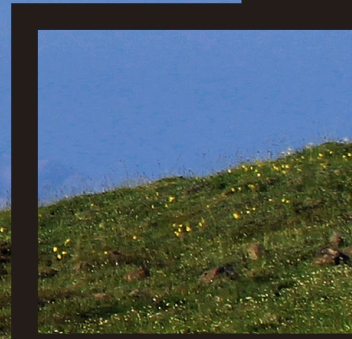




U.S. Global Change
Research Program

OUR CHANGING PLANET



THE U.S. GLOBAL CHANGE RESEARCH PROGRAM FOR FISCAL YEAR 2024

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 2024



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Please view the digital version for hyperlinks to additional information.

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 2024 edition of *Our Changing Planet* provides a summary of programmatic achievements, recent progress, and budgetary information for USGCRP. It thereby meets the requirements set forth in the U.S. Global Change Research Act of 1990 (Section 102, P. L. 101-606) to provide an annual report on federal global change research priorities and programs. It does not express any regulatory policies of the United States or any of its agencies or make any findings that could serve as predicates for regulatory action.

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U.S. GLOBAL CHANGE RESEARCH PROGRAM

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EXECUTIVE SUMMARY

The impacts of climate change are intensifying across the country, requiring leaders at all levels of government to build resilience in the face of unprecedented climate disruption. Climate change is compounded by other profound challenges to our shared environment and nature, collectively known as global change. As a nation, we face urgent questions about how we can take action to reduce risks while building a healthy, prosperous, and sustainable future for all.

The [U.S. Global Change Research Program \(USGCRP\)](#) advances global change science and informs our national response to the climate crisis—from President Biden’s climate, environmental justice, and nature priorities to decisions at all levels of government and society. *Our Changing Planet: The U.S. Global Change Research Program for Fiscal Year 2024* presents highlights of USGCRP’s recent accomplishments, outlines federal investments in global change research, and sets future priorities for federal global change research as USGCRP implements its [2022-2031 Strategic Plan](#).

This report demonstrates USGCRP’s commitment to empower the nation and the world to anticipate and respond to urgent risks of climate and global change by:

Expanding Participation in the Federal Global Change Research Enterprise

In February 2023, the Department of Homeland Security (DHS) became the [first new member of USGCRP in almost 20 years](#), expanding USGCRP’s membership to better meet national needs. DHS will work with USGCRP’s member agencies to leverage scientific research in achieving several of the Department’s mission areas, including strengthening preparedness and resilience.

USGCRP is working with departments and agencies that need global change information to serve their constituencies, and with external organizations that develop and use global change information, to both inform decisions and improve understanding of science needs. Interagency efforts are strengthening partnerships and supporting peer-to-peer learning around resilience and climate risk assessment, while outreach and workforce development efforts within and across agencies are helping to develop a more climate-informed workforce for the U.S. government.

New interagency data and information tools, accompanied by outreach and training, are supporting broader use of climate and global change information in planning and implementation of resilience, adaptation, and mitigation efforts within federal agencies and at the state, Tribal, and local government levels.

Advancing Global Change Research and Assessments

USGCRP’s Strategic Plan calls for increased exploration of broader global changes that interact with climate change—fulfilling USGCRP’s mandate to monitor, assess, and predict changes in the global environment.

Nature loss is a critical component of global change, shaping our ability to cope with climate change and other challenges. In 2022, USGCRP initiated the [First National Nature Assessment](#) (NNA1), to provide a holistic picture of how nature and its benefits to society are changing, and what it means for our economy, health, equity, climate mitigation and adaptation, and national security. NNA1 will draw on expertise from across the country and input from extensive public engagement to ensure that its products are both useful and usable. The Assessment will follow principles of a use-inspired, knowledge-informed assessment, shaped by both by the potential uses of the final products and by science and other forms of knowledge.

Other interagency work is supporting collaborative efforts to monitor and understand ecosystem change and explored nature-based solutions that boost climate resilience while restoring and protecting natural ecosystems and the benefits they provide. Efforts surrounding these topics are ongoing and will continue to be included in interagency planning and work for the near future.

Enhancing the Impact of Federal Global Change Research

In November 2023, USGCRP released the [Fifth National Climate Assessment](#) (NCA5), which provides the latest information on climate change impacts, risks, and responses in the United States (USGCRP, 2023). NCA5 was written by hundreds of experts, with extensive input from the public and peer reviewers throughout its development. The report will provide the basis for outreach, education, engagement, and decision-support efforts throughout Fiscal Year 2024 and beyond. Through enhanced public engagement and new report features and related resources, USGCRP continues to improve inclusion and accessibility in NCA development processes and products.

USGCRP is also expanding cooperation with international organizations, initiatives, and research networks. Collaborative efforts include strengthening capacity for climate risk and vulnerability assessment and carbon inventory and management in partner countries, as well as advancing key precipitation science and prediction capabilities.

Climate change impacts pose increasingly urgent risks to our health and well-being, driving demand for more specific and complex climate information and services. In spring 2023, USGCRP expanded its role to include coordination of a federal climate services framework that aims to improve federal capacity to deliver accessible, usable knowledge and information about the climate and how it is changing.

Future climate services efforts in Fiscal Year 2024 and beyond will advance translation of basic science into actionable climate information through common data platforms and decision support tools; leverage and empower regional applied science and service organizations to increase accessibility and usability of climate services; and enhance understanding of co-production processes so that climate services better incorporate communities and decision-makers.

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.” USGCRP builds scientific knowledge and makes it useful to governments, communities, businesses, and individuals as they integrate climate and global change information into their planning and take actions to build resilience.

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. The main focus areas related to global change research for each agency are provided in [Appendix 1. About the U.S. Global Change Research Program.](#)



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 Homeland Security; 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.

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 the goals of its [Strategic Plan](#) (USGCRP, 2022).

By finding alignments between the missions of its agencies and national needs, the Program coordinates federal investments in global change research and enables the use of data and knowledge in operations and decision-support capabilities across the nation and the world.

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, overseen by the [White House Office of Science and Technology Policy](#). The SGCR coordinates inter-agency activities through the USGCRP National Coordination Office and USGCRP's [12 Interagency Groups](#). The Interagency Groups bring agencies together to plan and implement research and related activities, spanning a range of climate and global change issues and approaches to understanding and informing responses to a changing environment (see [Program Structure](#)).

Information on program history and structure and the principal focus areas related to global change research for each member agency are available in [Appendix 1. About the U.S. Global Change Research Program](#).



IN THIS REPORT

As a supplement to the President's Fiscal Year 2024 (FY2024) Budget Request, this report highlights select Program accomplishments from calendar year 2022 and provides an outlook on FY2024 activities and priorities (see [Priorities for Future Global Change Research](#)). Highlighted accomplishments represent coordinated investments of two or more member agencies that contribute to meeting USGCRP's strategic goals.

USGCRP's scope includes, but is not limited to, agency programs represented in the budget crosscut, and the efforts described in this report are subset of overall Program accomplishments. A summary of annual agency expenditures under USGCRP's budget crosscut is provided in the [Budgetary Information](#) section.

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 and global change research.

2022 PROGRAM ACCOMPLISHMENTS

ADVANCING SCIENCE

Goal: *Advance scientific knowledge of interconnected natural and human systems and risks to society from global change.*

Federal investments in basic science help the nation and the world understand the interconnected Earth system, how it is changing due to human and natural influences, and how society can manage risks from environmental change. Earth system observations, modeling, process studies, and the social sciences capture changes in human and natural systems and provide insight into what future change means for society. USGCRP facilitates integration across disciplines to improve understanding of complex interactions among human and natural systems responding to change.

This section highlights interagency research activities that are advancing fundamental knowledge of global change processes.

Earth Observations

Observation-based understanding of the changing Earth system provides the foundation for Earth system models that allow researchers to understand and project future change in interconnected human and natural systems. Earth observations also provide the basis for decision-support tools that inform efforts to reduce greenhouse gas emissions and address the impacts of sea level rise, changing wildfire risk, intensifying extreme weather events, changes in ecosystems and biodiversity, and other global changes.

USGCRP agencies conduct Earth system observations at various spatial and temporal scales through satellite remote sensing and surface-based, in-water, in-ground, and airborne networks. Short-term field campaigns provide deeper understanding of processes on local scales that can affect climate or other systems at local to global scales. USGCRP agencies also track the status of and changes in diverse and dynamic human systems through observations of land use, health, economic activity, resource development and use, and other measures.

USGCRP's **Integrated Observations Interagency Working Group** (ObsIWG) facilitates coordination of observing 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.



2022 HIGHLIGHTS - OBSERVATIONS

Integrated Observations Interagency Working Group updates

In 2022, USGCRP's **ObsIWG** continued its [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. In fall 2022, USGCRP's **Coasts Interagency Group** collaborated with ObsIWG on a [seminar focused on coastal and ocean observation gaps](#) identified by Fifth National Climate Assessment authors.

Coordinated observations in the Upper Colorado River Basin support improved prediction of water resources from mountainous regions

Mountains are vital headwaters to many rivers, supplying a significant amount of the fresh-water used by the Earth's population. Predicting water supply in mountainous regions is especially challenging due to their complex terrain, and continued climate changes are expected to significantly impact water availability for millions of people. The Colorado River Basin, a primary source of water for much of the southwestern United States, is estimated to see reductions in runoff ranging between 10% to nearly 50% by mid-century, raising concerns about its long-term reliability as a critical water source. Snowmelt in the Rocky Mountain headwater region is the primary contributor of annual streamflow and water reservoir storage in the basin, but surface observing systems in the region are limited, and existing systems do not capture important land and atmospheric variables at fine enough scales to accurately predict the timing and availability of water resources.



