U.S. Global Change Research Program

OUR CHANGING PLANET

The U.S. Global Change Research Program for Fiscal Year 2023

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

A Supplement to the President's Budget for Fiscal Year 2023

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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 2023 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.

Image Credits

Cover: Front/back cover: Phytoplankton bloom off the Alaskan coast, June 2018. NASA image by Norman Kuring/NASA's Ocean Color Web, using Landsat data from the USGS.

Page vii: Aerial leaf peeping in Adirondack park. NASA Earth Observatory image by Joshua Stevens, using Landsat data from the USGS.

Page 2: Mississippi River. NASA Earth Observatory images by Joshua Stevens, using Landsat data from the USGS and NAIP imagery from the USDA.

Page 29: Shasta Lake and Lake Oroville, California. NASA Earth Observatory images by Lauren Dauphin, using Landsat data from the USGS and chart data courtesy of Pang-Wei Liu and Jay Famiglietti.

Page 34: Rice fields in California. NASA Earth Observatory images by Joshua Stevens, using Landsat data from the USGS and data from the Level-1 and Atmosphere Archive & Distribution System (LAADS) and Land Atmosphere Near real-time Capability for EOS (LANCE).

U.S. GLOBAL CHANGE RESEARCH PROGRAM

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Members of Congress:

As a Nation and global community, we are witnessing rapid changes to our shared environment, including climate change, the loss of ecosystems and nature, and many other related trends. In the face of these challenges, the agencies of the U.S. Global Change Research Program (USGCRP) are producing science, information, and tools that are driving new understanding of how our planet is changing and how society can respond. As mandated by Congress, USGCRP coordinates and advances research efforts across the Federal Government and with international partners.

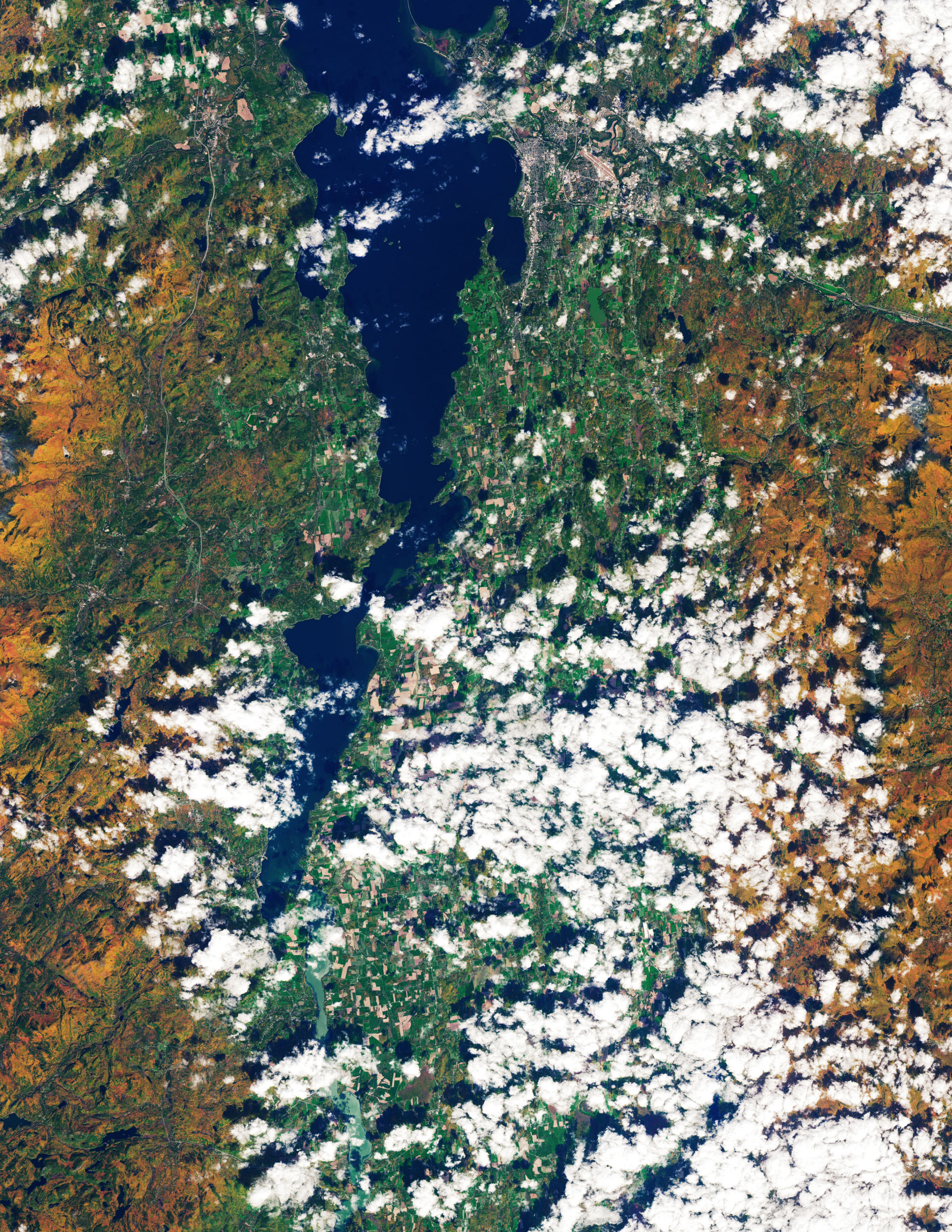
On behalf of USGCRP, I am pleased to transmit *Our Changing Planet: The U.S. Global Change Research Program for Fiscal Year 2023*. This report presents highlights of USGCRP's recent accomplishments and outlines future priorities as the Program begins to implement its 2022–2031 Strategic Plan. It also presents a summary of agency expenditures under USGCRP's budget crosscut, as required by the Global Change Research Act of 1990.

As more people face more severe climate change impacts, USGCRP is improving our understanding of global change; developing information and tools that support planning and decision-making at national, regional, and local levels; and engaging with communities that are most affected by impacts. These efforts provide the basis for strengthening the Nation's resilience to the effects of climate and environmental change on our communities, infrastructure, economies, and nature.

I appreciate the close cooperation of the participating agencies, and I look forward to working with members of Congress to continue strengthening this essential national program.

Sincerely,

Arati Prabhakar
Assistant to the President for Science and Technology
Director, White House Office of Science and Technology Policy



EXECUTIVE SUMMARY

The U.S. Global Change Research Program (USGCRP) coordinates research across federal member agencies to understand the human-caused and natural processes that influence our planet. Over more than three decades, USGCRP and its member agencies have documented patterns of climate change, ocean warming and acidification, ecosystem and biodiversity decline, and other large-scale changes that are transforming Earth's environment and capacity to support life, collectively known as global change. In collaboration with scientists around the world, USGCRP has contributed to unprecedented understanding of global change that has informed decisions by governments, businesses, organizations, and individuals coping with a rapidly changing environment.

Since the Program's founding, the Nation's information needs have evolved significantly. As more people experience more severe effects of climate change, a broader range of communities and institutions are integrating climate and global change considerations into their planning and operations and implementing adaptation and mitigation actions that require more specific and complex information. Building on the scientific accomplishments of previous decades, USGCRP's 2012–2021 Strategic Plan set a vision for research to inform this growing range of decisions, expanding the Program's focus on decision support. Under the 2012-2021 Plan, USGCRP and its member agencies provided the basis for significant improvements in the availability of information to support decision-making, including through more accessible scientific assessments that provide relevant, authoritative information to decision-makers.

Today, as the impacts of climate change worsen, compounded by the effects of other global changes, USGCRP agencies continue to advance core scientific capabilities that are driving new discoveries and supporting our ability to respond to change. Throughout 2021, USGCRP agencies strengthened capabilities in Earth observations, modeling, and understanding processes of change; furthered the integration of the social sciences in global change research; and advanced data management and sharing of actionable information. USGCRP and its member agencies translated knowledge to support decisions in critical areas, including health, coastal resilience, nature-based solutions, wildfire management, and biodiversity and ecosystems management. The Program laid the groundwork for development of the Fifth National Climate Assessment, which will synthesize the latest science on the impacts of climate change in the United States, emphasizing regional aspects of climate impacts and response actions. USGCRP also continued its engagement and collaboration with international global change research efforts, including strengthening research partnerships, building international capacity for climate risk and vulnerability assessments, and supporting U.S. participation in international assessments.

USGCRP recognizes the need to build on this work and continue to address critical research needs, leverage new and expanded approaches, and provide actionable knowledge on global change risks to a growing diversity of decision-makers. In 2021, USGCRP initiated development of its next Strategic Plan, which was released in December 2022. The 2022-2031 Plan is focused around four pillars: Advancing Science; Engaging the Nation; Informing Decisions; and Collaborating Internationally. The Plan includes a commitment to emphasize diversity, equity, inclusion, justice, and accessibility as

USGCRP and its member agencies collaborate to invest research funding, build a more diverse scientific workforce, engage with communities that are most affected by the impacts of global change, and translate results into useful and actionable information over the next decade.

In Fiscal Year 2023, USGCRP will lead activities that align with commitments made in the new Strategic Plan to expand participation in the federal global change research enterprise, deepen work on other drivers of global change beyond climate change, and enhance the impact of federal global change research, both domestically and internationally. Many of these activities were initiated in 2021 and 2022. For example, a regional engagement initiative in Latin America and the Caribbean, launched in 2021, aims to enhance local and regional capacity for climate risk and vulnerability assessments. In 2022, USGCRP announced a new assessment of the state of nature and the benefits it provides to society in the United States, reflecting the importance of changes in nature as an element of global change. The Program has also laid the groundwork for a platform that facilitates access to federal data for use by decision-makers at all levels and has continued efforts to expand the diversity of agencies that collaborate with USGCRP.

INTRODUCTION

The U.S. Global Change Research Program

The U.S. Global Change Research Program (USGCRP) was established by the Global Change Research Act (GCRA) of 1990 as "a comprehensive and integrated United States research program which will assist the Nation and the world to understand, assess, predict, and respond to human-induced and natural processes of global change."

Global change: *changes in the global environment (including alterations in climate, land productivity, the ocean or other water resources, atmospheric chemistry, and ecological systems) that may alter the capacity of the Earth to sustain life.*[1]

USGCRP's membership (Figure 1) includes agencies that conduct global change research and agencies that use it to carry out their missions. USGCRP represents the collective efforts of its member agencies as determined by annual Congressional appropriations and direction. The Program finds common ground through cooperation and leveraging of agency missions to advance program objectives described in USGCRP's decadal Strategic Plan. By finding alignments among the missions of agencies, the Program coordinates investments in global change research across the Federal Government and enables the use of the resulting data and knowledge in operations and decision-support capabilities across the Nation and the world.

Federal global change research capabilities coordinated through USGCRP provide the

Figure 1 – U.S. Global Change Research Program Member Agencies (*Top*) Department of Agriculture; Department of Commerce; Department of Defense; Department of Energy; Department of Health and Human Services; Department of the Interior (*Bottom*) 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.

foundation for addressing evolving national needs, including climate change impacts that pose increasingly urgent risks to the health and well-being of the American people, particularly those who are already vulnerable. USGCRP focuses on building scientific knowledge and making it useful to a broad range of governments, communities, businesses, and individuals as they integrate climate and global change information into their planning and operations and take actions to reduce risks.

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

USGCRP is steered by the Subcommittee on Global Change Research (SGCR) of the National Science and Technology Council's Committee on Environment, which is overseen by the White House Office of Science and Technology Policy (OSTP). The SGCR coordinates interagency activities through the USGCRP National Coordination Office and USGCRP's 11 Interagency Groups, which are the Program's primary vehicle for coordinating and implementing global change research activities across agencies (see Program Structure). The Interagency Groups span a range of interconnected climate and global change issues and address major components of Earth's natural and human systems, as well as cross-disciplinary approaches for addressing these issues.

Additional information on USGCRP's legal mandate, membership, and structure is available on the Program website. Details on program history and structure and the principal focus areas related to global change research for each member agency are provided in Appendix 1. About the U.S. Global Change Research Program.

In This Report

This Fiscal Year 2023 (FY2023) edition of USGCRP's annual report to Congress, *Our Changing Planet*, summarizes progress towards the goals outlined in the Program's 2012–2021 Strategic Plan, in accordance with the Program's mandate under the GCRA, while highlighting selected Program accomplishments carried out in calendar year 2021. Selected activities represent interagency collaborations that rely on coordinated investments of two or more member agencies and contribute to meeting USGCRP's strategic goals. In addition, this report outlines future priorities for the Program as USGCRP begins implementation of its 2022-2031 Strategic Plan through FY2023 and beyond (see Future Priorities).

As required by the GCRA, *Our Changing Planet* also presents a summary of annual agency expenditures under USGCRP's budget crosscut (see Budgetary Information). USGCRP's scope includes, but is not limited to, agency programs represented in the budget crosscut, and the efforts described in this document represent a subset of the overall accomplishments of the Program. Note that accomplishments resulting from single agency investments are not typically covered in this annual report. The reported budget crosscut also does not reflect agency investments in operational assets (e.g., NOAA weather satellites, DOE supercomputers) that provide data and capabilities that are also used for climate research.

PROGRAM ACHIEVEMENTS

2012–2021: A Decade of Advances in Science and Decision Support

USGCRP's 2012-2021 Strategic Plan set a vision for research to inform a growing range of decisions to manage risks from climate and global change, increasing the Program's focus on decision support for adaptation and mitigation. The 2012–2021 Plan was structured around four major goals: Advance Science; Inform Decisions; Conduct Sustained Assessments; and Communicate and Educate. The Plan also described opportunities for USGCRP to collaborate internationally, responding to the GCRA mandate to promote international cooperation on global change research. The following section highlights achievements under this Plan, spanning from 2012 to 2021.

Advance Science

Over the past decade, fundamental global change research supported by USGCRP member agencies has driven new insights into how the Earth system is changing, the effects on human and natural systems, and how society is responding. USGCRP and its member agencies expanded their portfolio of Earth observation capabilities in collaboration with international partners, strengthening our ability to monitor and understand Earth system change on a global scale. Higher-resolution Earth system models supported by USGCRP member agencies have provided a more detailed understanding of past, present, and future climate and its effects on society, and newer techniques are allowing for detection and attribution of human influence in observed changes. A more accurate accounting of how carbon flows through ecosystems, atmosphere, land, and ocean has contributed to a better understanding of how human-caused warming, land-use change, and other aspects of global change affect these flows. New interdisciplinary research has illuminated risks to complex, interdependent human and natural systems from climate and global change and provided a better understanding of the characteristics that make communities more vulnerable to climate change, as well as those that enable resilience.

