional processes in the Philippines and the western and southeastern United States, respectively. For $CAMP^2Ex$, NASA collaborated with the Naval Research Laboratory and Manila Observatory to investigate cloud formation in the western Philippines, one of the world's most unpredictable geographic regions for weather and climate modeling. For FIREX-AQ, NASA collaborated with NOAA to investigate the effect of wildfire and prescribed burns on atmospheric chemistry over the United States.

NASA is also planning for new missions in the near future to augment our understanding of the atmosphere. Upcoming launches include the Sentinel-6 Michael Freilich satellite to continue measurements of sea surface height (altimetry), together with partners in Europe and NOAA; the Landsat 9 satellite to continue the multi-decade record of land surface measurements with the U.S. Geological Survey; and the and Surface Water Ocean Topography (SWOT) satellite to continue and enhance measurements of freshwater and oceans in partnership with France and with contributions from Canada and the UK.

In the past year, major mission-related milestones have included the following:

- NASA selected the Geosynchronous Littoral Imaging and Monitoring Radiometer (GLIMR) instrument to help understand Earth's changing land and ecosystems. GLIMR will be mounted on a NASA-selected platform for launch in the 2026–2027 timeframe and will provide unique biological, chemical, and ecological observations of coastal waters within the Gulf of Mexico, portions of the southeastern United States, and the Amazon River Plume.
- NASA confirmed the Geostationary Carbon Observatory (GeoCarb) mission. GeoCarb is set to launch in 2022 and will provide observations of column CO_2, carbon monoxide (CO), and methane (CH_4) across North America, along with measurements of solar-induced fluorescence over the Western Hemisphere.
- NASA also identified a launch opportunity for the Tropospheric Emissions: Monitoring of Pollution (TEMPO) instrument, which is expected to occur in 2022. TEMPO is designed to measure air quality over North America in unprecedented detail during daylight hours.

National Science Foundation

The National Science Foundation (NSF) addresses global change issues through investments that advance frontiers of knowledge, provide state-of-the-art instrumentation and facilities, develop new analytical methods, and enable cross-disciplinary collaborations while also cultivating a diverse, highly trained workforce and developing educational resources. In particular, NSF global change programs support the research and related activities to advance fundamental understanding of physical, chemical, biological, and human systems and

the interactions among them. The programs encourage interdisciplinary approaches to studying Earth system processes and the consequences of change, including how humans respond to changing environments and the impacts on ecosystems and the essential services they provide. NSF programs promote the development and enhancement of models to improve understanding of integrated Earth system processes and to advance predictive capability. NSF also supports fundamental research on the processes used by organizations and decision makers to identify and evaluate policies for mitigation, adaptation, and other responses to the challenge of a changing and variable environment. Long-term, continuous, and consistent observational records are essential for testing hypotheses quantitatively and are thus a cornerstone of global change research. NSF supports a variety of research observing networks that complement, and are dependent on, the climate monitoring systems maintained by its sister agencies.

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

Smithsonian Institution

Within the Smithsonian Institution (SI), global change research is primarily conducted at the National Air and Space Museum, the National Museum of Natural History, the National Zoological Park, the Smithsonian Astrophysical Observatory, the Smithsonian Environmental Research Center, and the Smithsonian Tropical Research Institute. Research is organized around themes of atmospheric processes, ecosystem dynamics, observing natural and anthropogenic environmental change on multiple time scales, and defining longer-term climate proxies present in the historical artifacts and records of the museums as well as in the geologic record. Most of these units participate in the Smithsonian's Global Earth Observatories, examining the dynamics of forests (ForestGEO, formerly SIGEO) and coastal marine habitats (MarineGEO) over decadal time frames.

The Smithsonian also brings together researchers from around the Institution to focus on joint programs aimed at estimating volcanic emissions, understanding and sustaining biodiversity, monitoring animal migrations, characterizing working landscapes and seascapes, or studying emerging infectious diseases in wildlife and humans. Smithsonian paleontological research documents and interprets the history of terrestrial and marine ecosystems from 400 million years ago to the present. Other scientists study the impacts of historical environmental change on the ecology and evolution of organisms, including humans. Archaeobiologists examine the impact of early humans resulting from their domestication of plants and animals, creating the initial human impacts on planetary ecosystems.