An X-band precipitation radar (XSAPR) is pictured on Crested Butte Mountain in Colorado as part of the SAIL (Surface Atmosphere Integrated Field Laboratory) campaign. Source: image courtesy of the DOE Atmospheric Radiation Measurement (ARM) user facility.

To help improve understanding and prediction of water availability in the region, a suite of observational campaigns in the East River Watershed of the Upper Colorado River Basin is collecting detailed measurements of atmospheric and land-atmosphere interaction processes that impact mountain hydrology and runoff into the basin. The DOE-led [SAIL](#) (Surface Atmosphere Integrated Field Laboratory) and the NOAA-led [SPLASH](#) (Study of Precipitation, the Lower Atmosphere and Surface for Hydrometeorology) field campaigns coordinated a network of state-of-the-art observational sites from fall 2021 through summer 2023 in a remote headwater region in the Colorado Rocky Mountains. These atmospheric-focused observations were coordinated with long-term DOE research activities focusing on the terrestrial and hydrological processes of the watershed. Measurements include near-surface air temperature, cloud properties, precipitation amount, soil moisture, surface heat flux,

snow depth, and complex interactions between the surface and lower atmosphere that help to regulate evaporation of surface moisture and snow. Additional observations focusing on [snow-pack properties](#) were supported by NSF.

Initial results include analyses of a series of wintertime precipitation events that impacted the region in winter 2021-2022, including an extreme snowfall event in late December 2021; studies of aerosol properties and impact on precipitation and snow reflectivity; and the role of the North American monsoon on warm season precipitation. In addition, results include evaluation of a model's ability to capture the impact of changes in the Earth's surface energy balance during the seasonal snow cover transition on the vertical structure and circulation of the lower atmosphere. Ultimately, these advances will contribute to improving prediction capabilities of weather models and Earth System Models in complex terrain.

Observing campaign to provides new understanding of how high-altitude aerosols affect the climate

Stratospheric aerosols are tiny particles high in the atmosphere that play a role in Earth's climate by reflecting solar radiation, leading to a slight cooling. They also facilitate chemical reactions that reduce stratospheric ozone, which protects life on Earth from harmful ultraviolet solar radiation. Improved understanding of the processes that regulate the size, number, and distribution of stratospheric aerosols and their impacts on climate is essential to informing policy considerations around ozone-depleting substances, emissions into the stratosphere from rockets and aircraft, and proposed methods of solar radiation management that involve injecting aerosols or aerosol-forming gases into the stratosphere to limit human-caused climate change.

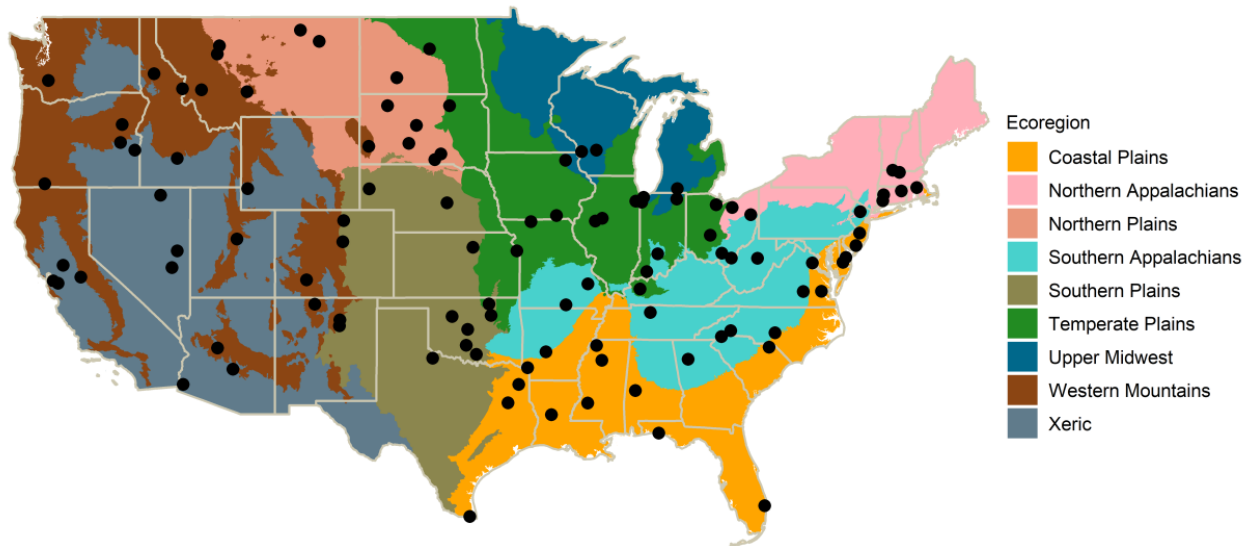
The NOAA [SABRE](#) (Stratospheric Aerosol processes, Budget and Radiative Effects) project is an extended airborne measurement program to collect the most detailed observations to date of gases and aerosols in the stratosphere. SABRE is funded by NOAA Earth's Radiation Budget Initiative, with support from NASA, particularly through the use of a NASA WB-57F high-altitude

research aircraft. The initial project phase includes four deployments to targeted regions throughout the globe over the span of a few years. Successful campaigns were conducted in 2022 from NASA JSC Ellington Field in Houston, TX, for initial test flights, and in 2023 from Eielson AFB near Fairbanks, AK, for high-latitude winter sampling. Upcoming deployments are planned to study the tropics and Southern Hemisphere. SABRE measurements are primarily made by NOAA, with NASA and several university groups providing additional key observations that are not within NOAA’s current capabilities. SABRE data will enable more accurate quantification of the climate and chemistry impacts from variations in stratospheric aerosols and gases in the present-day atmosphere and provide a foundation for improving global modeling of stratospheric aerosols in order to predict aerosol effects on the climate under future climate change scenarios.

Measurement of greenhouse gas emissions from U.S. reservoirs improves annual emissions inventory

Emissions inventories that identify each country’s sources and sinks of anthropogenic greenhouse gases are essential tools for addressing climate change. In accordance with the United Nations Framework Convention on Climate Change, the U.S. Government develops an annual report that tracks U.S. greenhouse gas emissions and sinks by source, economic sector, and greenhouse gas, going back to 1990. Emissions from reservoirs used for water storage are included in these inventories since reservoirs are human made; after lands are flooded through construction of a dam, decomposition of organic matter and accumulation of upstream sediment produces the greenhouse gases carbon dioxide and methane.

To improve incorporation of this data into the annual emissions survey, scientists at EPA, USGS, and DOE are collaborating to measure carbon dioxide and methane emissions from 108 U.S. reservoirs. [The Survey of Reservoir Greenhouse Gas Emissions \(SuRGE\)](#), taking place from 2020 through 2023, will inform a greater understanding of the amount of greenhouse gases emitted from U.S. reservoirs and the environmental factors that determine the rate of these emissions. For the first time, the [Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2020](#), published in 2022, included carbon dioxide and methane emissions from lands converted to use as reservoirs and other constructed water bodies (EPA, 2022). Additional survey results will inform future research modeling efforts and provide information to help water quality managers improve water quality while helping reduce greenhouse gas emissions.



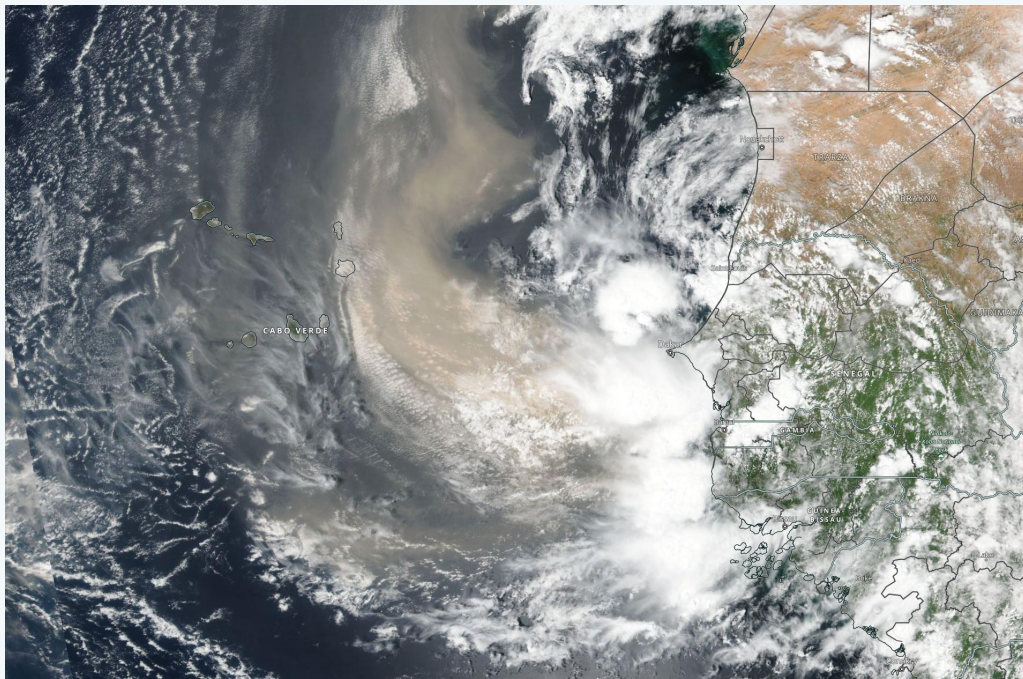
U.S. reservoirs being sampled for the Survey of Reservoir Greenhouse gas Emissions (SuRGE). Source: EPA.