The 2012-2021 Plan set a vision for expanded integration of social science into the Program to advance understanding of the human dimensions of global change and better inform adaptation and mitigation actions. After publication of the 2012-2021 Strategic Plan, USGCRP established a Social Sciences Coordinating Committee (SSCC) charged with fostering integration of social science methods, findings, and disciplinary perspectives into the Program's activities. The SSCC has engaged the broader social science community in this task—for example, through exploration of strategies to integrate social and environmental data into climate indicators that support decision-making. The SSCC has also helped ensure that social science expertise shapes the periodic National Climate Assessment (NCA; see Conducting Global Change Assessments).

In a 2017 report on USGCRP's accomplishments, the National Academies of Sciences, Engineering, and Medicine (NASEM) highlighted the Program's contributions in bringing

together the natural and social sciences to address global change research needs (NASEM, 2017). While challenges to integrating social science capabilities in federal global change research remain, NASEM notes that USGCRP has enabled and encouraged member agencies to support fundamental social science research that can advance the understanding of the human dimensions of global change, such as decision-making under conditions of uncertainty and Integrated Assessment Models that help decision-makers explore issues like the potential consequences of different greenhouse gas emissions pathways.

Inform Decisions

Over the past decade, USGCRP has supported free and open access to global change data, information, and tools through resources such as the U.S. Climate Resilience Toolkit (CRT), USGCRP Indicator Platform, and the Global Change Information System (GCIS). USGCRP member agencies have improved capabilities to translate data into accessible decision-support tools in areas including agriculture, health, coastal decision-making, and natural resources management.

Agencies within the USGCRP have made strides in delivering actionable science in support of decision-making, particularly at the regional scale. DOI's Climate Adaptation Science Centers, NOAA's Climate Adaptation Partnerships (formerly Regional Integrated Sciences and Assessments), and USDA's Climate Hubs rely on strong partnerships between scientists and information users. These regional centers carry out projects that help connect decision-makers with information and tools needed to manage risks associated with climate change, such as heat extremes. They also provide important knowledge and expertise to the NCA, including perspectives on decision-makers' information needs.

In another example, NASA's Applied Sciences Program has helped researchers, practitioners, and users apply insights from Earth and global change science to benefit the economy, health, quality of life, and environment around the globe. Projects are conducted in close collaboration with decision-makers, including those within USGCRP member agencies.

Conduct Sustained Assessments

USGCRP has strengthened its capacity to deliver authoritative, accessible scientific assessments that translate the latest science on climate change into terms relevant to decision-makers. The Program's assessment products have informed decisions at all levels of government, within the private sector, and among the public. They have also led to the identification of research directions and outputs, new collaborations, and supported broader and deeper engagement with stakeholders. USGCRP released NCA3 in 2014 and NCA4 as two volumes in 2017–2018: the *Climate Science Special Report* and NCA4 Volume II. USGCRP also produced special assessment reports on food security (2015), health (2016), and the carbon cycle (2018).

NCA3 and NCA4 showed a renewed commitment to an extensive public engagement process with stakeholders in different sectors and regions that helped produce relevant, usable information responsive to user needs. In response to public demand for more

localized information on climate impacts, NCA4 expanded emphasis on regional information, a model that is continuing for NCA5.

NCA3 introduced a risk-based framework for exploring topics that entail potentially serious consequences for people and natural systems, an approach that USGCRP continues to use. USGCRP developed NCA3 and subsequent reports in a web-based format that allows users to navigate the assessment and access the underlying information more easily. This included deployment of the GCIS, a web-based resource that includes fully transparent access to data used in USGCRP assessments. The GCIS continues to be a key feature of the NCA, providing an unmatched level of transparency to the reports' process and findings.

Communicate and Educate

Through many of the decision support and assessment activities described above (e.g., the NCA, the CRT), USGCRP and its member agencies use outreach and engagement to understand information needs, communicate global change research, and educate decision-makers and the public. These efforts are largely intended to build the capacity of people around the country and the world to respond to global change impacts. At the international level, USGCRP supports education and capacity-building efforts through core budget support for international science organizations that enables the global community to better understand and address global change challenges (see Coordinating International Global Change Research).

USGCRP has also helped coordinate educational initiatives across its member agencies, such as the interagency Climate Education and Literacy Initiative, launched in 2014 by OSTP in coordination with USGCRP and many of its member agencies. The effort helped connect students and members of the public with the best available, science-based information on climate change, including lesson plans, case studies, and place-based engagement at events and in national parks. Many of these activities made use of content from USGCRP assessment products.

Over the past decade, USGCRP has shifted to a broader engagement approach, which includes decision-makers in research planning and implementation when feasible and appropriate. In many instances, such a broader engagement approach may more effectively build response capacity and enable USGCRP to receive feedback on emerging research priorities and information needs.

Looking Ahead: the 2022–2031 Strategic Plan

USGCRP has built on the 2012–2021 Strategic Plan and the lessons learned from its implementation. The Program's 2022–2031 Strategic Plan, released in December 2022, addresses the challenge to advance fundamental science while better equipping the Nation to respond to and manage critical global change risks. It further emphasizes consideration of other types of global change beyond climate change, including biodiversity and nature loss. The new Plan sets a vision for expanded participation in the global

change research enterprise through engagement with new audiences, with the goal of more fully meeting the Nation's information needs (see Future Priorities).

2021 Accomplishments

Advancing Science

Federal investments in basic science provide the foundation for understanding the interconnected components of the Earth system, how they are changing due to human influence, and how society can respond. Earth system observations, modeling, and process studies illuminate complex interactions among social and natural systems and provide insights into what future change means for society. Integration across multiple disciplines offers improved understanding of the interactions among human, behavioral, and natural systems responding to change and supports efforts to build resilience to change. This section highlights interagency research activities that are advancing fundamental knowledge of global change.

Earth Observations

USGCRP agencies support a diverse observing portfolio that includes in situ, airborne, autonomous vehicle, and satellite-based sensors in and on the ocean, atmosphere, land, space, and cryosphere. Along with international partners, U.S. observing networks enable long-term monitoring and improved understanding of the changing Earth system that no single agency or organization can achieve alone. A recent highlight was the launch of the joint NASA–USGS Landsat 9 mission in September 2021, continuing a 50+ year record of data on land cover and land-use change, a major driver of global change. In addition, the Sentinel-6 Michael Freilich satellite, developed and operated in partnership between NASA, NOAA, and the European Space Agency, began transmitting sea surface height data in June 2021, providing critical information on how global sea level is changing. USGCRP agencies also conduct short-term field campaigns that provide deeper understanding of processes on local scales that can affect climate or other systems at local to global scales. These focused campaigns can be coordinated with long-term monitoring networks to produce enhanced insights.

USGCRP's **Integrated Observations Interagency Working Group (ObsIWG)** facilitates coordination of observations capabilities and related research relevant to climate and global change within USGCRP's member agencies. ObsIWG maintains a compendium of federal Earth observation activities that is used to support coordination of field campaigns and other observing efforts across agencies and identify gaps in observing networks. In 2021, ObsIWG initiated a monthly seminar series highlighting critical environmental questions and issues that can only be addressed using high-quality Earth observations, with emphasis on collaboration across federal agencies.

2021 Highlights

Tracking Aerosol Convection interactions ExpeRiment – Air Quality. In September 2021, NASA conducted the **TRACER–AQ** field campaign in the Houston metropolitan area to measure air quality, ozone, and meteorological factors that influence air pollution in the region. This effort was conducted in partnership with the DOE-led TRACER campaign, the Texas Commission on Environmental Quality, and several academic institutions, as part of a set of interagency field activities in the region in 2021 and 2022 studying interrelated questions of air quality, deep convective clouds (which often produce thunder and rain), and how aerosols influence the physics of deep convection. Results will be used to evaluate air quality models and satellite observations and understand the intersections between air quality and socioeconomic factors in the area. The group aims to build partnerships and collaborations to support the use of these observations by air quality managers and the public health sector.

TRACER–AQ research flights were conducted aboard a Gulfstream V research aircraft flying out of NASA's Johnson Space Center in Houston, Texas, as part of a field campaign that collected high-resolution data using platforms on land, over water, and in the air. Credits: Laura Judd/NASA.

Marine Biodiversity Observation Network. MBON is a global initiative composed of regional networks of scientists, resource managers, and practitioners working to integrate new and existing long-term data to improve understanding of changes and connections between marine biodiversity, climate, and ecosystem function. Globally, the MBON is a thematic node of the Group on Earth Observations Biodiversity Observation Network, working in partnership with the Intergovernmental Oceanographic Commission's Global Ocean Observing System and Ocean Biodiversity Information System. The U.S. MBON projects are integrating independent historical and current biology and ecosystem surveys with new observations, and expanding application of remote sensing methods, novel molecular (eDNA) technologies, passive acoustics, and traditional and novel animal telemetry research tools through data sharing and coordinated experiments. NOAA, NASA, BOEM (DOI), and ONR (DoD) are the U.S. leads for MBON.

Coral reefs, like this one in Cordell Bank National Marine Sanctuary, support a wide array of marine life. Credit: Joe Hoyt/NOAA.

National Coordinated Soil Moisture Monitoring Network. Accurate measurements of soil moisture conditions can provide valuable inputs for agricultural monitoring and planning, weather prediction, and drought and flood early warning. Working with the USDA and other partners, the multi-agency National Integrated Drought Information System is leading an effort to establish a national soil moisture monitoring network. The **NCSMMN** is a multi-agency, multi-institutional initiative to integrate soil moisture data from around the country and support a wide range of applications across sectors of the economy. In 2021, agency partners (including USDA, DOI, NOAA, and NASA) contributed to the development of a strategy for coordinating soil moisture monitoring technologies, with the ultimate goal of providing detailed soil moisture status products throughout the United States.

Global Change Processes

USGCRP member agencies conduct natural, behavioral, and social science research to improve knowledge of the causes and consequences of global change. This research illuminates complex interactions within and among the integrated natural and human components of the Earth system, such as the carbon cycle, agriculture, and health systems. Research to understand processes of global change integrates across many disciplines within Earth system science, including Earth observations, Earth system modeling, process research, and the social sciences.

Carbon Cycle Science

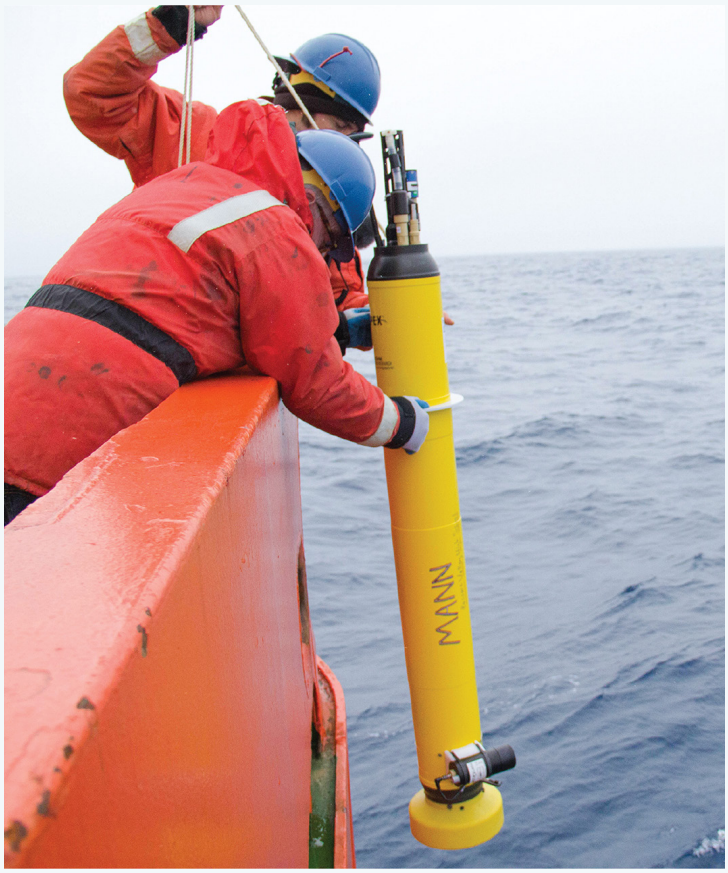
Human emissions of greenhouse gases, land use and deforestation, and other activities continue to alter Earth's carbon balance, driving climate change and other processes of global change that profoundly impact society. Understanding the rates and causes of the movement of carbon between the atmosphere, land, and ocean is essential for developing policies to mitigate climate change. USGCRP agencies conduct observations, modeling, and process research to document and understand carbon cycle change, future evolution, and the effects on society.

USGCRP's **Carbon Cycle Interagency Working Group (CCIWG)** supports carbon cycle research across the Federal Government and is responsible for defining program goals, setting research priorities, and reviewing the progress of the research programs that contribute to carbon cycle science. Agencies represented on the CCIWG support the U.S. Carbon Cycle Science Program and its North American Carbon Program (NACP) activity. These programs build community collaboration focused on carbon sources and sinks in North America and its adjacent oceans, supported by NSF, NASA, EPA, DOE, DOI, and USDA. In 2021, the NACP drafted a Science Implementation Plan for the next decade, which was released in 2022.

2021 Highlights

Southern Ocean Carbon and Climate Observations and Modeling. Supported by NASA and NSF, the **SOCCOM** project aims to drive new discoveries about the remote Southern Ocean and its influence on global climate. SOCCOM's observations team is deploying an array of nearly 200 Argo profiling floats with biogeochemical sensors throughout the Southern Ocean,

which is complemented by shipboard measurements, instrument and sensor development, and data analysis and modeling. This array of floats provides sustained monitoring of phytoplankton, particle, and carbon dynamics in a historically under-sampled region. Information from these observations, alongside new modeling analyses, will help improve a new generation of high-resolution Earth system models to both increase our understanding of the Southern Ocean's current workings and make better projections of the future trajectory of Earth's climate and biogeochemistry.



Researchers deploy biogeochemical floats in the Southern Ocean. Credit: Greta Shum/SOCCOM.

Assessing changes in global terrestrial live biomass over the 21st century. Ecosystems on land store large amounts of the carbon emitted by human activities, and protecting and restoring forests and other vegetation are important tools in slowing climate change. However, there are large uncertainties in global estimates of the balance between how much carbon ecosystems store and how much they release into the atmosphere due to deforestation, wildfire, and other disturbances. To improve estimates of the global carbon balance, NASA, USDA-FS, and other contributors assessed changes in the amount of carbon stored by live woody vegetation (such as trees and shrubs) globally over the course of the 21st century (Xu et al., 2021). The researchers used a combination of national forest inventories, remote sensing, and machine learning to reduce uncertainties and provide improved annual estimates of carbon emission and removal. They estimate that plants uptake 4.9 to 5.5 petagrams of carbon (PgC) each year, more than offsetting annual losses to disturbance that total 4.5 to 4.7 PgC annually and leaving a net of 0.23 to 0.88 PgC captured each year. For reference, fossil fuel emissions are between 6.9 and 10.0 PgC per year.