These activities are joined by related efforts in the areas of history and art, such as the Center for Folklife and Cultural History, the National Museum of the American Indian, the Anacostia Community Museum, the National Museum of African American History and Culture, 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 programs expand 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, education, and outreach 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.

REFERENCES

1. Global Change Research Act, 15 U.S.C. § 2921 (1990).

2. Taylor, P.C., W. Maslowski, J. Perlwitz, and D.J. Wuebbles, 2017: Arctic changes and their effects on Alaska and the rest of the United States. In: *Climate Science Special Report: Fourth National Climate Assessment, Volume I* [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 303-332. doi: 10.7930/J00863GK

3. Markon, C., S. Gray, M. Berman, L. Eerkes-Medrano, T. Hennessy, H. Huntington, J. Littell, M. McCammon, R. Thoman, and S. Trainor, 2018: Alaska. In: *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 1185–1241. doi: 10.7930/NCA4.2018.CH26

4. Wuebbles, D.J., D.R. Easterling, K. Hayhoe, T. Knutson, R.E. Kopp, J.P. Kossin, K.E. Kunkel, A.N. LeGrande, C. Mears, W.V. Sweet, P.C. Taylor, R.S. Vose, and M.F. Wehner, 2017: Our globally changing climate. In: *Climate Science Special Report: Fourth National Climate Assessment, Volume I* [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 35-72. doi: 10.7930/J08S4N35

5. Fahey, D.W., S.J. Doherty, K.A. Hibbard, A. Romanou, and P.C. Taylor, 2017: Physical drivers of climate change. In: *Climate Science Special Report: Fourth National Climate Assessment, Volume I* [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 73-113. doi: 10.7930/J0513W

6. Vose, J.M., D.L. Peterson, G.M. Domke, C.J. Fettig, L.A. Joyce, R.E. Keane, C.H. Luce, J.P. Prestemon, L.E. Band, J.S. Clark, N.E. Cooley, A. D'Amato, and J.E. Halofsky, 2018: Forests. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 232–267. doi: 10.7930/NCA4.2018.CH6

7. Ebi, K.L., J.M. Balbus, G. Luber, A. Bole, A. Crimmins, G. Glass, S. Saha, M.M. Shimamoto, J. Trtanj, and J.L. White-Newsome, 2018: Human Health. In: *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 539–571. doi: 10.7930/NCA4.2018.CH14

8. Smith, D.R., Jarvie, H.P. 2018. Carbon, nitrogen, and phosphorus stoichiometric response to hydrologic extremes in a tributary to Lake Erie, USA. Agricultural and Environmental Letters. 3:180043. doi: 10.2134/ael2018.08.0043

9. Mehan, S., Gitau, M.W., Flanagan, D.C. 2019. Reliable future climate projections for sustainable hydro-meteorological assessments in the Western Lake Erie Basin. Water. 11(3):581. doi: 10.3390/w11030581

10. Wilson, R., Beetstra, M., Reutter, J., Hesse, G., Fussell, K., Johnson, L., King, K.W., Labarge, G., Martin, J., Winslow, C. 2019. Commentary: Achieving phosphorus reduction targets for Lake Erie. Journal of Great Lakes Research. 45(1):4-11. doi: 10.1016/j.jglr.2018.11.004

11. Ibid.

12. Angel, J., C. Swanston, B.M. Boustead, K.C. Conlon, K.R. Hall, J.L. Jorns, K.E. Kunkel, M.C. Lemos, B. Lofgren, T.A. Ontl, J. Posey, K. Stone, G. Takle, and D. Todey, 2018: Midwest. In: *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 872–940. doi: 10.7930/NCA4.2018.CH21

13. Vose, J.M., Peterson, D.P., Luce, C.H., and Patel-Weynand, T., eds. 2019. Effects of drought on forests and rangelands in the United States: Translating science into management responses. Gen. Tech. Rep. WO-98. Washington, D.C.: U.S. Department of Agriculture Forest Service. 227 p. doi: 10.2737/WO-GTR-98

The U.S. Global Change Research Program
1800 G Street Northwest • Suite 9100 • Washington, DC 20006 USA
+1.202.223.6262 (phone) • +1.202.223.3065 (fax)
GlobalChange.gov