Airborne campaign investigates the origin of hurricanes in the eastern Atlantic Ocean

As dust moving off the Sahel and Sahara regions of Africa mixes with tropical clouds over the eastern Atlantic Ocean, rainy weather systems known as disturbances emerge. These tropical disturbances are often the seedlings for Atlantic hurricanes. By studying the origins of these disturbances in the eastern north Atlantic Ocean, scientists can better understand how they interact with individual cloud systems, may be dissipated by Saharan air and dust, and ultimately why they may or may not turn into powerful storms in the western Atlantic.

The [Convective Processes Experiment - Cabo Verde](#) (CPEX-CV) was a joint project between NASA and the European Space Agency, in coordination with NOAA's National Weather Service (NWS) and DoD's Naval Research Laboratory, to collect detailed measurements in the region using airborne instrumentation. Operating in September 2022, research flights launched daily from Sal Island, Cabo Verde, in the eastern Atlantic Ocean off the coast of western Africa. Observations captured details of how winds, dust, moisture, clouds, and the ocean interact to either build or prevent intensification of tropical disturbances that have the potential to become hurricanes. Data were delivered to operational weather forecasting centers globally, including those in the NWS, and used to aid in hurricane forecasting. Additionally, this field campaign collected data that are helping researchers examine the roles and significance of small-scale wind and turbulence features as mechanisms to transport dust particles long distances. This information will help improve understanding of the relationship between dust and the ability of tropical disturbances to turn into cyclones, with the aim of better characterizing and modeling how those processes might vary in a future climate state.

This information is feeding back to improve dust transport process representation in the [NASA Goddard Earth Observing System](#) (GEOS). GEOS is a global weather and climate model, capable of running at resolutions down to single-kilometer scales, that actively incorporates aerosols into its physical and microphysical processes.



On September 22, 2022, the CPEX campaign encountered and measured one of the largest dust events that NASA has ever sampled. While the DC-8 Airborne Laboratory captured data with its instruments, the Visible Infrared Imaging Radiometer Suite affixed to the Suomi NPP spacecraft captured the event from space as pictured above. Credit: NASA.

This information will help improve understanding of the relationship between dust and the ability of tropical disturbances to turn into cyclones, with the aim of better characterizing how that relationship might vary in a future climate state and thus influence the formation of tropical cyclones.

High-resolution satellite imagery supports monitoring of a nuisance macroalga in the largest U.S. marine protected area

Marine invasive and nuisance species are important, yet understudied issues faced by natural resource managers and coastal communities worldwide. When managing invasive species, one of the most valuable types of data needed by managers to launch a response is the extent of invasion across the area of interest. Satellite imagery is a useful tool for monitoring and mapping the distribution of invasive or nuisance algal species on coral reefs over the temporal and spatial scales needed for ecosystem management.

In a [recent study](#), NASA, NOAA, USFWS, and academic researchers used visual inspections of high-resolution satellite imagery, in combination with field surveys, to detect the newly discovered nuisance alga, *Chondria tumulosa*, at Manawai (Pearl and Hermes Atoll) in Papahānaumokuākea Marine National Monument, the largest marine protected area in the United States (Fraiola, 2022). Low-reflectivity (“dark”) survey sites were associated with average *C. tumulosa* cover that was seven times higher than nearby higher-reflectivity (“light”) sites. The ability to use satellites for the detection of nuisance or invasive species, such as expansive mats of *C. tumulosa*, provides managers with a valuable tool, especially in remote regions. This research was funded by NSF and the USFWS.

Modeling

USGCRP member agencies develop and use mathematical models to test hypotheses about Earth system behavior, understand how natural and human systems interact, simulate historical change, and project future changes. Earth system models help scientists and decision-makers understand and anticipate the impacts of climate and global change across a range of sectors, including agriculture, energy, water, land use, and national security. USGCRP agencies continue to improve integrated natural and human systems models, model spatial and temporal resolution, and the ability to provide stakeholders with actionable information. 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.

2022 HIGHLIGHTS - MODELING

8th U.S. Climate Modeling Summit supports collaboration across modeling centers

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. Ultimately, the IGIM and the Climate Modeling Summit seek to optimize the investments made by the

federal government in global-scale modeling and to better meet national needs for model-based information, tools, and understanding. The 8th U.S. Climate Modeling Summit was held in August 2022, alongside a technical workshop focused on the water cycle and water security. Workshop presentations and discussions focused on model development and evaluation, observational and modeling insights, and emerging approaches, including ultra-high-resolution modeling and artificial intelligence/machine learning. The [8th U.S. Climate Modeling Report](#) provides a summary (Danabasoglu & Leung, 2022).

New modeling framework aims to enhance exploration of coastal risks

The Coastal Integrated Hydro-terrestrial Modeling (C-IHTM) workstream of USGCRP's **Coasts Interagency Group** is engaging agency principal investigators in the development of a new framework for scenario discovery and model- and data-driven stress-testing. This framework is being developed primarily by principal investigators under the direction and guidance of the C-IHTM workstream, the **IGIM**, and the **Interagency Integrated Water Cycle Group**. The framework will be designed to allow for combining models at different spatial scales and purposes to address a wide range of topics. The status of the work was presented at the American Geophysical Union annual meeting in late 2022.

Future peak flow along the Rio Grande may arrive early due to climate change

The Rio Grande is the primary source of water for more than 13 million people in Colorado, New Mexico, Texas, and northern Mexico, serving irrigation, municipal, and industrial water needs. However, as populations increase and crop patterns change, water demand is increasing at the same as the region is undergoing a decrease in supply due to drought and climate change.

To understand how climate change is expected to affect future water supply in the Upper Rio Grande Basin, which includes parts of Colorado, New Mexico, and western Texas, [a study from DOI and USACE](#) paired a streamflow model with projected climate data (Moeser et al., 2021). Researchers found that by the end of the century, peak runoff on the Rio Grande could arrive a month earlier in the season due to climate change, negatively impacting a watershed where demand already exceeds supply. When peak streamflow occurs earlier than average, it affects

the ability of reservoir managers to store water to meet needs later in the summer when demand is highest. Streamflow projections from the study can be used by water managers to better understand the impacts of climate change on water resources used by farmers, municipalities, and industry, and plan for imbalances between supply and demand.



Upstream image of Lobatos stream gauge on the Rio Grande
Source: USGS.

Improved sea ice analysis and predictions support planning and operations in changing polar regions

The U.S. Navy is working with other USGCRP member agencies to develop innovative sea ice analysis products and improve sea ice predictions that support increased activity in

polar regions as sea ice extent continues to decline. Navy research activities are leveraging the wealth of data provided by [NOAA's Joint Polar Satellite System \(JPSS\)](#) and other satellite programs to improve operational sea ice products and the [CICE model](#), which simulates changes to Arctic sea ice and its interactions with the polar environment over seasonal to decadal timescales (DOE, 2023). Development and maintenance of CICE have been led and coordinated by DOE since the early 1990s, with contributions from NOAA, NASA, NSF, ONR, and many other participants.

In 2022, the Navy developed an improved JPSS [Visible Infrared Imaging Radiometer Suite](#) sea ice algorithm to significantly increase the volume of observational data that can be assimilated into sea ice analysis and prediction systems, a process that helps ensure that models are aligned with real-world conditions as they evolve. Results indicate reduced ice edge errors (or the average distance between forecasted and observed ice extent) of 51% in the Arctic and 89% in the Antarctic region.



Sea ice in the Arctic Ocean. Credit: Patrick Kelley, U.S. Coast Guard.

Navy researchers are also collaborating with USGCRP partners to develop and implement a regional Arctic prediction capability that incorporates interactions among air, sea, land, and ice components, allowing for a fuller picture of how the region is evolving. Researchers are working to couple the CICE model and community [Noah Land Surface Model \(Noah-LSM\)](#) within its Coupled Oceanographic and Atmospheric Mesoscale Prediction System (COAMPS®) to improve operational planning and decision-making. In 2022, the Noah-LSM component in the atmosphere model was updated to include enhanced snow processes for land, land ice, and sea ice areas. These improvements support improved sea ice predictions and a more comprehensive understanding of a rapidly changing Arctic.

Climate-driven changes in heat stress increase extinction risk across some animal populations

Animals that depend on external sources of body heat (for example, fish and reptiles) are known as ectotherms and are especially sensitive to shifts in climate conditions outside the range they are accustomed to. However, risk assessments often focus on changes in average temperature, ignoring the effects of shifts in temperature variability over time on population health. To provide a fuller picture of how heat risks to ectotherm populations might evolve as the climate changes, researchers funded by NSF and NASA integrated fine-scale climate projections from the latest generation of Earth System Models into an ecological model that [simulates the effects of heat stress on 38 globally distributed ectotherm species](#) (Duffy et al., 2022). The study revealed complex regional changes in population stability over the twenty-first century but a universal increase in extinction risk and suggests that temperate species may face higher risk than tropical species. These results highlight the importance of accounting for the effects of projected changes in average temperatures, as well as the variance of temperature, to accurately predict global responses of species to warming.