Social Sciences

The social sciences are an integral part of understanding the drivers of climate and global change, how society is responding, and opportunities to build resilience and reduce risks. USGCRP member agencies conduct research on the behavioral, societal, economic, and cultural aspects of global change and are continuing to enhance interdisciplinary research into the complex interactions between human and natural systems responding to change.

USGCRP's **Social Sciences Coordinating Committee (SSCC)** fosters integration of the methods, findings, and disciplinary perspectives of the social, behavioral, and economic sciences and interdisciplinary and transdisciplinary approaches into USGCRP activities in support of the Program's goals.

In Fall 2021, the SSCC hosted a three-part public webinar series on food, culture, and climate, with the goal of highlighting the ways in which social science research considers climate change in a socio-cultural context. The series, with sessions on terrestrial and marine food systems as well as applications, drew roughly 400 attendees over the three sessions. A new white paper summarizes the main ideas of the series.

Drying salmon in Lake Clark, Alaska. Climate change is affecting many aspects of the food system, including access to culturally significant foods like salmon. Credit: NPS.

The SSCC provides regular input to USGCRP's assessment reports and serves as a resource for author teams on incorporating social sciences into their chapters. After the release of NCA4, the SSCC developed a white paper outlining findings and recommendations for the further integration of social science topics into future NCAs, based on focus groups conducted with report authors, which was later released as a journal article (Maxwell et al., 2022). These SSCC efforts informed the creation of the new Social Systems and Justice chapter in NCA5. In addition, the SSCC, in collaboration with several environmental justice experts on NCA5 author teams, provided informal guidance to authors, including preferred language and framing considerations for discussions of equity and environmental justice.

For additional details on SSCC activities in 2021, see the Diversity, Equity, Inclusion, Justice, and Accessibility section.

Earth System Modeling

The U.S. climate modeling community has made significant contributions to the development, analysis, and intercomparison of Earth system models that provide insight into current and future Earth system change. Earth system modeling supported by a variety of USGCRP agencies continues to evolve, including through development of more sophisticated predictions that combine climate change with impacts across a variety of agricultural, energy, water, and land-use sectors. USGCRP agencies are greatly improving integrated natural and human system models, the spatial and temporal resolution of climate change models, and the ability to provide stakeholders with actionable information that meets their needs.

The U.S. climate modeling community, through substantial funding and participation from USGCRP agencies, contributes to the World Climate Research Program, which is the primary international coordination mechanism for climate system research (see Coordinating International Global Change Research). This includes contributions to the international Coupled Model Intercomparison Project (CMIP), involving thousands of researchers and many modeling centers, that have led to major advances in climate and Earth system modeling. CMIP model output underpins major scientific assessments, including the Intergovernmental Panel on Climate Change reports and the NCA, as well as many climate adaptation efforts and research projects.

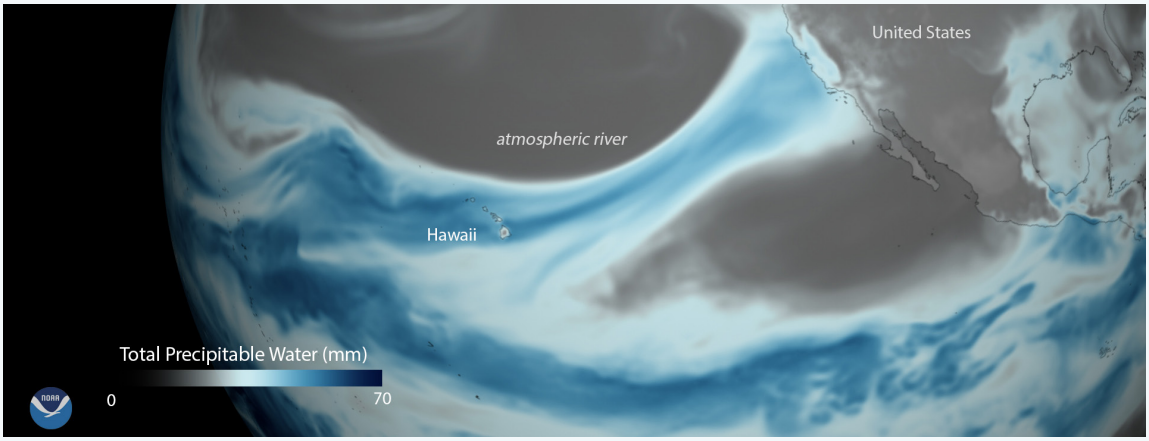
USGCRP's Interagency Group on Integrative Modeling (IGIM) coordinates global change–related modeling activities across the Federal Government and provides guidance to USGCRP on modeling priorities.

2021 Highlights

7th U.S. Climate Modeling Summit. Since 2015, USGCRP's IGIM has convened an annual **U.S. Climate Modeling Summit**. The Summit brings together representatives from the U.S. CMIP-class climate model development centers and from operational climate prediction programs, with the goal of improving the coordination and communication of national climate modeling goals. Alongside many of the summits, a technical workshop focused on a high-priority modeling topic facing the U.S. and international modeling communities has also been convened. In 2021, the workshop focused on Earth system predictability. Outcomes included identification of several studies that modeling centers could undertake collectively, focused on accelerating the exploration and effective use of inherent Earth system predictability through advanced modeling. The 7th U.S. Climate Modeling Summit Report provides a summary.

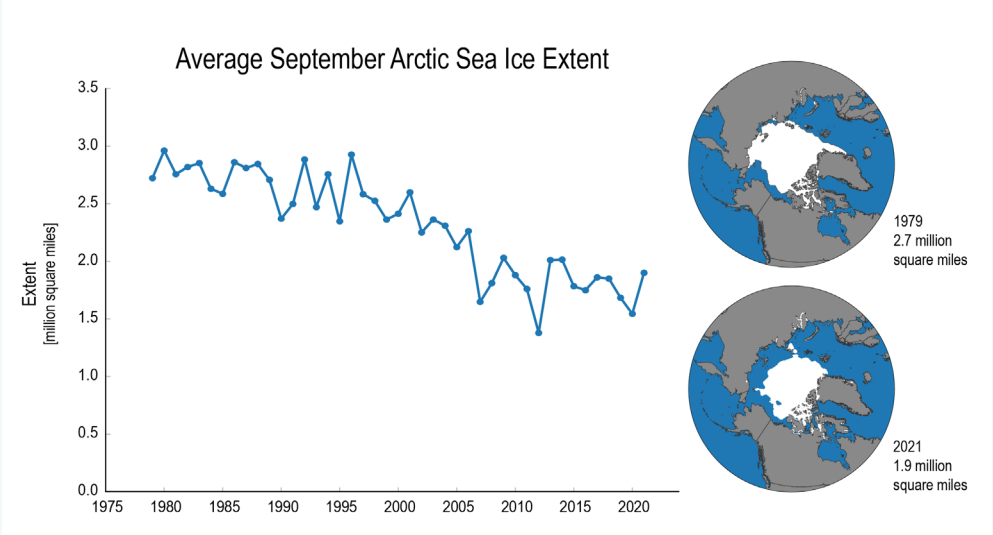
Advancing modeling of a key source of extreme precipitation. Atmospheric rivers are long, narrow regions in the atmosphere that move moist air from the tropics to higher latitudes, producing heavy rain and snow upon landfall. They provide much of the rainfall in the western United States and are frequently associated with extreme weather across large parts of the country. The international **Atmospheric River Tracking Method Intercomparison Project (ARTMIP)** is seeking to improve understanding of the linkages between climate change and atmospheric rivers. ARTMIP consists of participants from national laboratories, universities, and research centers through funding from DOE, NOAA, NASA, NSF, and international groups. ARTMIP recently completed two major experiments designed to understand how the use of different methods to detect atmospheric rivers in large climate model datasets impacts

understanding of their behavior in observations and in future climate simulations (O'Brien et al., 2021; Collow et al., 2022).



Visualization of an atmospheric river bringing moisture from the tropics to the West Coast of the United States, April 6, 2018. Satellites can detect this moisture, and the data can be used to calculate the amount of water that could fall as precipitation under the right atmospheric conditions. Credit: NOAA, using data from the Global Forecast System Model.

Predicting Arctic sea ice change. The **CICE model** simulates changes to Arctic sea ice and its interactions with the polar environment over seasonal to decadal timescales. The model's development and maintenance have been led and coordinated by DOE since the early 1990s, with contributions from NOAA, NASA, NSF, ONR, and many other participants. CICE and its support infrastructure are the global standard for sea ice modeling for multiple applications, including scientific research, climate modeling, forecasting, and operations planning. In 2021, the CICE Consortium—a group of primary developers and users of the CICE model—earned a spot in the R&D World's top 100 innovation awards and won the Gold Medal for Corporate Social Responsibility for both the CICE code and the Consortium as an organization.



Arctic sea ice typically reaches its annual minimum extent in September. Average September sea ice extent in the Arctic has continued to decrease over the past four decades. Some projections suggest that the Arctic will be virtually ice-free during summers by the middle of this century. This graph shows a decline in Arctic sea ice extent of about 30% from 1979 to 2021. Source: USGCRP Indicator Platform.

Modeling study shows that Hurricane Sandy damages were worsened by climate change. In 2012, Hurricane Sandy hit the East Coast of the United States, creating widespread coastal flooding and over $60 billion in economic damages. A recent modeling study funded by NASA, NOAA, and NSF, with contributions from DOE and the USGS, found that the impacts of Hurricane Sandy were significantly worsened by sea level rise attributable to climate change (Strauss et al., 2021). Researchers simulated water levels and damages both as they occurred and as they would have occurred across a range of lower sea levels, showing that tens of thousands more people were affected, and more than $8 billion in damages from the storm were the result of human-caused sea level rise. This approach can be applied to impact assessments for other past and future coastal storms.

Damage to the New Jersey coast from Hurricane Sandy. Credit: U.S. Air Force photo by Master Sgt. Mark C. Olsen.

Diversity, Equity, Inclusion, Justice, and Accessibility

The impacts of global change, and how effectively people and communities can respond to them, are interconnected with historical and current inequities. Effective responses to global change challenges require diversity of thought, knowledge, and experience, as well as careful evaluation of risks, impacts, and responses from the perspectives and practices of equity and environmental justice. USGCRP and its member agencies are emphasizing diversity, equity, inclusion, justice, and accessibility throughout their activities, aiming to expand participation in federal global change research and help ensure that the benefits of federal research are shared equitably. Selected efforts in 2021 are highlighted in this section.

Fifth National Climate Assessment. Priorities for NCA5 include ensuring that the development process is inclusive of diverse voices, that the assessment content incorporates science on equity and justice, and that engagement and communication opportunities are accessible to broad audiences. Selected efforts towards these goals include the following:

- In selecting authors, chapter leads were instructed to consider a range of criteria—such as career stage, gender, geography, expertise, and assessment experience—resulting in author teams that represent diverse backgrounds, perspectives, and expertise.

- NCA5 includes a new chapter on Social Systems and Justice, which uses an environmental justice framing to assess the impacts of climate change across the Nation.
- USGCRP's Social Sciences Coordinating Committee (SSCC), in collaboration with several environmental justice experts on NCA5 author teams, provided informal guidance to authors on writing about equity and environmental justice topics.
- Authors were provided with training on the use of Indigenous Knowledge, and staff participated in Tribal Consultations to inform an update of author guidance on the use of Indigenous Knowledge in NCA5.

North American Carbon Program diversity assessment. In early 2021, the North American Carbon Program, which coordinates the research activities funded by several USGCRP agencies, conducted a survey to assess the diversity, experiences, and interests of its membership with respect to equity, inclusion, and accessibility. The resulting assessment outlines the results and proposed actions to improve diversity in the Earth, atmospheric, and ocean sciences.

Social Sciences Coordinating Committee equity and justice workstream. The SSCC created a new workstream in early 2021 in response to the Biden–Harris Administration's emphasis on equity and environmental justice. The group has shared information on agency equity and justice activities that intersect with climate change science; collected existing resources; and led an interagency discussion on justice, equity, diversity, and inclusion in calls for proposals.

Coasts Interagency Group federal seminar series. In April–May 2021, USGCRP's Coasts Interagency Group convened a seminar series for federal agencies on the science of coastal decision-making that hosted federal and non-federal speakers with expertise on various topics, including diversity, equity, inclusion, and justice. The series was well attended, and the recordings have been viewed and shared widely within the federal family.

Informing Decisions

USGCRP and its member agencies emphasize actionable science to inform decision-making in response to global change, including development of decision-support tools and information powered by interagency research and assessment products. USGCRP agencies make data from Earth observations, modeling, and process research freely available to the public and the private sector and are continuing efforts to make research outputs more relevant, useful, and usable for decision makers and managers. Many of USGCRP's Interagency Groups support these efforts through sharing information and experience, producing publications, and supporting co-investment and co-development of tools and information resources to help agencies align their climate adaptation strategies and priorities.

This section highlights activities coordinated by USGCRP Interagency Groups, as well as other interagency projects and programs that are using global change science to address decision-support needs.

Coastal Decision-Making

Coastal areas and the economies they support are increasingly vulnerable to multiple stressors, including sea level rise, more frequent and intense tidal flooding and storm surge, ecosystem degradation and loss of ecosystem services, and land sinkage caused by oil and gas extraction and other human activities. USGCRP facilitates research across agencies to improve understanding of processes that affect the range and timing of coastal impacts and supports development of information and tools for informed coastal planning.

USGCRP's **Coasts Interagency Group (CoastsIG)** provides a venue for interagency collaboration to improve our understanding of climate-related changes affecting the Nation's coasts and develop information and tools that can help coastal communities plan adaptation strategies. In December 2021, the CoastsIG released a report summarizing its 2020 multi-agency workshop on coastal integrated hydro-terrestrial modeling. The group's coastal integrated hydro-terrestrial modeling workstream has also moved forward with several interagency meetings to advance mutual interests and collaborate on modeling studies, including planning for a February 2022 NOAA–DOE meeting focused on the Great Lakes region.

Annapolis, Maryland, affected by tidal flooding. Tidal flooding has increased dramatically across U.S. coastlines over the past 50 years as global average sea level has risen, driven by human-caused climate change. Credit: NOAA.

2021 Highlights

Updated interagency sea level rise scenarios. Throughout 2021, the interagency Sea Level Rise Task Force, under the auspices of USGCRP's CoastsIG and the Subcommittee on Ocean Science and Technology, engaged in extensive collaboration to produce the 2022 Sea Level Rise Technical Report, which provides the most up-to-date sea level rise projections for all U.S. states and territories by decade for the next 100 years and beyond (Sweet et al., 2022). The report projects that sea levels along the U.S. coastline will rise an additional 10–12 inches by 2050, with regional variation. Agencies at the federal, state, and local levels use these projections in planning to manage risks related to sea level rise. A suite of federal tools, including NASA's Interagency Sea Level Rise Scenario Tool and NOAA's Sea Level Rise Viewer, is making

these data accessible and customizable. The results will also underpin discussions of coastal impacts in NCA5. The Sea Level Rise Task Force includes members from NOAA, NASA, EPA, DoD, FEMA, USGS, and USACE, as well as several academic institutions.

Effects of Sea Level Rise Program - Surface Transportation Resilience Initiative. U.S. coastlines are experiencing more frequent and severe coastal flooding, both recurrent tidal flooding events and life-threatening storm surge events. NOAA and DOT have initiated four four-year projects to investigate the effects of coastal flooding on surface transportation infrastructure. The projects are advancing modeling approaches that evaluate how effective different infrastructure designs are at reducing the impacts of repeated coastal flooding events, pairing pavement deterioration modeling with coastal flood and ecosystem modeling. Research teams are engaging with community decision-makers, state transportation agencies, and natural resources agencies to ensure that results effectively inform coastal planning and project development. The projects are part of NOAA's National Centers for Coastal Ocean Science Effects of Sea Level Rise Program.

Marine transportation response and recovery operations during major hurricanes. In December 2021, the U.S. Committee on the Marine Transportation System issued the third report in a series about the response and resilience of the Nation's marine transportation system after major hurricanes. The report assessed the impacts to ports from the 2020 hurricane season, which saw a record-breaking number of storms form in the Atlantic basin during a global pandemic. Three storms were examined in-depth: Hurricanes Laura, Sally, and Delta. The report was authored by the Marine Transportation System's Resilience Integrated Action Team, which includes members from EPA, NOAA, USACE, DoD, DHS, and DOT.

Managing Health Risks

Climate change is already increasing health risks for all Americans, with higher risks for populations that are already vulnerable. These threats are expected to increase as the climate continues to change. USGCRP agencies are investigating the impacts of climate and global change on human health and well-being, monitoring climate-related health outcomes, and translating scientific advances into decision-support tools.

USGCRP's **Interagency Crosscutting Group on Climate Change and Human Health (CCHHG)** coordinates, implements, evaluates, and communicates federal research and scientific activities related to the human health impacts of climate change. The CCHHG develops data-driven scientific products, such as tools, indicators, and assessments, and facilitates communication among stakeholders to help provide end-user input into federal research efforts. In addition to its U.S.-focused activities, the CCHHG supports USGCRP and its member agencies by bringing health expertise to international negotiations, collaborative projects, and capacity-building activities.

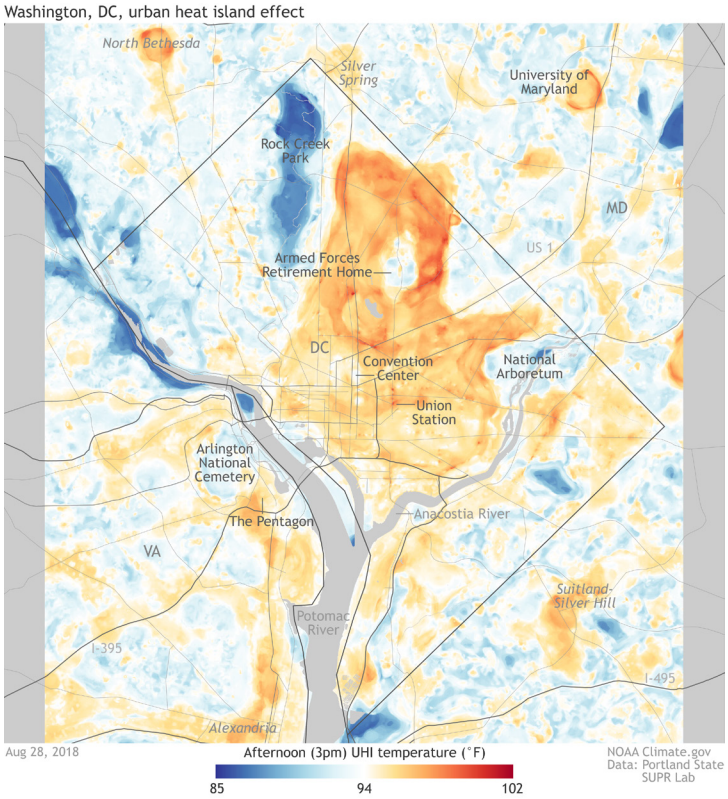
In 2021, the CCHHG supported the global GEO Health Community of Practice in holding a global conversation on the use of Earth observations and climate information for decision-making around COVID-19, and in convening regionally focused workshops on the use of observations for health in the Americas, Africa, and Asia. The GEO Health Community of Practice is a network of governments, organizations, and observers that seeks to use environmental observations to improve health decision-making, with support from NASA and NOAA.

Led by NASA and EPA, the CCHHG created a compendium of federally funded research

activities focused on the human health impacts of climate change in the United States. The purpose of this product is to inform federal agency coordination of CCHHG efforts and ensure that federal research regarding climate and health is readily accessible to inform development of NCA5.

In a new paper, the CCHHG Indicators workstream conceptualized what a national integrated system of climate change and human health indicators could look like, with the goal of assembling and tracking data on climate-related risks and health outcomes that can inform risk reduction measures (Liu et al., 2021). This paper is the foundation of two new indicator projects: 1) identifying heat and health indicators for a national integrated system and 2) a case study on vibriosis (an illness caused by bacteria that are sensitive to climate conditions) as a basis for creating a national integrated system of climate and food safety indicators in collaboration with the new CCHHG workstream on Climate Change, Food Systems, and Nutrition Security.

The CCHHG's international workstream also continues to serve as an important venue for information exchange and conferral on key whole-of-government initiatives related to climate and health, such as the President's Emergency Plan for Adaptation and Resilience, the United Nations Framework Convention on Climate Change Conference of the Parties, and the Belmont Forum's preparations for its latest round of climate–environment–health call for proposals (see Coordinating International Global Change Research).



Map showing the temperature differences across Washington, DC, on August 28, 2018, at 3pm. The map shows the urban heat island effect within cities as different levels of development and tree canopy can cause drastic temperature differences. The temperature data are colored in shades of blue (coolest half of the day's temperature range) to red (warmest half). Credit: NOAA.

2021 Highlights

A seasonal climate and health forecasting tool for heat. The CDC's Heat and Health Tracker, developed in collaboration with NOAA and its NWS, provides local heat and health information to help communities prepare for and respond to extreme heat events. This includes monthly and future projections of the expected number of days that are at or above a dangerous level of heat based on climatological norms. The Heat and Health Tracker also includes a Heat-Related Illness and Temperature map of the rate of emergency department visits associated with heat-related illness per 100,000 visits by region.

Monitoring and assessing urban heat island variations and effects. As the climate changes, hotter-than-usual days and nights are becoming more common, and heat waves are expected to become more frequent and intense. Cities experience higher temperatures than surrounding areas–known as the urban heat island effect–and residents often face higher health risks during extreme heat events. To help monitor changes in the health challenges associated with heat waves in urban areas, the USGS and EPA are developing data, analyses, and indicators for characterizing trends in the urban heat island effect. Integration of long-term USGS–NASA Landsat surface temperature data and annual land cover change information from the 1980s to the present is allowing for new ways to study changes in urban heat island intensity across U.S. cities and beyond. Data are available for 50 U.S. cities and surrounding areas.

Mapping the hottest neighborhoods in communities to inform cooling solutions. Neighborhoods in the same city can differ in temperature by as much as 20°F, due to differences in tree cover and other factors that influence the intensity of the urban heat island effect. To learn where action is needed to protect disproportionately affected populations now and in the future, the interagency National Integrated Heat Health Information System (NIHHIS, led by NOAA and the CDC) and partner CAPA Strategies LLC launched community-led urban heat island campaigns that map the hottest parts of cities. Through this program, NIHHIS works with communities to inform equitable heat resilience solutions based on campaign results. Citizen scientists from each community collect temperature and humidity data in their neighborhoods, helping to increase awareness of the health risks of heat within each community. As of 2021, 24 communities across the country and internationally have mapped their urban heat islands. Data from the program have been used in a variety of ways, including to support tree planting strategies, installation of pavement that absorbs less heat, educational efforts, and more. All data reports are open source and available on Heat.gov.Num

Nature-Based Solutions

Nature-based solutions are actions to protect, sustainably manage, or restore natural or modified ecosystems to address societal challenges, simultaneously providing benefits for people and the environment (CEQ, OSTP, & DCPO, 2022). These measures can help buffer communities from the impacts of climate change, nature loss, and other aspects of global change, while offering additional benefits, including removal of carbon dioxide from the atmosphere. An increasing number of organizations across the public and private sectors are investing in nature-based solutions as part of their strategies to manage risks (Bridges et al, 2021). However, more evidence is needed to understand the potential of various types of nature-based solutions to achieve certain benefits. USGCRP agencies are studying the effectiveness of different nature-based solutions, identifying knowledge gaps, and providing information to resource managers.

USGCRP's **Federal Adaptation and Resilience Group (FARG)**, which fosters collaboration to increase the resilience of federal investments to the impacts of climate change, initiated discussions and information-sharing activities around nature-based solutions, which will lay the groundwork for additional FARG activities and collaborations on nature-based solutions. The FARG has a Natural Resource Management workstream that has hosted webinars on carbon inventory and sequestration, nature-based solutions for shoreline protection and conservation, and other related topics.

Inspecting newly planted vegetation on dunes on a restored barrier island in Barataria Bay, Louisiana. Restoration of dune habitat helps slow the loss of land to erosion, improving the ability of barrier islands to buffer the mainland from the effects of sea level rise, storms, and associated flooding. Credit: NOAA.

2021 Highlights

Restoring barrier islands for coastal protection. Barrier islands—narrow deposits of sand that form along the coast—help protect mainland coastal communities from storms and serve as important habitats for many species. Restoring or enhancing barrier islands can build coastal resilience to the effects of storms and protect important habitats that sustain coastal economies. Sediment management (e.g., dredging) can be done as a nature-based solution, if it is designed appropriately, and dredge materials are used to restore or enhance habitat near at-risk communities. A new study conducted by the USGS and FWS provides resource managers—including USACE and BOEM—with valuable information they can use to anticipate and evaluate impacts of sediment removal and placement within barrier islands (Miselis et al., 2021), and potentially increase the instances where sediment management creates both environmental and social benefits and reduces tradeoffs. The report identifies both beneficial and detrimental impacts from sediment management practices depending on where and how they are applied within barrier island systems, as well as knowledge gaps that can help prioritize future federal research, modeling, and monitoring efforts.

Managing Biodiversity and Ecosystem Change

Nature is in decline, a trend caused by five major drivers: climate change, habitat loss, pollution, invasive species, and overharvesting. These drivers are causing disruptions in life cycles, food webs, and the ecological connectivity of species, trends that are expected to accelerate as the major drivers persist. USGCRP member agencies are tracking the effects of climate change, habitat destruction, and other forces of global change on species, ecosystems, biodiversity, and the benefits they provide to society, and informing actions to conserve biodiversity and employ nature-based solutions to address multiple threats.

The invasive spotted lanternfly is a threat to many fruit and tree crops in the United States. Photo by Steve Ausmus, USDA/ARS.

Supporting management of invasive species at the regional level. The Regional Invasive Species and Climate Change (RISCC) Management Networks are working to reduce the compounding effects of invasive species and climate change by synthesizing relevant science, communicating decision-makers' needs to researchers, building stronger scientist–stakeholder communities, and conducting priority research. The RISCC effort started in the Northeast region in 2016 with a collaboration among USGS researchers, university scientists, and state agency partners. It has since expanded to the Pacific Islands, Northwest, North Central, and Southeast regions, as well as new collaborations with NSF and the USDA-FS. The RISCC networks serve the science needs of stakeholders in DOI, USDA, state agencies, Tribes, local governments, and nongovernmental organizations. In 2021, the Northeast RISCC compiled resources for state agencies to share existing invasive species risk assessments and adapt risk assessment protocols to be more cognizant of climate change. This information is being used by the states of New York, Maine, and Massachusetts to identify high-priority, range-shifting invasive plants to recommend for proactive regulation.

Collaborative forest management in a changing climate. The **Adaptive Silviculture for Climate Change (ASCC)** project is a collaborative effort to help guide forest managers in preparing forest ecosystems for climate change. Scientists, land managers, and a variety of partners have developed seven initial trial sites as part of this multi-region study to research long-term ecosystem responses to a range of climate change adaptation actions. USDA-FS scientists partnered with universities and local, state, and federal agencies (including DOI and USACE) to develop the first ASCC project in an urban national park,

the Mississippi National River and Recreation Area in the Twin Cities, Minnesota. Data are being collected to understand how different management approaches affect species and forest health in a changing climate. Long-term data collection for this 20-year study is conducted by local university students and community scientists, and outreach to community members includes signs installed at the park that communicate the cultural importance of floodplain forests using Indigenous art and language.

Wildfire Management

Climate change, along with other human activities, is leading to larger and more severe wildfires, bringing harmful impacts both near and far from fire-prone areas, as well as increasing costs for fire suppression. Other global change trends, including land use change and ecosystem decline, interact with wildfire trends and influence risks to people and ecosystems. Many USGCRP agencies are investigating the public health, socioeconomic, and ecological implications of increasing wildfire and supporting efforts to reduce risks through proactive land management and other strategies.

The Telegraph Fire, Arizona, summer 2021. Credit: USDA-FS photo by Andrew Avitt.

Assessing information needs for wildland fire rapid management. In 2021, USGCRP's Integrated Observations Interagency Working Group, the U.S. Group on Earth Observations, and the Interagency Council for Advancing Meteorological Services collaborated to develop a rapid assessment of Earth observation and information shortfalls in support of wildland fire management and related activities. The effort will help to meet the wildland fire community's observation and information needs.

Comparing air quality and health impacts from wildfire and prescribed fire. A 2021 report from EPA, USDA-FS, DOI, and NIST compared the air quality and health impacts of smoke from prescribed fire, which is used as a land management tool, with smoke from wildfire. The report found that using prescribed fire is not without risk as it can result in smoke-related air quality and public health impacts—but at a much smaller scale compared to wildfire. The assessment could be informative to multiple levels of government as they engage and plan for future land and fire management activities. The report also contributes to the identification of future research efforts to examine air quality and public health impacts due to smoke from fire.