Global Change Processes

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

2022 HIGHLIGHTS – GLOBAL CHANGE PROCESSES

Carbon Cycle

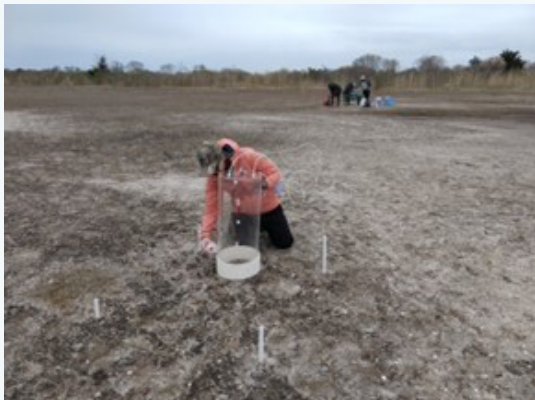
Carbon Cycle Interagency Working Group updates

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. In 2022, the CCIWG's Interagency Carbon Dioxide Removal Coordination workstream compiled information on agency carbon dioxide removal research activities to inform cross-agency discussion. The CCIWG also provided expertise to the newly created Greenhouse Gas Monitoring & Measurement Interagency Working Group (co-led by the Office of Science and Technology Policy, the Office of Management and Budget, and the White House Climate Policy Office), which is working to develop a comprehensive national system to measure, monitor, report, and verify carbon dioxide, methane, and other greenhouse gas emissions and removals from the atmosphere. The system will facilitate the dissemination and availability of validated, science-based greenhouse gas data for use by federal agencies; local, state, and Tribal governments; the private sector; and the public in mitigation efforts.

Field, lab, and remote sensing studies assess greenhouse gas fluxes from drowning and restored wetlands

Coastal salt marshes, found on every coast in the United States, are essential for healthy fisheries, coastlines, and communities. They serve as important habitats, maintain water quality, and sequester carbon from the atmosphere, while also providing protection from storm surge and erosion. As sea level rise accelerates, salt marshes are increasingly vulnerable to drowning and loss, affecting their ability to provide ecosystem services, particularly carbon sequestration. Sediment placement in degraded, low-elevation marshes, typically using nearby dredged sediment, is one option to increase elevation and extend the lifespan of the marsh, increasing resilience to sea level rise.

EPA scientists are collaborating with NOAA, the National Estuarine Research Reserves, Save the Bay, and academic scientists to track how much carbon dioxide and other greenhouse gases are absorbed or emitted from marsh soils and vegetation in drowning coastal marshes and recently restored marshes in Rhode Island. Marshes were previously restored by adding clean dredged sediments to increase elevation and improve resilience (Raposa et al., 2022). In field and lab experiments, researchers examined greenhouse gas and sediment accretion responses to the sediment enhancement techniques. This research effort will improve understanding of



A researcher with a chamber used to measure greenhouse gas absorption by and emissions from marsh soils and vegetation. Source: EPA.

carbon sequestration recovery following application of dredged sediments to drowning marshes.

Coupled with greenhouse gas flux measurements will be marsh recovery metrics, such as plant recolonization and soil characteristics at each site. These measurements are a part of a monitoring program, which also includes measures of fish and crustaceans, birds, sediment accretion, and marsh elevation. The project’s overall goal is to evaluate the performance of marsh restoration efforts and to better inform assessment of marsh health in a changing environment.

Over the past decade, [USGS has integrated field- and remote sensing-based studies](#) to quantify the impacts of climate and land use change on carbon sequestration in both coastal and inland wetlands and to inform

and assess impacts of wetland restoration efforts on federal lands. USGS has worked on and co-funded these studies with a wide range of partners from federal agencies (including USDA, DoD, NSF, SI, NPS, and USFWS), state agencies, academia, non-governmental organizations, and local entities. In 2022, USGS published results of several key studies. For example, one [study](#) demonstrated that hydrologic restoration of coastal wetlands produced elevation gains and enhanced carbon burial capacity (Eagle et al., 2022). [Another study](#) showed that restoration of tidal exchange in coastal wetlands dominated by invasive *Phragmites* (a non-native reed grass) limits methane emissions and enhances their climate regulating benefits (Sanders-DeMott et al., 2022). By quantifying the effects of land use and wetlands restoration on carbon sequestration, the USGS and agency partners are working to support climate action planning at the local, state, Tribal, and national scales.

Biodiversity and Ecosystems

North American tree migration differs from East to West

Suitable habitats for forest trees may be shifting rapidly as the climate changes. These environmental alterations affect important processes in seed production and quality (called fecundity), seedling establishment, and seedling recruitment into larger-sized trees. Previous studies tracking the shift in suitable habitat for forests have been inconclusive, in part because seed production and the subsequent success of the seedlings may have different responses to changes in climate.



A [new analysis of these components at a continental scale](#) using long-term seed production datasets and national-scale forest inventories, conducted by a large team of academic, USDA-FS, and USGS researchers, with

The ability of tree species to adapt to a shifting climate will depend strongly on capacity of natural regeneration to produce viable seeds and seedling recruits; this adaptation will be particularly challenging for species such as longleaf pine (*Pinus palustris*) that are more episodic in their seed production. Credit: Don C. Bragg/USDA-FS.

support from NASA and NSF, reveals an ongoing poleward migration of northern tree species (Sharma et al., 2022). Recruitment and fecundity both contribute to northward spread in the West, while fecundity limits spread in the East. Despite a fecundity hotspot in the Southeast, low fecundity could slow the rate of eastern forest adaptation, which could increase the challenges for managing and conserving forest diversity and structure. Natural resource planning efforts can benefit from knowledge of life-history stages and the species and genetic variants that are best able to tolerate future conditions and sustain mature forests.

Natural infrastructure in dryland streams offer a nature-based solution to boost climate resilience

Nature-based solutions are ecosystem-based approaches to achieve climate mitigation and adaptation goals and combat nature loss. A [new study](#) by USGS, NOAA, and academic researchers evaluates one such approach: natural infrastructure in dryland streams (NIDS) are beaver- or human-made structures of earth, debris, wood, or rock that, when installed in dryland streambeds, can have a range of benefits (Norman et al., 2022). Impacts of NIDS include storing water, sediment, and carbon; creating or restoring wetlands in degraded watersheds of arid landscapes; and sustaining processes and functions that reverse desertification and boost the resilience of stream- and river-based ecosystems to the effects of climate change.

The study is the latest product of the [Sky Island Restoration Collaborative](#), a 10-year binational collective of federal/State government organizations, the San Carlos Apache Tribe, universities, non-governmental organizations, and private landowners working to improve restoration outcomes across the Madrean Sky Islands Ecoregion of the desert Southwest. This research highlights the potential to reverse degradation in large watershed-scale restoration efforts. Widespread implementation of NIDS could have significant effects on the global water and carbon cycles, help mitigate climate change through sequestration of carbon, and improve the resilience of dryland ecosystems to climate change.

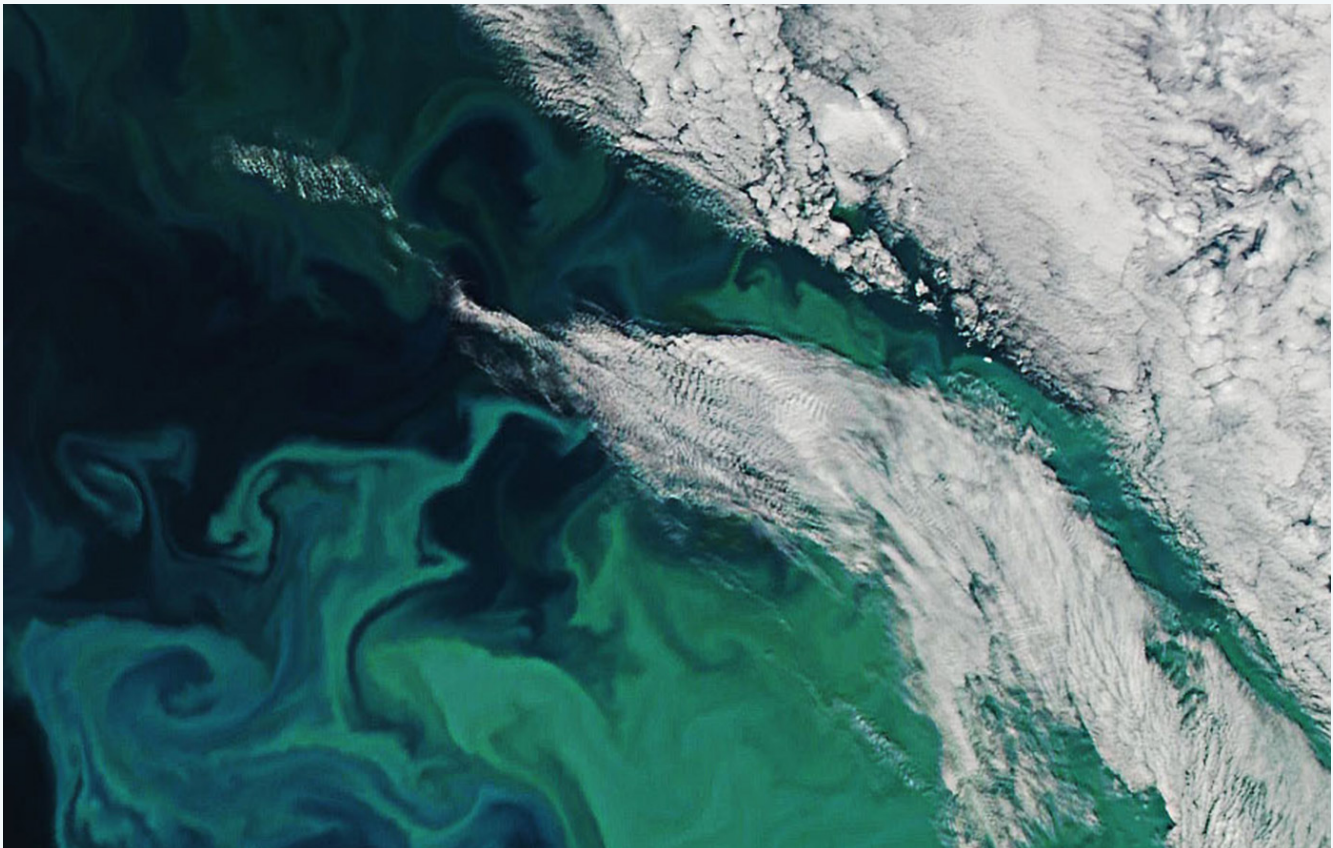


Examples of Natural Infrastructure in Dryland Streams (NIDS), including a) check dams at El Coronado Ranch; b) leaky weir at Cienega Ranch; and c) Zuni Bowl (One-rock Dam) at Cebolla Wilderness Area within the El Malpais National Conservation Area. Source: USGS.