Science–management partnership on climate–fire–ecosystem interactions. A major challenge for natural resource managers in the western United States is anticipating and planning for ecosystem changes caused by complex interactions among climate, wildfire, and vegetation. The **Southwest FireCLIME** research partnership brings scientists and managers together to support decision-making processes around fire management in a changing climate. The project synthesized current knowledge of regional climate–fire–ecosystem dynamics through a formal science synthesis and annotated bibliography, forecasts of future vegetation change under different climate–fire regimes, adaptation tools including a menu of adaptation options, and a vulnerability assessment tool. Southwest FireCLIME is funded by the interagency Joint Fire Science Program (DOI and USDA-FS). Additional partners include universities and non-governmental organizations.

Sharing Lessons Learned

Learning networks and activities help scientists and practitioners address critical climate and global change-related challenges through sharing of knowledge, experiences, and best practices. USGCRP member agencies are helping convene climate service providers and decision-makers to improve knowledge sharing about climate variability and change and how they can build resilience.

Farmland in Moca, Puerto Rico. Credit: USDA/Preston Keres.

Expanding the Drought Learning Network to the U.S. Caribbean. The **Caribbean Drought Learning Network (CDLN)** is a peer-to-peer network that links climate service providers, climate researchers and resource managers to share knowledge and strengthen collaboration and communication in drought research and management in Puerto Rico and the U.S. Virgin Islands, where drought constrains agricultural production, impacts the economy, and diminishes quality of life. The goal of this network is to produce and share information, lessons learned, and needs in preparing for, responding to, and recovering from drought affecting farms, forests, and rural communities. One benefit of the CDLN is preserving the continuity of knowledge between severe droughts so that communities retain preparedness. The CDLN is led by the USDA Caribbean Climate Hub, with participation from the USDA-FS, the National Drought Mitigation Center, and NOAA's National Integrated Drought Information System. The Drought Learning Network was previously implemented in the U.S. Southwest and was expanded to the U.S. Caribbean in 2021.

Conducting Global Change Assessments

USGCRP produces regular 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. The flagship assessment product, mandated by the GCRA, is known as the National Climate Assessment (NCA). Development of NCA5 is currently underway, with anticipated delivery in late 2023. USGCRP approaches assessment as an ongoing and evolving process that enables scientists and stakeholders to address issues of emerging importance on an ongoing basis. USGCRP's assessments undergo extensive, multi-phase reviews from federal agency experts and the public as well as an external, independent peer review by NASEM. Development of these assessments is designed to be transparent and inclusive, providing opportunities for public participation throughout the process. USGCRP member agencies continue to contribute to USGCRP assessment products by providing expert authors and reviewers, and through continually advancing science by developing scenarios, tools, model data, climate indicators, and other resources that underpin assessment findings.

USGCRP's Interagency Groups develop products and tools and provide guidance that contributes to the assessment process. USGCRP's **Sustained Assessment Working Group (SAWG)** focuses on improving the effectiveness and production efficiency of the NCA, including aspects of the assessment process, scenario products and data tools, indicators, research needs and gaps, special reports, evaluation, and engagement with assessment contributors and users. Throughout 2021, SAWG hosted a monthly speaker series dedicated to the future of the NCA. The group invited external experts to discuss future needs and priorities that an NCA would address and the potential structures or framings it might use. Speakers included practitioners, scientists, science communication experts, and others who spoke to issues including stakeholder engagement; interdisciplinary integration; data and downscaling; diversity, equity, and inclusion; and user-driven science.

Throughout 2021, the interagency Sea Level Rise Task Force, under the auspices of USGCRP's Coasts Interagency Group and the National Science and Technology Committee's Subcommittee on Ocean Science and Technology, engaged in extensive collaboration to produce the 2022 Sea Level Rise Technical Report, which provides the most up-to-date sea level rise projections for all U.S. states and territories by decade for the next 100 years and beyond (see Coastal Decision-Making), and will underpin discussions of coastal impacts in NCA5.

USGCRP also participates in international scientific assessments conducted by the Intergovernmental Panel on Climate Change and other organizations. For more detail, see the International Assessments section.

The Fifth National Climate Assessment

Development of NCA5 continued throughout 2021, with many important milestones. NCA5 builds on the lessons learned from previous assessments, while aiming to enhance the diversity of its authors and contributors, address emerging priority topics, and enhance public engagement processes. In the spring and summer of 2021, the NCA5 Federal

Irrigation using water from the Ruby Reservoir, Montana. Credit: Lance Cheung/USDA.

Steering Committee selected the report's federal coordinating leads and chapter leads. Chapter leadership then selected a diverse group of expert contributors—nearly 500 authors and 200 technical contributors—representing all 50 states, Puerto Rico, the U.S. Virgin Islands, Guam, and Palau. For more details on author selection, see the Diversity, Equity, Inclusion, Justice, and Accessibility section.

In response to federal and public feedback received since the publication of NCA4, NCA5 has added two new chapters (Economics; Social Systems and Justice) and a climate indicators appendix that highlights key physical, ecological, and social systems data used to track trends and impacts related to our changing climate. Several members of USGCRP's Indicators Interagency Working Group—which focuses primarily on leveraging existing federal indicators efforts to support USGCRP's assessment activities—are serving as authors on the appendix. NCA5 will also include five new sections focused on cross-cutting topics: wildfire in the western United States, COVID-19, risks to supply chains, compound extreme events, and blue carbon.

In Fall 2021, USGCRP hosted the first chapter leadership and all-author meetings to provide training for around 500 authors on foundational NCA topics, including author roles and responsibilities, legal guidelines, source material requirements, timeline, figure development, and documentation. A key element of this training included discussion of themes that cut across chapter topics, such as environmental justice and Indigenous Knowledge and perspectives. Following orientation, author teams developed annotated outlines, which USGCRP agencies reviewed prior to release for public comment.

Building on the successful public engagement efforts of NCA4, NCA5 planned a new public comment opportunity and 34 online public engagement workshops. Largely organized in 2021, these engagement efforts gathered feedback on chapter outlines and informed the author teams' approach early in the writing process.

Coordinating International Global Change Research

The long-term strength of global change research capabilities depends on engagement and collaboration globally. As part of its mandate under the GCRA, USGCRP builds and sustains partnerships with research programs of other nations and international organizations to promote international cooperation around global change research and strengthen research capacity in developing countries. USGCRP's **International Activities Interagency Working Group (IAIWG)** works with member agencies to promote and contribute to international and intergovernmental cooperation on global change research and engages with international organizations and initiatives in a variety of ways. IAIWG is also engaging in and supporting the development of international content for NCA5.

The Coast Guard Cutter Polar Star transits through pack ice in the Southern Ocean, en route to resupply U.S. Antarctic research stations. Credit: Aidan Cooney/U.S. Coast Guard.

International Research Coordination

In support of its international mandate, USGCRP currently helps provide core budget support to three international science organizations: **Future Earth**, which builds interdisciplinary, cross-sectoral partnerships to advance global sustainability science; the **SysTem for Analysis, Research, and Training (START)**, which provides opportunities for research, education, and training to scientists, policymakers, and practitioners in developing countries; and the **World Climate Research Programme (WCRP)**, which is the primary international coordination mechanism for climate system research.

In November 2021, IAIWG brought together representatives from USGCRP member agencies and the secretariats of Future Earth, START, WCRP, and the Inter-American Institute for Global Change Research to strengthen communication among the organizations and identify opportunities for future collaboration. Outcomes included the potential for collaboration around the development of a transdisciplinary research and leadership capacity-building opportunity.

USGCRP also actively collaborates with the **Belmont Forum**, an international partnership that catalyzes funding for research in support of resilience and sustainability. The United States played a leading role in the development of a Belmont Forum Climate, Environment, and Health Collaborative Research Action (CRA) launched in April 2019. Several agencies worked together to provide support for U.S.-based scientists to collaborate in the research effort. USGCRP's Interagency Crosscutting Group on Climate Change and Human Health and IAIWG are assisting with engagement and outreach efforts for Round 2 of the CRA, which is co-chaired by NOAA and NSF. The CRA will support international interdisciplinary research teams working to understand how climate variability and change influence human health and well-being and to support effective responses. Round 2 is prioritizing engagement and participation from lower- and middle-income countries. Scoping workshops have been completed in the regions of Latin America/Caribbean, Asia/Pacific, Africa, and Europe. The call for proposals launched in February 2023 and will support capacity-building and networking activities for prospective researchers, with an emphasis on those from lower- and middle-income countries.

Capacity Strengthening

As part of its international mandate, USGCRP builds and sustains partnerships to promote knowledge-sharing that supports research, data collection, and assessment capabilities in developing countries.

In 2021, USGCRP initiated a new regional engagement effort, the Initiative for Enhancing Capacity for Climate Risk Assessment and Catalyzing Partnerships to Inform Decisions in Latin America and the Caribbean, or **LACI**. Its overarching vision is to provide opportunities for partnerships among Caribbean, Latin American, and North American countries to enhance capacity for climate risk and vulnerability assessments that would support local and regional decision-making in response to climate change impacts. LACI is focused on fostering and building partnerships, peer-to-peer learning and training, and data synthesis and analysis. LACI is a collaborative effort among USGCRP and the U.S. Group on Earth Observations and regional partners, including AmeriGEO and the Inter-American Institute for Global Change Research.

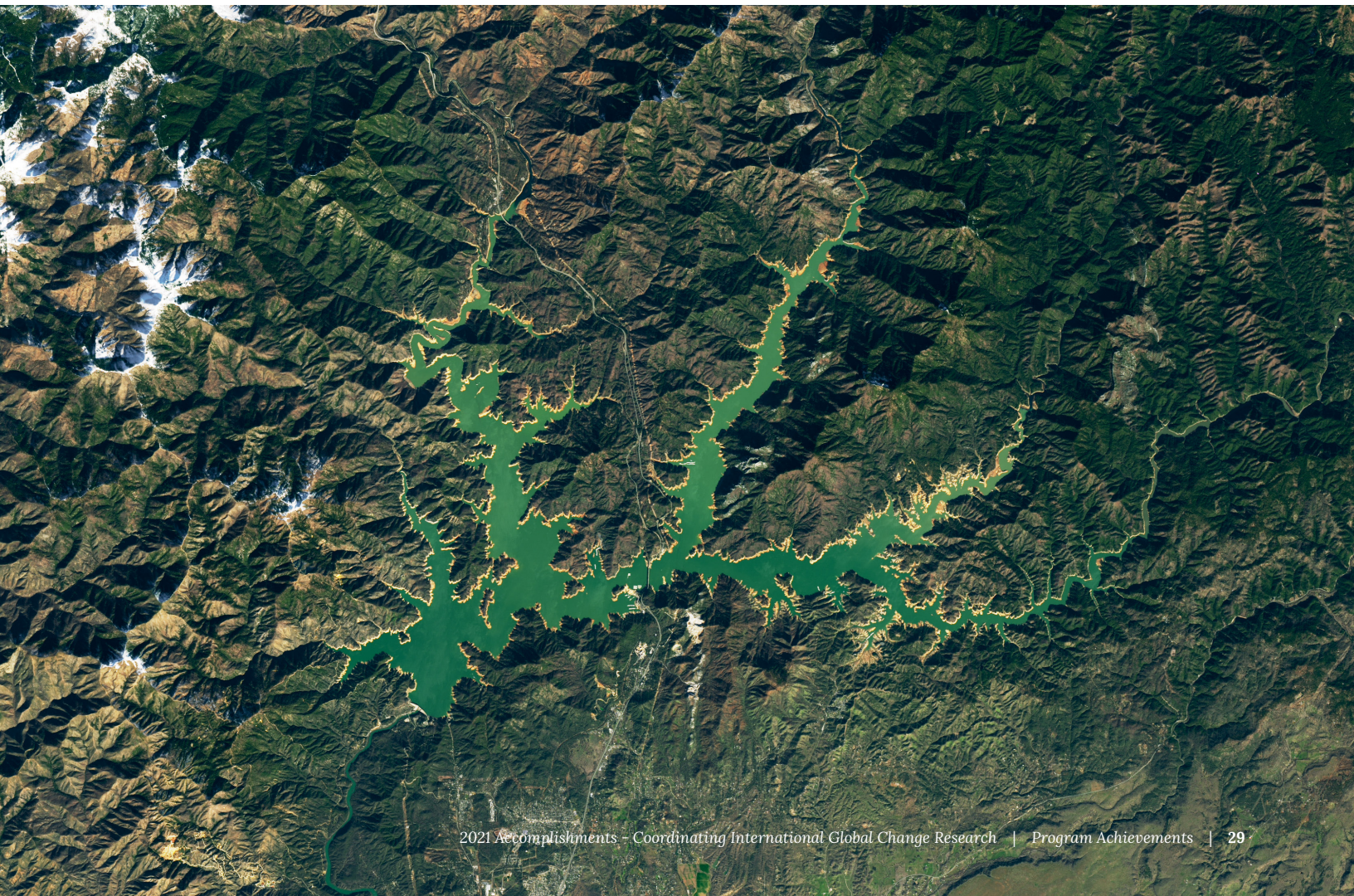
In 2021, IAIWG conducted a survey of federal agency capacities to support the LACI effort. The SGCR approved phase 1 of the project in October 2021. The IAIWG LACI Workstream (consisting of representatives from DOI, DOS, NASA, NOAA, NSF, and USAID) conducted a series of partnership-building and scoping activities. Activities included in-depth analysis of the Latin American and Caribbean countries' National Adaptation Plans, surveys of the regional climate risk priorities and capacities, and surveys of the U.S. Government capacity to support LACI efforts. Representatives from 13 countries (Argentina, Brazil, Canada, Chile, Colombia, Ecuador, El Salvador, Jamaica, Mexico, Panama, Peru, Uruguay, and the United States) participated in the partnership-building workshop in November 2021. These activities fostered the creation of a rapport between LACI participants and helped identify countries' visions and needs for a climate-resilient future, existing capacities, and steps forward towards development of a pilot project.

International Assessments

USGCRP plays a vital coordinating role in international scientific assessments that provide policymakers with regular updates on the state of global change science on a planetary scale.

The United States is a substantial contributor to the intellectual content of Intergovernmental Panel on Climate Change (IPCC) reports, with well over 100 writing team members serving during the Sixth Assessment Report (AR6) cycle. The U.S. Government routinely provides comprehensive reviews of the draft reports, involving a process open to the public, hundreds of targeted reviewers, and convened expert panels to ensure rigor of submitted comments. USGCRP also provides travel support to facilitate non-federal U.S. scientist participation in international assessment activities, including the IPCC, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, the Arctic Council, and the United Nations Environment Programme Ozone Assessment Panels (Scientific and Environmental Effects).