Research partnership links marine biodiversity and ocean carbon, oxygen, and nutrient cycles

Plankton—organisms that drift with ocean currents—are critical to marine ecosystems and are highly sensitive to changes in their environment, including in the temperature, salinity, pH level, and nutrient concentration of the water. [Bio-GO-SHIP](#) is a partnership between NOAA, NASA, and university researchers aiming to develop new understanding of the link between physical and chemical characteristics of ocean water and global ocean plankton diversity, abundance, and biogeochemical roles in the context of a changing ocean.

A global quantification of plankton biodiversity, size, structure, and other important properties offers a series of opportunities for integration between in situ and remote-sensing observations. Since 2007, the [GO-SHIP](#) program has collected repeated ship-based measurements of physical and geochemical properties from the deep ocean to the surface. Bio-GO-SHIP adds biological measurements that will enable researchers to understand how ocean ecology is changing in face of global climate change. Ultimately, Bio-GO-SHIP will provide both scientists and policymakers with a stronger understanding of how the spectrum of marine biodiversity impacts ocean carbon, oxygen, and nutrient cycles, with implications for marine life, fisheries, and global climate.



Phytoplankton blooms in the Barents Sea, acquired with the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Aqua satellite on July 15, 2021. Credit: NASA Earth Observatory image by Joshua Stevens, using MODIS data from NASA EOSDIS LANCE and GIBS/Worldview

Social Sciences

Interagency collaboration advances social sciences integration into federal global change research activities

USGCRP and its member agencies are prioritizing integration of social science insights and methods to understand global change risks, opportunities to build resilience, and effective delivery of climate and global change information. USGCRP's [Social Sciences Coordinating Committee](#) (SSCC), in collaboration with other USGCRP Interagency Groups, fosters integration of social science methods, findings, and disciplinary perspectives across agency and Program activities.

In February 2022, the SSCC and USGCRP's **Coasts Interagency Group** hosted a gathering of over 100 federal social scientists who work on climate change to discuss their portfolios and how to overcome barriers to greater integration of social sciences into climate research. The meeting also served as a valuable opportunity to connect people from different agencies who do not regularly engage with each other and to expose federal social scientists to the issues and opportunities associated with global change.

In 2022, the SSCC released a report summarizing [discussions at their 2021 webinar series on climate, food, and culture](#) (USGCRP SSCC, 2022). The report has a strong emphasis on equity and justice and highlights the importance of history in understanding climate impacts and the ability to adapt as well as the intersectionality of climate with a host of social structures and stressors. This work builds on past efforts from USGCRP and USDA, specifically the 2015 assessment *Climate Change, Global Food Security, and the U.S. Food System*, by approaching the topic through the lens of a broader range of social sciences (Brown et al, 2015).

The SSCC, in collaboration with the **Integrated Observations Interagency Working Group** (ObsIWG), hosted a seminar in fall 2022 focused on innovative approaches to socioeconomic observations. The seminar invited non-federal speakers to share emerging research on generating observations of socioeconomic variables for use in climate change research. The seminar was part of a [series of seminars on Earth observations in a changing climate](#) that the ObsIWG is conducting in partnership with other USGCRP Interagency Groups.

Open-source framework advances the quantification and monetization of climate impacts

EPA's [Framework for Evaluating Damages and Impacts](#) (FrEDI) provides a fast and transparent framework for assessing the physical and economic impacts of climate change in the United States through the end of the 21st century, under any future scenario. This open-source framework draws upon a broad range of peer-reviewed studies from across the climate science and economic literature, including modeling contributions from NOAA, CDC, and others, to allow users to quickly assess and better understand the detailed story of when, where, and to whom climate change impacts are projected to occur, as well as how these impacts may change under custom mitigation or adaptation scenarios. Continued development in 2022 expanded the scope and number of impact studies included within FrEDI (~20), as well as increased usability of the [open-source code used for analysis](#). FrEDI currently provides the most comprehensive and detailed analysis of its kind and is part of the [CIRA project](#), a broader effort to quantify and monetize the impacts of climate change in the United States.

ENGAGING THE NATION

Goal: *Enhance the Nation's ability to understand and respond to global change by expanding participation in the federal research enterprise.*

To better meet growing information needs, USGCRP's Strategic Plan calls for increased engagement among scientists, affected communities, and decision-makers as well as with non-member federal agencies and departments that need global change information to serve their constituencies, in order to improve understanding of science needs. Throughout 2022, USGCRP provided briefings on the Program and opportunities for non-member agencies to get involved in its activities, including through participation in USGCRP Interagency Groups. USGCRP also worked closely with the Council on Environmental Quality to support federal agencies in leveraging scientific information for

the development and implementation of their Climate Adaptation Plans and contributed to the development of a [guide for applying climate science information in federal agency climate adaptation planning](#) (OSTP, 2023).

In 2022, USGCRP also laid the groundwork for expanding its membership to better serve national needs for improved risk management capabilities in the face of climate and global change. In February 2023, the Department of Homeland Security became the [first new member of USGCRP in almost 20 years](#). DHS will work with USGCRP's 13 other member agencies to leverage scientific research in meeting several of the Department's mission areas, including strengthening preparedness and resilience.

2022 HIGHLIGHTS – ENGAGING THE NATION

New report outlines opportunities for advancing climate action through partnerships

FEMA leads the Resilient Nation Partnership Network (RNPN), a peer-to-peer network of individuals and communities that are putting knowledge into practice to advance community resilience. In October 2021, FEMA and NASA co-hosted an RNPN forum on climate action. In 2022, the RNPN released a follow-on report, [Building Alliances for Climate Action: Advancing Climate Action through Partnerships](#) (RNPN, 2022). The report outlines perspectives on climate resilience from federal leaders, Indigenous and community leaders, academics, and others. It includes ideas and perspectives on how science and information can be used and delivered to support climate resilience. The report also provides selected resources on adaptation, climate change, local resilience, equity, financing, managed retreat and climate migration, nature-based solutions, and social resilience.

Interagency partnerships support knowledge-sharing on drought resilience

The [USDA Climate Hubs](#) and the multi-agency [National Integrated Drought Information System](#) (NIDIS) continue to strengthen partnerships and advance drought and climate change knowledge-sharing in support of building resilience to drought-related risks. NIDIS federal partners include USDA, CDC, FEMA, NASA, NOAA, NSF, USACE, DOE, DOI, DOT, and EPA.

In response to ongoing and significant drought conditions, the [Southern Plains Climate Hub](#) co-organized the [Southern Plains Drought Early Warning System](#) Drought Partners Meeting with NIDIS. Over 60 participants attended in person, including those from state climate offices, universities, extension, the USGS [South Central Climate Adaptation Center](#), National Drought Mitigation Center, and Tribal Nations (Sac and Fox Nation, Quapaw Nation, Chickasaw Nation, and Cheyenne Arapaho Tribe). Topics covered regional climate projections, climate whiplash events (characterized by abrupt shifts in extreme weather conditions), fire management, and flash drought and impacts.



Drought-tolerant vegetation, Phoenix, AZ.
Credit: Christofer Bang, NSF.

The [Midwest Climate Hub](#) worked with NIDIS and additional partners to plan and hold the Midwest/Missouri River Basin Drought Early Warning System [Regional Meeting](#) in Omaha, Nebraska. This meeting provided opportunities for developing partnerships and information sharing around drought prediction and adaptation efforts in the Missouri River Basin and Midwest.

The [Caribbean Climate Hub](#) stood up the [Caribbean Drought Learning Network](#) to increase drought communication by collaborating on bimonthly drought updates for Puerto Rico and the U.S. Virgin Islands. This work also supported drought monitoring by promoting rainfall monitoring through the [Community Collaborative Rain, Hail and Snow Network](#) and advocating for increased drought impact reporting through direct reports and the [Condition Monitoring Observer Reports](#) drought tool.

Pacific Drought Knowledge Exchange provides tailored climate information to support planning and management

Tropical Pacific Islands are increasingly vulnerable to drought, which can cause severe drinking water shortage, extensive crop damage, and harmful impacts on ecosystems. Established in 2019, the [Pacific Drought Knowledge Exchange](#) (PDKE) facilitates collaborative relationships between scientists and resource managers in the region, aiming to provide customized, accessible drought data and products to support planning and management. PDKE is funded and guided by an alliance of federal and state agencies, associations, and non-profit organizations, and is implemented by science staff from the East-West Center, Clark University, USDA-FS Pacific Southwest Research Station, DOI's [Pacific Islands Climate Adaptation Science Center](#), the [USDA Southwest Climate Hub](#), and the University of Hawai'i at Mānoa.



Dead māmane trees in a field of dead kikuyu grass.
Source: photo by E. Parsons (Vose et al., 2016).