In 2021, USGCRP facilitated the U.S. Government review of the IPCC Working Group II and III contributions to the AR6 report and preparations for review of the AR6 Synthesis Report, initiated in January 2022. IPCC Working Group I delivered its report for the AR6 cycle, *Climate Change 2021: The Physical Science Basis*, in August 2021. USGCRP assisted in managing the virtual U.S. delegation to the plenary session for approval of the Working Group I report, and in communicating key takeaways.

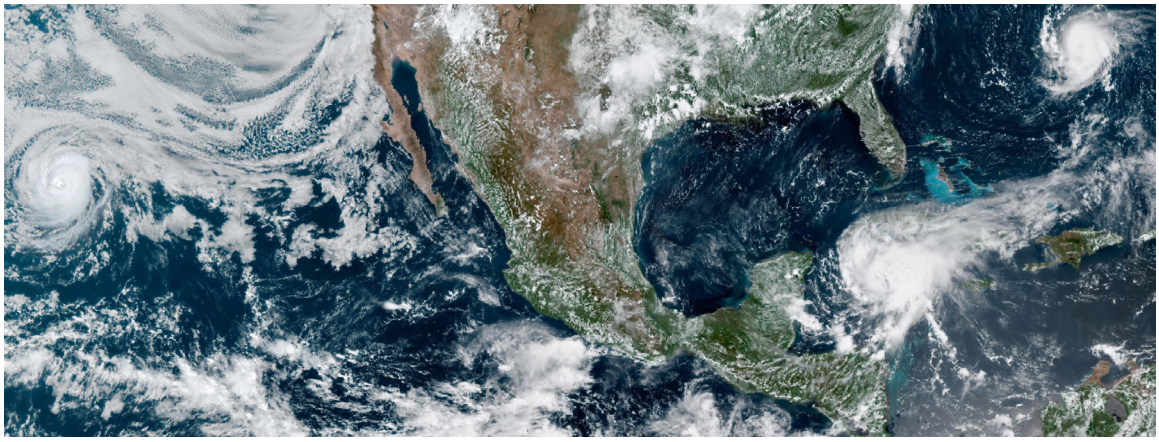


FUTURE PRIORITIES

A New Vision for Global Change Research: 2022–2031

In 2021, USGCRP initiated development of its 2022–2031 Strategic Plan to guide federal global change research over the next decade, as required by the GCRA. The development of the Plan, which was informed by input and review from federal agencies, NASEM, and the public, lays the foundation for meeting new and growing challenges, as well as demands for useful, accessible, and inclusive data and information.

The Plan includes the following vision: "A Nation, globally engaged and guided by science, meeting the challenges of climate and global change for the benefit of all." The Plan builds on USGCRP's previous Strategic Plan, leveraging new approaches and lessons learned, and prioritizing new, urgent research questions. The Plan is organized around four pillars: Advancing Science; Engaging the Nation; Informing Decisions; and Collaborating Internationally. While USGCRP prioritized Advancing Science and Informing Decisions as strategic goals for 2012–2021, over the next decade the Program will address new research priorities, put new approaches in practice, and develop new products. Engaging the Nation and Collaborating Internationally are two new pillars for 2022–2031.



Storms offshore and wildfire smoke streaming across North America, August 18, 2021. Credit: NASA Earth Observatory image by Lauren Dauphin, using GOES 16 imagery courtesy of NOAA and the National Environmental Satellite, Data, and Information Service.

Fiscal Year 2023 Priorities

In Fiscal Year 2023 (FY2023), USGCRP will focus on implementing the new Strategic Plan. USGCRP initiated activities in 2021 and 2022 that align with commitments made in the 2022–2031 Strategic Plan to expand participation in the federal global change research enterprise, deepen work on other drivers of global change, and enhance the impact of federal global change research. These activities will continue throughout FY2023 and beyond.

Advancing Science

USGCRP's work to advance key scientific questions continues to be the Program's core strength. USGCRP will continue to enhance our understanding of human-induced and natural processes of global change across the full spectrum of natural and social sciences. Emphasizing and integrating social sciences in the Program has been an area of growth over the past decade and will continue to be a priority for USGCRP. In implementing research efforts, the Program and its member agencies will continue to promote an open, inclusive, and transparent process for creating and disseminating scientific knowledge, consistent with the principles advanced by the 2023 Year of Open Science, led by the Office of Science and Technology Policy (OSTP, 2023). Many USGCRP agencies have announced open science initiatives.

Examples of key research areas that will benefit from interagency collaboration include the following:

- Increased exploration of other global changes beyond climate change, such as biodiversity and nature loss. For example, while the direct connections between climate change and biodiversity have been a historic focus of the program, USGCRP is expanding to consider the impacts of other drivers of change on biodiversity.
- Addressing emerging and critical research questions, such as how tipping points—abrupt and irreversible changes in interconnected social and natural systems—affect our responses to global change.
- Understanding different types of response measures to manage global change impacts, which has important potential to inform the actions that decision-makers take.

Many initiatives that coordinate and advance science will be led through USGCRP's Interagency Groups. For example, the IGIM will continue to coordinate Earth system modeling efforts and will hold its 9th Annual Modeling Summit in FY2023. The SSCC will work with other Interagency Groups to advance the integration of social sciences into their work. With the support of many agencies through the Interagency Integrated Water Cycle Group, NOAA is leading the development of a long-term research and monitoring program of the Western Hydroclimatology Program, as required by the FY2022 Consolidated Appropriations Act.

USGCRP and its member agencies continue to expand their focus on science to support climate and global change responses and solutions, including nature-based solutions. In response to a 2022 interagency report to the National Climate Task Force on nature-based solutions (CEQ, OSTP, & DCPO, 2022), USGCRP is synthesizing what is known about the effectiveness of nature-based solutions. USGCRP will make an online evidence library accessible to the nature-based solutions community in 2023 and will analyze this evidence base to determine current confidence in the effectiveness of diverse nature-based solutions for climate mitigation, adaptation, and other societal benefits.

Engaging the Nation

Climate change and other global changes are impacting more people, and a greater diversity of people, than ever before. As a result, USGCRP needs a whole-of-society approach to understand global change, its impacts, and our responses. Engaging the Nation is a new pillar in the 2022–2031 Strategic Plan that reflects this broader approach. USGCRP will broaden its engagement across federal agencies, through Federal Regional Science Organizations (e.g., the NOAA Climate Adaptation Partnerships, DOI Climate Adaptation Science Centers, and USDA Climate Hubs), and with frontline communities.

USGCRP will incorporate different ways to engage people and organizations across the Nation, such as workshops, webinars, and podcasts. Agencies across the Federal Government are developing formal department-wide or agency-wide climate adaptation plans and are analyzing and preparing for the impacts of climate change. As a result, USGCRP has an opportunity to provide information that serves the needs of these agencies. USGCRP will broaden its engagement with federal agencies, which can help ensure that the Program is producing useful and usable information. USGCRP will also develop guidance on the use of climate information by federal agencies, which is consistent with a FY2022 Consolidated Appropriations Act directive.

USGCRP's strategy for Engaging the Nation will be consistent with its Diversity, Equity, Inclusion, Justice, and Accessibility statement. This will help ensure that the Program is embodying a diversity of perspectives, providing scientific tools to address the full range of climate and global change impacts in every corner of the country, and equitably serving the information needs of all Americans.

Informing Decisions

USGCRP is addressing growing demands for more comprehensive and specific climate and global change information to guide decision-making. USGCRP will continue to prioritize making its information available in ways that are accessible, useful, and easily customizable by local decision-makers and practitioners.

USGCRP will continue providing information about climate trends by maintaining and expanding its Indicator Platform. USGCRP is also developing the Climate Resilience Information System (CRIS), which will enable the use and application of climate projections and other related datasets. The need for information that is locally relevant and tailored to specific decision needs is growing, leading to a proliferation of information platforms. CRIS will power the more efficient development of customized tools, including

new and existing federal climate portals, by providing a consistent set of climate projections and climate-relevant federal data. Ultimately, CRIS is intended to ensure that products of the climate research enterprise are accessible and useful to decision-makers.

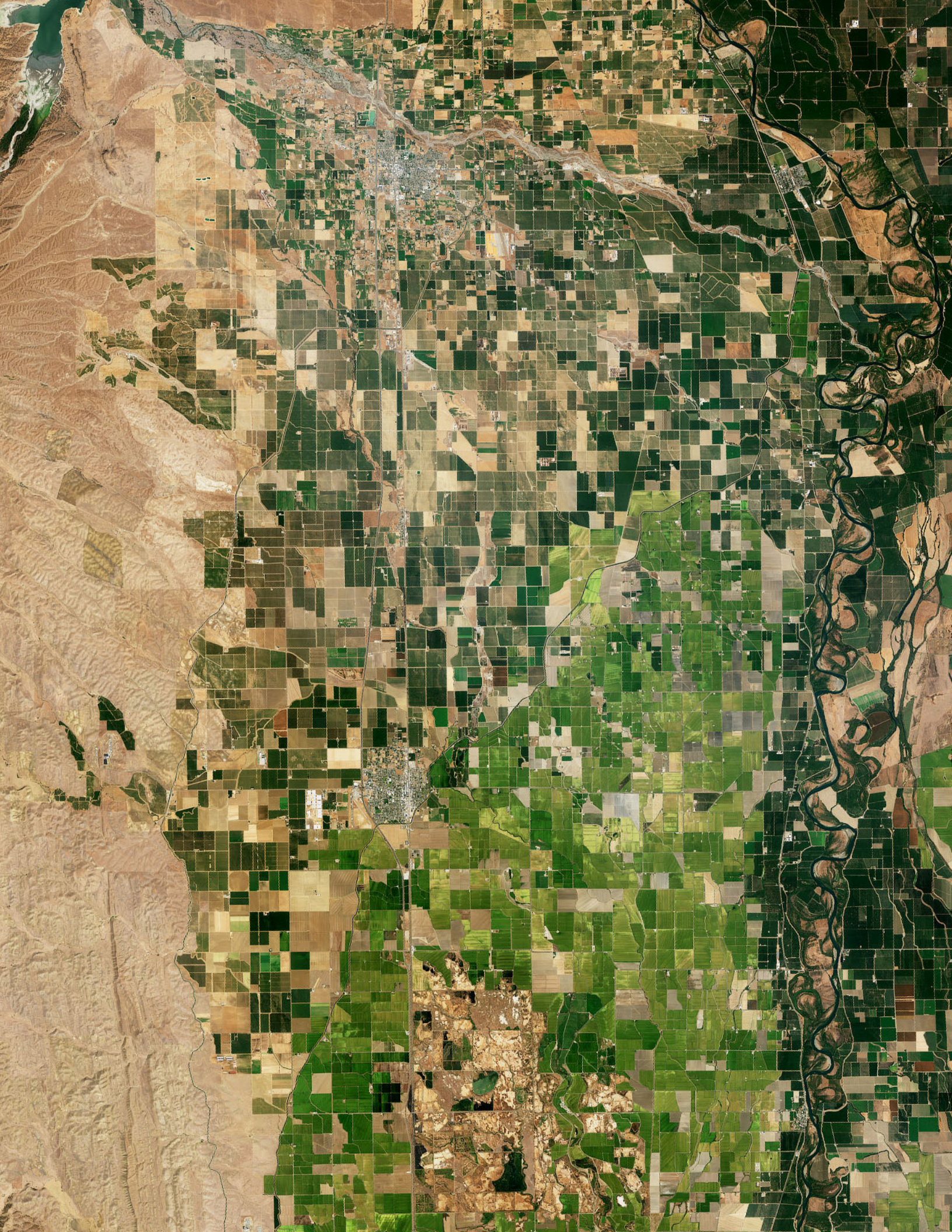
USGCRP will also continue to improve the accessibility and relevance of the NCA and other scientific assessments. USGCRP will continue its work on NCA5, which is expected to be released in late 2023. In 2022, USGCRP initiated an assessment of the condition of nature within the United States, with anticipated release in 2026. The National Nature Assessment will provide a comprehensive picture of the Nation's lands, waters, and wildlife and how they might change in the future, including their interactions with climate, the economy, public health, environmental justice, and national security. As with other USGCRP assessments, the **National Nature Assessment** will draw on expertise from across the Federal Government, Indigenous communities, academia, non-profit organizations, and the private sector. The assessment process will emphasize collaboration with potential users of the report to ensure that it provides relevant information and is informed by diverse perspectives.

Collaborating Internationally

International engagement and collaboration continue to be a priority for USGCRP, consistent with the GCRA mandate to promote international cooperation around global change research and build research and decision-support capacity in developing countries. To address this mandate more fully, Collaborating Internationally was established as a pillar in the new Strategic Plan. USGCRP sees opportunities to enhance collaboration with existing partners and develop new relationships, and will continue to support international assessment processes, including the Intergovernmental Panel on Climate Change.

LACI is a new regional engagement effort launched by USGCRP in 2021 that seeks to provide opportunities for partnerships among Caribbean, Latin American, and North American countries to enhance capacity for climate risk and vulnerability assessments that would support local and regional decision-making in response to climate change impacts (see Coordinating International Global Change Research). LACI activities will continue throughout FY2023.

USGCRP will also support the emerging **Global Precipitation Experiment (GPEX)** in FY2023. GPEX was established as a cross-WCRP activity to bring the international weather, water, and climate communities together with the goal of improving precipitation science and prediction at different temporal scales and for weather, subseasonal-to-seasonal, interannual, and decadal timescales. GPEX will convene existing national and international initiatives on precipitation science and applications from both WCRP and non-WCRP programs and jointly plan future activities to achieve the GPEX objectives.



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.

Fiscal Year 2023 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 2021 Enacted ($M)	FY 2022 Enacted ($M)	FY 2023 President's Budget ($M)
Department of Agriculture	118	140	302
Department of Commerce	445	483	730
Department of Energy	305	354	383
Department of Health and Human Services	29	29	261
Department of the Interior	207	232	375
Department of Transportation	1	2	2
Department of State	0	0	0
Environmental Protection Agency	20	19	51
National Aeronautics and Space Administration	1608	1750	1966
National Science Foundation	660	737	1055
Smithsonian Institution	8	8	14
U.S. Agency for International Development	0	0	0
Total	**3,401**	**3,754**	**5,139**

APPENDIX 1. ABOUT THE U.S. GLOBAL CHANGE RESEARCH PROGRAM

Program History

The U.S. Global Change Research Program (USGCRP) was established by Presidential Initiative in 1989 and mandated by Congress in the Global Change Research Act (GCRA) of 1990 to develop and coordinate a "comprehensive and integrated United States research program which will assist the Nation and the world to understand, assess, predict, and respond to human-induced and natural processes of global change."

USGCRP coordinates and integrates global change research and resources across federal agencies, uses research results and products to inform decisions, and facilitates international cooperation on global change research. The Program emphasizes research that can be used to answer critical questions about the changing Earth system and how the United States and the world can respond to those changes. USGCRP's legal mandate is available on the Program website.

As directed by the GCRA, USGCRP produces the following Congressionally mandated products:

- a new strategic research plan every ten years, with triennial revisions and updates;
- an annual report to Congress; and
- a quadrennial assessment of current and future impacts of climate change on the United States, known as the National Climate Assessment.

Program Structure

USGCRP is directed by the Subcommittee on Global Change Research (SGCR) of the National Science and Technology Council's Committee on Environment, which is overseen by the White House Office of Science and Technology Policy. The SGCR is composed of representatives from USGCRP's member agencies. The SGCR coordinates interagency activities through 11 Interagency Groups, supported by the USGCRP National Coordination Office (NCO). An interagency distributed cost budget supports the NCO and other Program activities.

Interagency Groups are USGCRP's primary vehicle for implementing and coordinating global change research activities within and across agencies. The groups are composed of representatives from federal departments and agencies responsible for activities in each research area. They span a range of interconnected climate and global change issues and address major components of the Earth's environmental and human systems, as well as cross-disciplinary approaches for addressing these issues. The groups bring agencies together to plan, develop, and implement coordinated activities and identify and address future research and Program needs. Interagency Groups allow federal scientists and program managers to communicate with each other on emerging directions within their agencies, their stakeholder needs, and best practices learned from agency activities.

- Carbon Cycle Interagency Working Group (CCIWG)
- Coasts Interagency Group (CoastsIG)
- Federal Adaptation and Resilience Group (FARG)
- Indicators Interagency Working Group (IndIWG)
- Integrated Observations Interagency Working Group (ObsIWG)
- Interagency Crosscutting Group on Climate Change and Human Health (CCHHG)
- Interagency Group on Integrative Modeling (IGIM)
- Interagency Integrated Water Cycle Group (IWCG)
- International Activities Interagency Working Group (IAIWG)
- Social Sciences Coordinating Committee (SSCC)
- Sustained Assessment Working Group (SAWG)

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 activities reflect the challenges posed to agriculture, forests, and natural resources by climate change, and the promise of addressing the climate challenge from within the land sector. USDA's research aims to understand the role of agricultural and forest systems in contributing to climate change, the risks and vulnerabilities facing these sectors, opportunities to reduce emissions and increase carbon sequestration, and strategies to enhance productivity while building resilience to climate change. USDA's climate science program integrates engagement with stakeholders to generate use-inspired research that informs on-the-ground decision-making in real time. Creating healthy ecosystems and resilient communities through sustainable forests and rangelands, climate-smart crop and livestock systems, and a robust natural resource base via a full scientific understanding of climate change is USDA's Strategic Goal #1.

Adaptation planning at USDA identifies research priorities that inform changes in farming and land management to support long-term resilience within specific geographical and production contexts. Those research activities strengthen disaster preparedness and recovery, increase access to decision-support tools and technologies, and engage stakeholders through outreach and education to build additional adaptive capacity.

USDA leads the way in developing science-informed conservation and land management practices that reduce greenhouse gas emissions, increase carbon storage in soils and in above-ground vegetation, and generate renewable fuels that recycle carbon dioxide from the atmosphere.

Within USDA, climate change research activities harness the combined strengths of the Agricultural Research Service (ARS), the Forest Service (FS), the National Institute of Food and Agriculture (NIFA), the Economic Research Service (ERS), the National Agricultural Statistics Service (NASS), and the Natural Resources Conservation Service (NRCS). The Department's scientific reach extends beyond the direct federal investment to include its network of Land Grant and Minority Serving Colleges and Universities, Cooperative Extension, an active extramural research enterprise, and the USDA Climate Hubs.

USDA's cross-Departmental research is linked to land managers through the USDA Climate Hubs. The Climate Hubs and their partners develop locally specific tools and resources to increase climate change adaptation capacity across the country through engagements, assessments, demonstrations, and tool development. The Hubs' library of scientific resources empowers producers and other stakeholders to adapt existing scientific information to specific circumstances while simultaneously improving adaptation, mitigation, and production outcomes.

The Department actively coordinates across agencies and mission areas at multiple organizational levels to plan, execute, engage, and learn from its applied research efforts. USDA actively cultivates employee understanding of climate change's effects on its mission through educational workforce development activities focused on applied climate change science training.

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.

From daily weather forecasts, severe storm warnings, and climate monitoring to fisheries management, coastal restoration, and supporting marine commerce, NOAA's products and services support economic vitality and affect more than one-third of America's gross domestic product. NOAA's dedicated scientists use cutting-edge research and high-tech instrumentation to provide citizens, planners, emergency managers, and other decision-makers with reliable information they need, when they need it.

NOAA's mission to better understand our natural world and help protect its precious resources extends beyond national borders to monitor global weather and climate and work with partners around the world.

NOAA holds key leadership roles in shaping international ocean, fisheries, climate, space, and weather policies. NOAA's many assets—including research programs, vessels, satellites, science centers, laboratories, and a vast pool of distinguished scientists and experts—are essential, internationally recognized resources. NOAA works closely with other nations to advance our ability to predict and respond to changes in climate and other environmental challenges that imperil Earth's natural resources, human life, and economic vitality.

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 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 Military Services that respond to specific national security requirements and may also be leveraged to address the strategic goals of the USGCRP. DoD's environmental 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. In meeting the requirements within Executive Order (EO) 14008, Tackling the Climate Crisis at Home and Abroad, DoD released agency-wide documents including the Defense Climate Risk Analysis report (2021) to incorporate climate change security implications across relevant DoD strategy, planning, and programming documents and processes. The DoD Climate Adaptation Plan (2021) and its subsequent Progress Report (2022) was also released to articulate a bold vision for climate adaptation and align adaptation and resilience efforts with the department's warfighting mission. Some DoD initiatives related to environmental change and resilience include the following:

- The Army continues to focus on addressing Arctic mobility and infrastructure challenges and released its Climate Strategy in 2022.
- The Navy is developing global weather, ocean, and sea ice prediction models at the seasonal (months) timescale as well as exploring new platforms for sustained observational capability in the Arctic. The Department of the Navy also released its Climate Action 2030 report in 2022.
- The Air Force published its Climate Action Plan (DAF CAP) in October 2022 and is currently finalizing its Climate Campaign Plan, which is the implementation plan for the DAF CAP.
- The Navy and the Air Force are collaborating with U.S. interagency partners on Earth system modeling, developing the next generation of predictive models.
- Since FY2019, the Office of the Deputy Assistant Secretary of Defense, Environment and Energy Resilience continues to evolve the DoD Climate Assessment Tool (DCAT). This tool is a Department-wide screening-level climate hazard assessment tool based on an existing geospatial tool developed by the U.S. Army Corps of Engineers (USACE) for the Department of Army (Office of the Assistant Secretary for the Army for Installations, Energy, and Environment). DoD is enhancing DCAT and expanding the installations included in the tool to assess exposure to climate and weather impacts.
- 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 multiscale models; and advanced software tailored to models that can be ported to DOE's fastest supercomputers. DOE also invests in 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 greenhouse gas 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 and sustainability of the U.S. transportation sector include the following:

- The Federal Aviation Administration (FAA) is working on many fronts to address concerns related to climate change. The FAA is following a whole of government

approach described in the United States Aviation Climate Action Plan to put the sector on a path towards achieving net-zero emissions by 2050. This plan outlines efforts being taken across the Federal Government to reduce emissions through new technologies, sustainable aviation fuels, and improved operational procedure concepts. The FAA is also working through their university partners to understand the impacts of aviation activity on climate change and to evaluate and mitigate the risks of sea level rise and other impacts of climate change on FAA infrastructure and the ability to safely operate the National Airspace System. FAA is leading an effort to develop an implementation plan for a national airport strategy to provide a top-down framework for investments in airport infrastructure, including resilience.

- The Federal Highway Administration (FHWA) and the Federal Transit Administration (FTA) are working with States, public transportation agencies, and metropolitan areas to improve the condition and increase the resilience of the Nation's Highways and public transportation systems, respectively, and to reduce greenhouse gas emissions. FHWA and FTA are supporting transportation agencies through ongoing programs that include assessing vulnerabilities; considering resilience in the transportation planning process; incorporating resilience in asset management plans; addressing resilience in project development and design; optimizing operations and maintenance practices; and deploying alternative fuel vehicle infrastructure. FTA and FHWA are also working to ensure that resilience is considered when rebuilding damaged transportation infrastructure after a natural disaster.

- The Federal Railroad Administration (FRA) challenged the rail industry to meet net-zero greenhouse gas emissions by 2050 and is working with the rail industry to transition from fossil fuels for locomotives to zero emissions technologies. FRA's activities include coordinated research into the safety of zero emission locomotive technologies and grant funding for the purchase of cleaner, more efficient and zero emissions locomotives. Through the historic funding in the Bipartisan Infrastructure Law, FRA is expanding and improving passenger rail access which provides lower-carbon dioxide options for intercity transportation. FRA is leading research into, among other things, emissions from maintaining and constructing the rail network and the embedded carbon in rail products. In addition, FRA is evaluating and exploring opportunities to make the national rail network more resilient and assure infrastructure investments are built to withstand future climate change impacts.

- The Maritime Administration (MARAD), through the Maritime Environmental and Technical Assistance (META) program has been actively supporting research and development efforts focused on maritime decarbonization, emissions reductions, and energy efficiency for several years. Through this effort, the META program collaborates with government, industry, and academic partners to advance knowledge on "what works" for the various components of the maritime sector as it addresses the challenge of greenhouse gas emissions reduction. Results from META's efforts support U.S. domestic and international policy mechanisms. Complementary to META's efforts, MARAD's Office of Ports and Waterways has been collaborating with various federal agencies (e.g., EPA, NOAA, FHWA) to account for greenhouse gas emissions and other environmental impacts associated with port infrastructure development and related activities.

- The Pipeline and Hazardous Materials Safety Administration (PHMSA) Offices of Pipeline Safety (OPS) and Hazardous Materials (OHMS) are conducting research projects that address safety, environmental sustainability, and climate change. OPS is conducting research to promote safer systems for underground gas storage and liquefied natural gas facilities, as well as research related to the use and transport of hydrogen and hydrogen/natural gas blended fuels by pipeline. In addition, OPS is hoping to reduce methane emissions by sponsoring advanced research in methane detection and leak

control. OHMS also focuses on hazardous materials packaging, particularly ways to reduce risks related to the transport of lithium batteries, and new packaging needed to address hazards associated with emerging energy technologies.

- The Office of International Transportation and Trade engages bilaterally and multilaterally to foster a zero-emission global transformation that addresses climate mitigation, adaptation, and resilience through standards, policies, strategies, research, trade promotion, and technical cooperation and assistance.

- The Office of the Assistant Secretary for Research and Technology is working in partnership with FHWA and three Metropolitan Planning Organizations—Hampton Roads, Hillsborough, and Houston Galveston—to develop the Resilience and Disaster Recovery (RDR) Tool Suite. The first public version of the RDR Tool suite was released in August 2022. The tool suite will assist transportation agencies in infrastructure investment planning and prioritization across a range of uncertain future hazards. The RDR Tool Suite utilizes the robust decision-making concept, incorporates a benefit–cost analysis, ranks projects based on economic return, and demonstrates the benefits of reduced repair cost to promote faster recovery that helps improve roadway network connectivity. The partnership is currently working to enhance the tool suite to include transit and equity considerations.

- The Office of the Assistant Secretary for Research and Technology 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 modeling 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) 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 to protect human health and the environment and statutory requirements, and includes: 1) improving scientific understanding of global change effects on air quality, water quality, ecosystems, and human health in the context of other stressors; 2) assessing and defining adaptation options to effectively prepare for and respond to global change risks, increase resilience of human and natural systems, and promote their sustainability; and 3) developing an understanding of the potential environmental and human health impacts of greenhouse gas 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, understand, and minimize the vulnerabilities to and 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

The National Aeronautics and Space Administration's (NASA) global change activities span the entire Earth Science Division, from satellite observations and technology development to research and analysis, informing real-life applications of NASA 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 human communities.

As of January 2023, NASA's portfolio includes 25 missions in operation, the combined measurements of which enhance our understanding of our changing planet. These include 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 conservation, 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. A major effort this year is the Transform to Open Science (TOPS) initiative, which is a significant component of NASA's contribution towards the Biden Administration's Year of Open Science, announced on January 11, 2023.

To help us understand the distribution of water on Earth, including in the ocean and on land, NASA recently launched the Surface Water Ocean Topography (SWOT) mission, a joint project of NASA and the National Centre for Space Studies (CNES) in France (with contributions from the Canadian Space Agency and United Kingdom Space Agency). SWOT launched from Vandenberg Air Force Base in California aboard a SpaceX Falcon 9 rocket on December 16, 2022. As NASA's first open-science compliant science team, SWOT mission team will be releasing pre-validated data sets after the completion of the calibration phase in Fall 2023 to welcome input from a broader science community, followed by a release of fully validated data

sets in Spring 2024.

Additional recent launches included the latest in the series of Landsat satellites (Landsat 9), a joint project of NASA and the US Geological Survey (USGS), part of the Department of Interior, to continue the more than 50-year record of land cover observations that serve as the basis for studies of subjects like tropical deforestation and global forest dynamics, urban expansion, water use, coral reef degradation, glacier and ice-shelf retreat, natural and man-made disasters, and climate change.

Landsat 9 launched from Vandenberg Space Force Base on September 27, 2021, aboard an Atlas V401 launch vehicle. The next mission in the Landsat series (Landsat Next) entered formulation in November 2022.

The Earth Surface Mineral Dust Source Investigation (EMIT), which will map the surface mineralogy of arid dust source regions via imaging spectroscopy in the visible and short-wave infrared (VSWIR), was launched to the International Space Station (ISS) on July 14, 2022, on a SPACE-X Dragon spacecraft, and successfully docked to the ISS on July 16, 2022. The maps of the source regions will be used to improve forecasts of the role of mineral dust in the radiative forcing (warming or cooling) of the atmosphere. EMIT has also demonstrated its capability to measure distributions of the greenhouse gases such as carbon dioxide and methane in source regions, with a particular emphasis on "methane super-emitters" for which data were made available beginning in late 2022 from the NASA/USGS Land Processes Distributed Active Archive Center (DAAC) in South Dakota.