The PDKE focuses its collaborative work on providing resource stewards with easier access to 1) sector- and geography-specific climate information, 2) better and more comprehensive information, 3) improved technical assistance, and 4) a more collaborative information-transfer environment through participation in knowledge co-production. The PDKE produces climate change, climate variability, and drought “portfolios” featuring site-specific historical and forecasted information. This information is used to better integrate climate knowledge into management planning, better understand how past and projected climate can be used for designing effective management actions, support educational and outreach efforts, and enhance drought resilience.

New monitoring network will track effects of sea level rise on mangrove forests in Western Pacific Islands

Continued sea-level rise from a changing climate is expected to result in the loss of many coastal mangrove trees, which will significantly impact human populations on remote Western Pacific Islands that rely on mangrove forests for food, building materials, and firewood.

Mangroves also protect local communities from tsunamis and cyclones and are important for climate change mitigation because they remove and store large amounts of atmospheric carbon dioxide in trees and sediments. Understanding how the elevation of the coast is changing at finer resolutions is a critical data gap in efforts to identify which coastal areas will be most impacted by changes in sea level rise and determine how to protect or restore them.



A mangrove forest in Palau. Source: USDA-FS.

To address this need, a new project, led by researchers from USDA-FS and USGS, will build a [Pacific Mangrove Monitoring Network \(PACMAN\)](#) with partners from the Republic of Palau, the Federated States of Micronesia (Kosrae, Pohnpei, Yap), the Micronesia Challenge (regional challenge to conserve 30% of terrestrial resources by 2030), and the Micronesia Conservation Trust. Using standard methods such as rod surface elevation tables and novel methods such as a ground-based light detection and ranging (LiDAR) system, PACMAN will measure how fast mangrove forest floors are rising or falling relative to sea-level rise, identify the factors influencing that rate, and develop strategies to help mangrove forests keep up with

sea-level rise. The project team will also develop a user-friendly program to allow resource managers on each island to process and analyze data that they have collected. Information will then be shared through groups created through social media outlets, as well as through annual virtual meetings.

Training course builds climate literacy in the federal workforce

In December 2021, USDA launched a [year-long monthly climate literacy training course](#) for its employees, aiming to help develop a more climate-informed workforce for the U.S. Government. During live seminar events, expert speakers from NOAA, DOI, USDA, non-governmental organizations, and the private sector provided information and responded to questions on a range of climate change related topics, including the foundational science of climate change, the effects of climate change and extreme events on croplands, animal agriculture, and forests, and climate adaptation and mitigation response options for the agriculture and forestry sectors. An average of 800 staff members attended each seminar, and seminar recordings were converted for use on USDA's formal internal training platform. Following the live seminar events, [recordings were made available to the public](#) on USDA's website (USDA, 2023).

GLOBE student research symposium builds a community of Earth science learners

The [GLOBE](#) (Global Learning and Observations to Benefit the Environment) Program is a science and education initiative that engages a network of students, educators, scientists, and members of the public from more than 125 countries across the world to better understand, sustain, and improve Earth's environment. GLOBE provides participants worldwide with the opportunity to participate in data collection and the scientific process and contribute meaningfully to our understanding of the Earth system and global environment. NASA is the lead

federal sponsor, and NOAA, NSF, and DOS are federal co-sponsors. The backbone of the GLOBE Program is a set of 40+ measurement protocols developed by research scientists with GLOBE's education focus in mind. Each protocol outlines a rigorous data collection methodology and the specifications for instruments that meet measurement requirements. All GLOBE observational data are freely available to the public.

In 2023, 212 students across the United States presented 68 scientific research projects during a series of seven [GLOBE Student Research Symposia](#) (SRS). The annual SRS are opportunities for students grades 5-12 to discuss and share their scientific research with one another and with STEM professionals. Projects ranged from monitoring reports about ice and snow up north in Fairbanks, Alaska, to insights about the impacts of cloud formations on humidity down south in Kenner, Louisiana. SRS projects are the result of GLOBE students' investigations that use GLOBE Protocols and/or GLOBE data. These investigations are often focused on a topic or question that are relevant to the students', and GLOBE educators', local communities.

Interagency information sharing promotes collaboration on federal environmental justice and health equity efforts

USGCRP's Strategic Plan emphasizes a focus on diversity, equity, inclusion, justice, and accessibility, as its agencies collaborate to invest research funding, build capacity with a more diverse scientific workforce, engage with frontline communities, and translate results into useful and actionable information. To support interagency collaboration, USGCRP's [Interagency Crosscutting Group on Climate Change and Human Health](#) (CCHHG) collected agency activities related to diversity, equity, inclusion, and accessibility efforts at the agency and interagency levels. The CCHHG asked agencies to provide updates and areas of potential collaboration around the intersections of climate change, public health, environmental justice and equity, and diversity and inclusion. Annual updates on activities will be shared across participating agencies and USGCRP Interagency Groups, with the goal of supporting new interagency collaboration around these topics.

Podcast series shares perspectives on coastal science and decision-making

USGCRP's [Coasts Interagency Group](#) developed a three-part podcast series focused on the science of coastal decision-making. The series follows up on a series of federal seminars the group hosted in 2021 and brings similar content to a public audience. The episodes were released beginning in November 2022 via the NOAA Ocean Podcast (NOAA, 2023a), addressing:

- [equity and justice in coastal planning](#)
- [what the latest behavioral science research can tell us about how people make conservation and environmental decisions](#)
- [perspectives from a panel of government experts on the science of coastal decision-making, and what the future might look like if more effective decision-making is adopted](#)



Historical structures in Fort Jefferson, Dry Tortugas National Park, FL, are threatened by sea level rise. Source: NPS.

INFORMING DECISIONS

Goal: Provide accessible, usable information to inform decisions on mitigation, adaptation, and resilience.

USGCRP and its member agencies are working together to address growing demands for more comprehensive, specific, and accessible climate and global change information to guide decision-making. Enhanced engagement processes seek to ensure that decision-makers' information needs, including information on the equity dimensions of global change impacts and responses, are addressed. USGCRP's **Federal Adaptation and Resilience Group** (FARG) fosters interagency collaboration to increase resilience to climate variability and change.

In 2022, USGCRP and its member agencies continued efforts to ensure that the best-available science produced by the federal government is accessible to inform key mitigation and adaptation decisions at various scales to avoid or reduce risks from climate and global change, including achievement of key milestones in the development of major scientific assessments and the release of new federal data, tools, and information resources. In addition, a workstream of the FARG is providing guidance on the processing of downscaled model data and model weighting to support regional and local climate information in the National Climate Assessment.

2022 HIGHLIGHTS – INFORMING DECISIONS

Scientific Assessments

Fifth National Climate Assessment meets key milestones

As directed by the Global Change Research Act, USGCRP produces a periodic assessment of the science of climate change, its present and future impacts on the United States, and options for reducing risk, known as the National Climate Assessment (NCA). The NCA evaluates climate impacts across a wide range of interests, including water, forests and ecosystems, coasts and the ocean, agriculture and rural communities, the built environment, energy and transportation, health and air quality, and economic and social systems. The Fifth National Climate Assessment (NCA5) met critical milestones in 2022, including organization of a series of public engagement workshops and submission of a full report draft for public and peer review, that help ensure that the report is an authoritative, accessible, and relevant reference for the Nation. The final [report](#) was delivered in November 2023 (USGCRP, 2023).



The Ántukš-Tiñqapapt or “sun trap” solar array recently installed by the Confederated Tribes of the Umatilla Indian Reservation in Oregon. Source: DOE.

USGCRP initiates First National Nature Assessment

In 2022, USGCRP initiated an assessment of the condition of nature within the United States, with anticipated release in 2026. [The First National Nature Assessment](#) (NNA1) 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. Like other USGCRP assessments, NNA1 will draw on expertise from the federal government, Indigenous communities, academia, and the private sector; establish an array of public engagement opportunities to ensure the report is useful, usable, and informed by the best-available knowledge; and undergo extensive review from federal agency experts and the broader public.



Red Pine Lake in Little Cottonwood Canyon on the Uinta-Wasatch-Cache National Forest in Utah.
Credit: USDA-FS photo by Timothy Kennedy.

New report assesses the science of wildland fire smoke

Area burned by wildfire in the United States has grown since the 1980s, the result of decades of fire exclusion, increased fuel loads, and recent periods of severe drought influenced by climate change. In the last two decades, increasingly heavy smoke from wildfires has exposed millions of people to unhealthy pollution levels for extended periods, causing significant negative health impacts across the United States. Multiple scientific efforts are addressing the need for better wildland fire smoke information, and investments in smoke modeling, predictions, and forecasting have increased, both as a research area and in support of wildfire response efforts.

A [new scientific assessment](#) led by USDA-FS, with participation from CDC, EPA, and NOAA, synthesizes research and knowledge on wildland fire smoke, including its public health and economic impacts, and highlights knowledge gaps for future research (Peterson et al., 2022). The assessment also surveys current management and regulatory issues related to smoke management and identifies issues that may arise with future prescribed fire programs and intensifying wildfire seasons. This assessment underscores the importance of research on wildfire smoke emissions, prediction of impacts, and public and firefighter health effects as the United States addresses climate change and its effects.

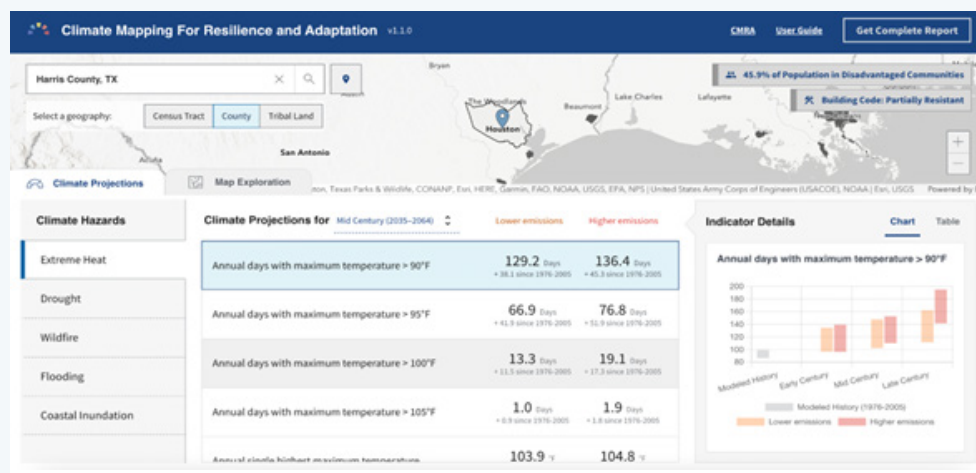


Fire researchers observe the behavior of a prescribed fire in the Indian Creek area of Fishlake National Forest, Utah. Credit: Kreig Rasmussen, USDA-FS.

Adaptation and Resilience

Climate Mapping for Resilience and Adaptation portal helps communities prepare for future conditions

The new interagency [Climate Mapping for Resilience and Adaptation](#) (CMRA) portal helps state, local, and Tribal governments and leaders understand their exposure to climate-related hazards, now and throughout this century (CMRA, 2023). CMRA integrates decision-relevant information from across the federal government to allow users to explore how people and assets in their community may be affected by climate-related hazards. Specifically, CMRA helps people explore how climate conditions in their location are expected to change over the coming decades. The CMRA Assessment Tool integrates information from federal data sources and initiatives, including the [U.S. Climate Resilience Toolkit](#), [Drought.gov](#), [Heat.gov](#), NOAA’s [2022 Sea Level Rise Technical Report](#) (Sweet et al., 2022), FEMA’s [National Initiative to Advance Building Codes](#), and the Council on Environmental Quality’s [Climate and Economic Justice Screening Tool](#).



CMRA is hosted by NOAA and was published in September 2022 as part of an interagency partnership, working under the auspices of USGCRP and with guidance from the [U.S. Federal Geographic Data Committee](#), which is led by DOI. The project was led by NOAA and DOI with support from DOE, USGS, and NASA.

An image from the [CMRA Tool](#) showing the projected increase in selected climate variables by midcentury (2035–2064) under lower emissions and higher emissions pathways for Harris County, Texas. Source: CMRA.

Regional adaptation seminars support climate resilience decision-making

As climate change continues to transform recovery from and resilience to extreme events, USGCRP agencies are collaborating to share learning on climate adaptation and empower risk-informed decision-making.

The FEMA National Exercise Division is working with local, state, and Tribal, and federal partners (including USDA, NOAA, and EPA) to deliver regional climate adaptation seminars, highlighting partnerships and resources to support the emergency management community and state, local, and Tribal partners in adapting to climate change impacts. This progressive series of exercises aims to increase climate literacy among emergency managers and support informed decision-making among state, local, and Tribal partners working to build climate resilience.



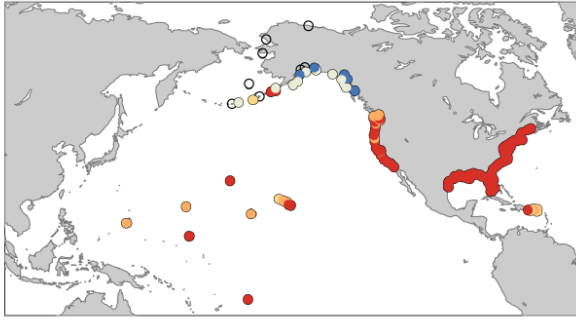
A rain garden being installed at the Palmer Senior Center in Southcentral Alaska to help manage stormwater runoff. Credit: USFWS/Katrina Mueller.

Interagency effort provides updated U.S. sea level rise projections

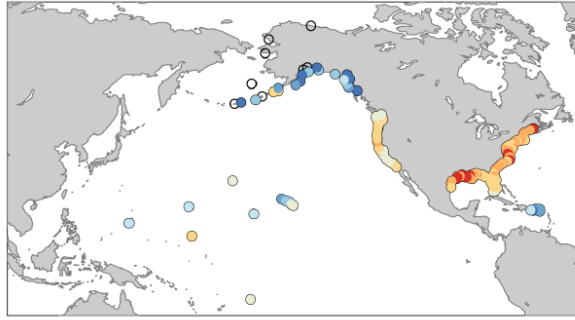
The interagency [2022 Sea Level Rise Technical Report](#) provides the nation with authoritative information to help communities assess potential changes in average tide heights and flood frequencies as they take action to adapt to sea level rise (Sweet et al., 2022). The report provides the most up-to-date sea level rise projections for all U.S. states and territories by decade for the next 100 years and beyond, finding that sea levels along the U.S. coastline are expected to rise an additional 10–12 inches by 2050, with regional variation. This report provides greater confidence in estimates of sea level rise out to 2050 than the [previous report](#) (Sweet et al., 2017) because of advances in sea level science and the use of multiple lines of evidence: both the trends in the amount of relative sea level rise already observed and the models of future sea level rise closely match one another in the next 30 years. The report is the latest product of the Interagency Sea Level Rise Task Force, with authors from NOAA, NASA, EPA, USACE, FEMA, and USGS.

Led by local and state practitioners, with federal staff and technical input from the Interagency Sea Level Rise Task Force, a first-of-its-kind [Application Guide](#) (Collini et al., 2022) was created to complement the Sea Level Rise Technical Report. In addition, in advance of the release of the Technical Report, programs from NASA and NOAA closely coordinated on the updates of their tools and products to reflect the updated sea level rise data. This enabled users to access the latest new data in viewers and tools, including the [Interagency Sea Level Rise Scenario Tool](#) (NASA, 2023) and NOAA's [Sea Level Rise Viewer](#) (NOAA, 2023b), concurrently with the release of the technical report. Agencies at the federal, Tribal, state, and local levels use these projections in planning to manage risks related to sea level rise.

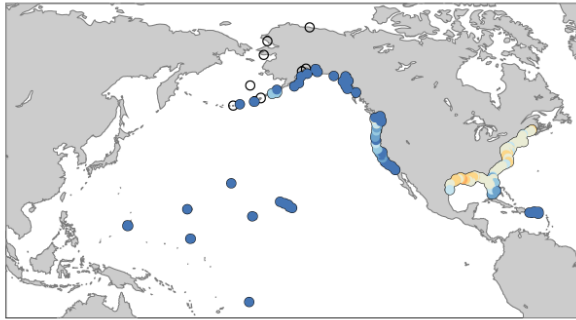
a) NOAA Minor HTF in 2050 (Extrapolation-Scenario)



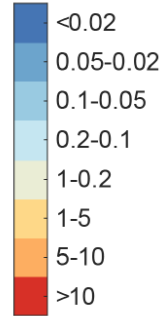
b) NOAA Moderate HTF in 2050 (Extrapolation-Scenario)



c) NOAA Major HTF in 2050 (Extrapolation-Scenario)



Events perYear



Sea level rise will create a profound shift in coastal flooding over the next 30 years by causing tide and storm surge heights to increase and reach further inland. The maps show coastal high tide flooding (HTF) frequencies projected at 2050 considering the sea level scenario that closely aligns with the current rise trajectory for a) minor (mostly disruptive, nuisance), b) moderate (typically damaging), and c) major (often destructive) HTF. Source: NOAA.

Climate and Health Outlook provides actionable information on reducing health risks from extreme events