In the recent past (November 2021), NASA selected the latest in its series of Earth Venture satellites, the Investigation of Convective Updrafts (INCUS) mission to study the behavior of tropical storms and thunderstorms, including their impacts on weather and climate. The mission will be a collection of three SmallSats, flying in tight coordination. The principal investigator for INCUS is Susan van den Heever at Colorado State University in Fort Collins. The mission will be supported by several NASA centers including the Jet Propulsion Laboratory in Southern California, Goddard Space Flight Center in Greenbelt, Maryland, and Marshall Space Flight Center in Huntsville, Alabama, with key satellite system components to be provided by Blue Canyon Technologies, and Tendeg LLC.

The next major satellite launch for NASA's Earth Science program is Tropospheric Emissions: Monitoring of Pollutants (TEMPO), currently expected in the spring of 2023. The TEMPO instrument is a UV-visible spectrometer and will be the first ever space-based instrument to monitor air pollutants hourly across the North American continent during daytime. It will collect high-resolution measurements of ozone, nitrogen dioxide and other pollutants, data which will revolutionize air quality forecasts. The principal investigator for TEMPO is Kelly Chance of the Harvard Smithsonian Astrophysical Observatory. The TEMPO instrument will fly aboard a commercial geostationary communications satellite as a hosted payload, with launch provided by a SPACE-X Falcon-9 rocket. Also due to launch in 2023 are the four satellites that constitute the Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS) mission. TROPICS will measure temperature and humidity soundings and precipitation with spatial resolution comparable to current operational passive microwave sounders but with unprecedented temporal resolution. The TROPICS principal investigator is William Blackwell of the Lincoln Laboratory of the Massachusetts Institute of Technology. TROPICS will be launched by Rocket Lab USA as part NASA's Venture-class Acquisition of Dedicated and Rideshare (VADR) launch services contract.

NASA has continued the process of moving forward with the Earth System Observatory (ESO). This observatory is comprised of an integrated set of missions that includes the Designated Observables identified by the National Academies of Science, Engineering, and Medicine (NASEM) in their 2018 Decadal Survey for Earth Science, Thriving on Our Changing Planet:

A Decadal Strategy for Earth Observation from Space, as well as the NASA-Indian Space Research Organization Synthetic Aperture Radar (NISAR) mission, targeted for launch in 2024. Individually, these missions deliver important environmental measurements. Taken together, as a single Observatory, these missions will provide unprecedented ability to study Earth's interacting components and the relationship of human-induced and naturally occurring processes in shaping Earth's present and future. In addition, the NASA Earth System Observatory will include a new, competed Earth System Explorer line involving competitive opportunities for medium-sized instruments and missions. Key Decision Point reviews were held to allow two of the ESO missions (Surface Biology and Geology, Atmospheric Observing System) to move into formulation. The Mass Change mission is expected to enter formulation in 2023.

NASA continues to conduct numerous field campaigns using surface-based measurements, aircraft, and ships and to support several surface-based measurement networks. Among the most notable field experiments carried out recently was the Convective Processes Experiment – Cabo Verde (CPEX-CV) in the summer of 2023, using NASA's DC-8 aircraft and a collection of remote sensing instruments and dropsondes to study the dynamics of convection in the tropical and subtropical eastern Atlantic Ocean, including the influence of dust blown westward over the Atlantic Ocean from the Saharan desert. The campaign not only addressed this fundamental atmospheric process, but also provided correlative and complementary information for the European Space Agency's Aeolus satellite, the first satellite measuring atmospheric wind profiles. NOAA and the Department of Defense (Naval Research Laboratory) participated in the mission, and data was delivered in near-real time to meteorological forecasting and modeling centers globally for operational support. Numerous other campaigns included those associated with the third Earth Venture Suborbital program. In summer 2023, a major campaign will be the joint NASA/NOAA Synergistic TEMPO Air Quality Science (STAQS) campaign to measure air quality over three US cities (Los Angeles, New York, and Chicago) using three NASA aircraft and a variety of in situ and remote sensing instruments. These data will complement and correlate with the TEMPO data that will come available during that time period. NASA also plans to fly the Biodiversity Survey of the Cape (BioSCape) airborne campaign in southwestern South Africa, October through December 2023. BioSCape will feature 16 teams of U.S. and South African investigators, two NASA aircraft carrying three imaging spectrometer (hyperspectral) instruments and a laser-scanning lidar, and a large number of in-situ sensors, all to study the distribution and abundance of biodiversity, the role of biodiversity in ecosystem function, and the impacts of biodiversity change on ecosystem services within a global biodiversity hotspot.

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 represent 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) supports research and activities to address diverse global change challenges across many sectors. USAID partners with dozens of countries to strengthen capacity and governance and create the legal and regulatory environments needed to improve development outcomes in the face of global change.

USAID carries out development activities that are guided by the Agency's Climate Strategy. The strategy lays out a whole-of-Agency approach, calling upon each operating unit to contribute to objectives and targets which include (by 2030): supporting at least 80 Nationally Determined Contributions or National Adaptation Plans, reducing 6 billion tons of carbon dioxide

equivalent (CO2e) emissions globally, enabling the improved climate resilience of 500 million people, and increasing equitable engagement of critical populations (including Indigenous People and local communities, women, and youth) in 40 partner countries.

The Agency administers specific funding streams to address the climate crisis. These funds are used to assist partner countries as they adapt to the impacts of climate change, reduce greenhouse gas emissions from land (for example, by avoiding deforestation and conserving peatlands), and advance clean energy economies. The Agency prioritizes addressing global change to ensure the well-being of populations at significant risk of harm from global change.

USAID recognizes the critical need for global change research and analysis in many areas including global health, biodiversity loss, ocean plastics, agriculture, and migration. The Agency's Learning Agenda—one type of research—strengthens development outcomes by increasing the quantity and quality of data available to help test and refine theories of change. These data are typically shared within the U.S. Government and with external partners. USAID uses theories of change to design activities. These depend on our understanding of relationships between current conditions and the results expected from a proposed intervention. USAID is continually monitoring progress, revising our understanding of those relationships, and using the lessons learned to adjust programming. In this vein, USAID:

- supports research and interventions to stem large-scale changes that are transforming Earth's capacity to support life and driving ecosystem and biodiversity decline and ocean warming and acidification.

- invests in the integration of climate data into early warning systems, including for flood, drought, and malaria. Early warning systems for malaria are building on research originally funded by NIH.

- partners with more than 50 countries to support people, communities, and larger populations in developing systems to anticipate, prepare for, and adapt to current and future climate impacts.

- enables inclusive landscape planning, emissions disclosure, and international financing so that local and international stakeholders establish low-emissions value chains for commodities that drive deforestation.

- confronts ocean plastics pollution at the source by encouraging private sector investment in solid waste management systems and, with local partners, strengthening policies and incentives to recover and divert plastic waste from landfills.

- supports pilot programs to identify and scale the most effective approaches for addressing air pollution in developing countries, advancing solutions that deliver climate, health, and development benefits.

- helps partner countries deploy clean energy technologies that can sustainably power economic and social development.

- supports efforts to reduce threats from increased interaction between humans and animals (wild and domesticated), including infectious disease threats on-farm and in markets; advance interventions in communities at high-risk for viral spillover; and related behavioral change research.

USAID also supports activities that conduct research on topics such as:

- estimating and accounting for land-based carbon stocks and greenhouse gas fluxes
- the role of forests in food security
- diverse aspects of agriculture and the food system, including the development and deployment of climate resilient crop varieties, innovative technologies for water management, and research on other climate-smart agricultural practices
- linkages between participatory natural resources management and democratic outcomes
- connections between wildlife trafficking and zoonotic disease transmission

USAID is committed to advancing the impact of development programs by strengthening the leadership of, and improving development outcomes for, populations that are often at the greatest risk of the impacts from global change. These may include poor and ultra-poor households, women and girls, persons with disabilities, LGBTQI+ people, displaced persons, migrants, Indigenous Peoples and local communities, children in adversity and their families, youth, older persons, religious minorities, ethnic and racial groups, people in lower castes, persons with unmet mental health needs, and people of diverse economic class and political opinions.

ACRONYMS

AmeriGEO: Americas Group on Earth Observations

AR6: Sixth Assessment Report

ARTMIP: Atmospheric River Tracking Method Intercomparison Project

ASCC: Adaptive Silviculture for Climate Change

BOEM: Bureau of Ocean Energy Management

CDC: Centers for Disease Control and Prevention

CDLN: Caribbean Drought Learning Network

CCHHG: Interagency Crosscutting Group on Climate Change and Human Health

CCIWG: Carbon Cycle Interagency Working Group

CEQ: Council on Environmental Quality

CMIP: Coupled Model Intercomparison Project

CoastsIG: Coasts Interagency Working Group

CRA: Collaborative Research Action

CRT: Climate Resilience Toolkit

CRIS: Climate Resilience Information System

DCPO: White House Office of Domestic Climate Policy

DHS: Department of Homeland Security

DoD: Department of Defense

DOE: Department of Energy

DOI: Department of the Interior

DOS: Department of State

DOT: Department of Transportation

EPA: Environmental Protection Agency

FARG: Federal Adaptation and Resilience Group

FEMA: Federal Emergency Management Agency

FWS: U.S. Fish and Wildlife Service

FY: Fiscal Year

GCIS: Global Change Information System

GCRA: Global Change Research Act

GEO: Group on Earth Observations

GOES: Geostationary Operational Environmental Satellites

GPEX: Global Precipitation Experiment

HHS: Department of Health and Human Services

IAIWG: International Activities Interagency Working Group

IGIM: Interagency Group on Integrative Modeling

IPCC: Intergovernmental Panel on Climate Change

LACI: Initiative for Enhancing Capacity for Climate Risk Assessment and Catalyzing Partnerships to Inform Decisions in Latin America and the Caribbean

MBON: Marine Biodiversity Observation Network

NACP: North American Carbon Program

NASA: National Aeronautics and Space Administration

NASEM: National Academies of Sciences,

Engineering, and Medicine

NCA: National Climate Assessment

NCO: USGCRP National Coordination Office

NCSMMN: National Coordinated Soil Moisture Monitoring Network

NIHHIS: National Integrated Heat Health Information System

NIST: National Institute of Standards and Technology

NOAA: National Oceanic and Atmospheric Administration

NPS: National Park Service

NSF: National Science Foundation

NWS: National Weather Service

ObsIWG: Observations Interagency Working Group

ONR: Office of Naval Research

OSTP: Office of Science and Technology Policy

RISCC: Regional Invasive Species and Climate Change Management Networks

SAWG: Sustained Assessment Working Group

SGCR: Subcommittee on Global Change Research

SI: Smithsonian Institution

SOCCOM: Southern Ocean Carbon and Climate Observations and Modeling

SSCC: Social Sciences Coordinating Committee

START: SysTem for Analysis, Research, and Training

TRACER-AQ: Tracking Aerosol Convection interactions ExpeRiment – Air Quality

USACE: U.S. Army Corps of Engineers

USAID: U.S. Agency for International Development

USDA: U.S. Department of Agriculture

USDA-FS: U.S. Department of Agriculture Forest Service

USGCRP: U.S. Global Change Research Program

USGS: U.S. Geological Survey

WCRP: World Climate Research Programme

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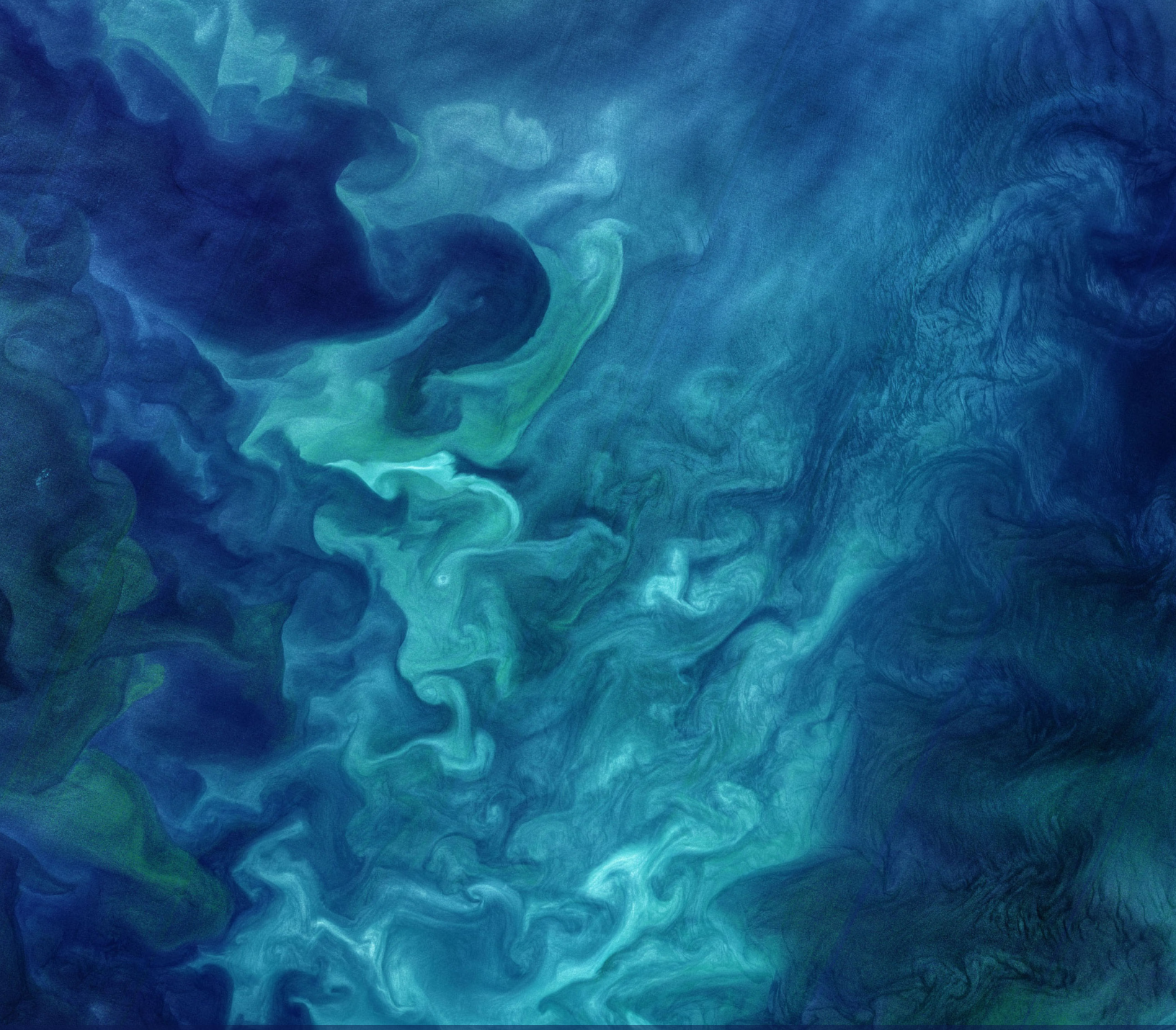

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