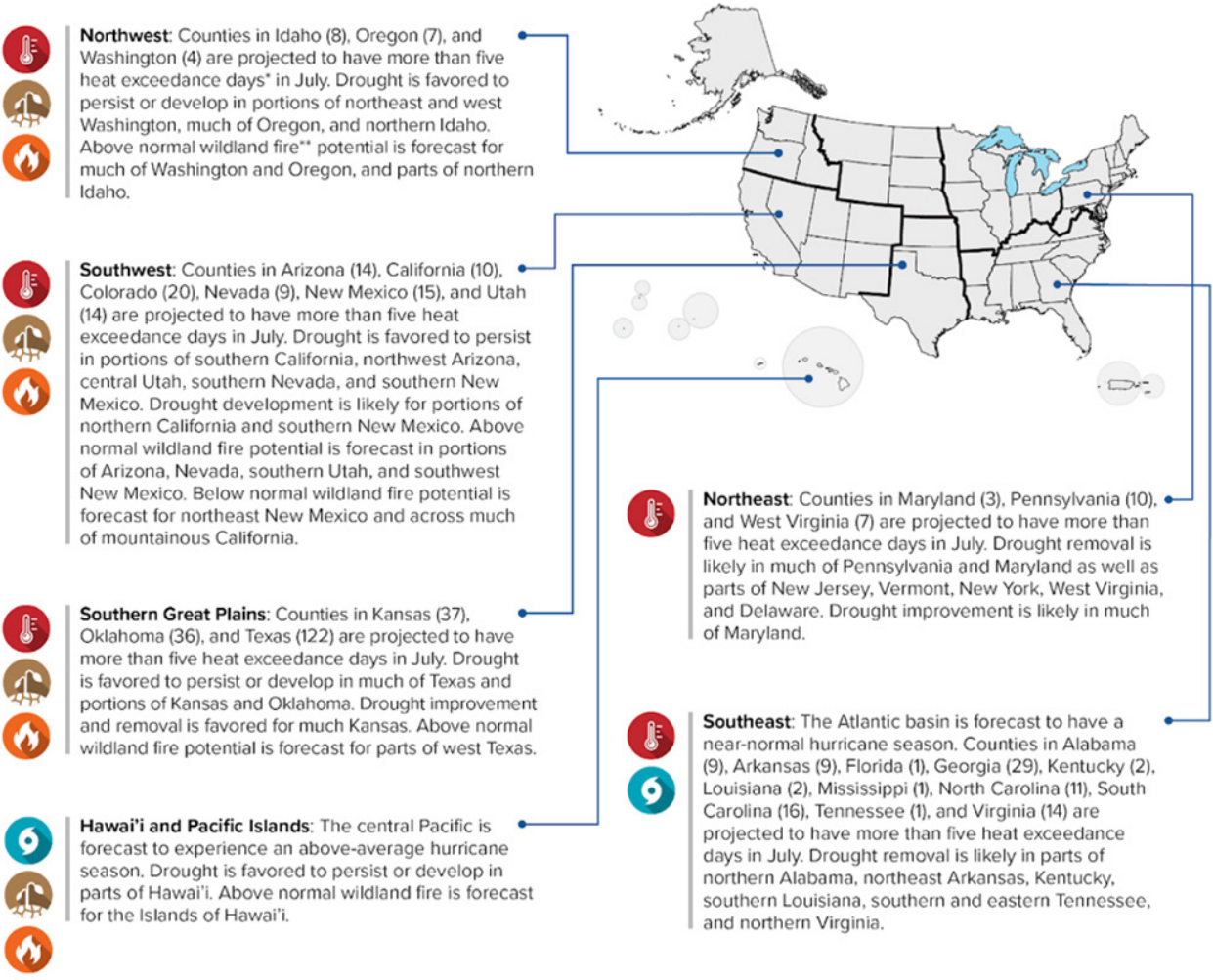
Building upon years of development by USGCRP’s Climate Change and Human Health Group, in May 2022, HHS initiated a monthly [Climate and Health Outlook](#) (CHO), in partnership with NOAA, EPA, USDA, DOI, and other federal agencies. Aimed at both the public and health professionals, the CHO interprets 30-to-90-day climate-related hazard forecasts from a health perspective. In addition to showing where climate-related hazards are likely to be greater in coming months, the CHO identifies the health outcomes associated with those hazards, who is most at risk, and what resources are available to protect people’s health.

In addition to informing the public and healthcare professionals about how extreme weather and other climate-related phenomena like wildfires can impact our health, the CHO provides actionable information about protective measures and resources and how to target them. Innovative aspects of the CHO include the development of a geospatial database of county-level indicators of risk and vulnerability, the novel use of public health surveillance data to provide insights into the actual burden of health impacts associated with heat and other hazards, and a comprehensive listing of tools and resources that public health departments and health care professionals can use to reduce the health impacts associated with extreme weather events.

Climate and Health Outlook

ISSUED JULY 2023

The Climate and Health Outlook is an effort to inform health professionals and the public on how our health may be affected in the coming months by climate events and to provide resources for proactive action. An [associated webpage](#) includes additional resources and information, including more detail on the wildfire and drought outlooks and populations at risk.



Drought Wildfire Hurricane Heat

*A "heat exceedance day" is when the daily maximum temperature is above the 95th percentile value of the historical temperature distribution in that county.
 **Smoke from wildfires can impact health hundreds of miles from site of the fire.
 Developed with data from the Centers for Disease Control and Prevention, the National Oceanic and Atmospheric Administration, and the National Interagency Fire Center.

We want to hear from you! Please send your feedback on ways to improve the Climate and Health Outlook to ocche@hhs.gov. 1

COLLABORATING INTERNATIONALLY

Goal: *Build global capacity to respond to global change through international cooperation and collaboration.*

The long-term strength of global change research capabilities, and their ability to support decision-making at local to national to international scales, depends on engagement and collaboration globally. As part of its mandate under the Global Change Research Act, 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. Efforts highlighted this year are working to strengthen capacity for climate risk assessment, advance carbon management for climate mitigation, provide technical assistance to island nations working to build resilience, and advance precipitation science and prediction.

2022 HIGHLIGHTS – COLLABORATING INTERNATIONALLY

Regional effort to build partnerships in Latin America and the Caribbean develops pilot concepts

The Initiative for Enhancing Capacity for Climate Risk Assessment and Catalyzing Partnerships to Inform Decisions in Latin America and the Caribbean, or **LACI**, is a collaborative effort between USGCRP, the **U.S. Group on Earth Observations**, and regional partners, including **AmeriGEO** and the **Inter-American Institute for Global Change Research**. LACI's core team includes members from USGS, NOAA, NSF, NASA, USAID, DOI, and DOS. The overarching vision for LACI is to provide opportunities for partnerships between 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.

In a series of scoping workshops in 2022, representatives from 14 countries (Argentina, Brazil, Canada, Chile, Colombia, Ecuador, El Salvador, Jamaica, Mexico, Panama, Paraguay, Peru, Uruguay, and the United States) identified local needs and co-developed nine pilot concepts. As a result, four task teams were established to further co-design the LACI pilots. The anticipated pilot activities have an overarching objective of catalyzing partnerships between stakeholders across geographic, disciplinary, and institutional borders to facilitate regional capacity exchange on climate risk assessment.

Collaboration strengthens capacity for blue carbon management and inventory in Costa Rica

Coastal wetlands like mangroves, salt marshes, and seagrasses play a significant role in carbon storage and sequestration around the world, providing some of the highest density stores of carbon in the biosphere. This long-term storage is known as coastal blue carbon. To date, only a few countries have incorporated blue carbon into their national greenhouse gas

inventories, which help track progress towards meeting international climate commitments. The [Blue Carbon Inventory Project](#) (BCI), led by NOAA with funding from DOS, works with partner countries to advance the development of greenhouse gas emissions mitigation, coastal resource management, and resilience strategies that reflect the societal and climate mitigation value of mangrove ecosystems. The BCI leverages ongoing programs within NOAA, new and ongoing work by EPA, USDA-FS, the Smithsonian Environmental Research Center, and USAID. The BCI is part of the [Transparency Accelerator for Greenhouse Gas Inventories](#), a capacity-building initiative established by EPA and DOS to help developing countries develop sustainable greenhouse gas inventory management systems that enable transparent, accurate, complete, comparable, and consistent inventories.

In 2022, the BCI held a series of virtual and in-person workshops with Costa Rica to identify blue carbon inventory and management priorities and develop and provide in-person training to build capacity for blue carbon management and national greenhouse gas inventories. Ultimately, these efforts help ensure that the capacity and expertise exist to effectively manage blue carbon ecosystems, while quantifying the ecosystem services they provide for inclusion in national greenhouse gas inventories, carbon markets, and pay-for-service programs. Building on the successful Costa Rica model, the BCI is currently expanding efforts to additional partner countries in the Pacific, Africa, and Asia. In 2022, NOAA worked in close partnership with the EPA, the Smithsonian Environmental Research Center, and numerous non-governmental organizations to implement this work.

Island-Led Resilience 2030 project informs adaptation and mitigation efforts in island nations

Island-Led Resilience 2030 (ILR2030) is a NOAA-led project, funded by DOS, to partner with the [Local2030 Islands Network](#), a coalition of 20 island jurisdictions within and outside the United States committed to advancing the U.N. Sustainable Development Goals (SDGs) through island-led solutions, with an emphasis on reaching net-zero greenhouse gas emissions and strengthening resilience in island economies to combat climate change. DOE, USAID, NOAA, DOS, EPA, and DOI are partners in the Local2030 Islands Network, as part of a cross-government effort to foster island adaptation and resilience.

The Local2030 Islands Network helps provide technical assistance and collaboration in the form of peer-to-peer learning opportunities, such as support for Communities of Practice (CoP), and capacity-building activities, including training, research, extension, and engagement. Since the launch of the network, NOAA has supported two of the Network's CoPs (Data for Climate Resilience and Sustainable and Regenerative Tourism) and has also assisted in

the development of island data dashboards for island members of the Network to track their progress towards achieving the SDGs. Efforts supported by the partnership integrate scientific and decision-support capabilities across NOAA and other agencies and organizations, including DOS, DOE, USAID, and the Ocean Foundation.



Fagatele Bay at National Marine Sanctuary of American Samoa. Credit: Matt McIntosh/NOAA.

Clean Air Catalyst supports international air quality action

Most cities in low-and middle-income countries lack information on the primary and secondary drivers of poor air quality. This lack of data and technical know-how hinders their ability to address the sources of emissions that are polluting the air and contributing to climate change. The USAID-funded [Clean Air Catalyst](#) (Catalyst) is piloting an innovative data-to-impact methodology to accelerate clean air action in three cities: Indore, India; Jakarta, Indonesia; and Nairobi, Kenya. The program pairs global scientific partners with local scientists to resolve key uncertainties about the sources and root causes of air pollution and identify solutions. USGCRP partners are supporting these efforts to deploy air monitoring equipment and conducting state-of-the-art modeling and analysis.

In Jakarta and Nairobi, the Catalyst is coordinating with DOS to utilize the data from the reference grade air quality monitors that the Department has installed on Embassy property to help [measure air pollution levels](#), identify sources and impacts, and act on that data with relevant policies and measures. The Catalyst is also installing EPA reference method instruments for additional monitoring in all three cities and will rely on EPA guidance for quality assurance project plans and analysis of air pollutant samples to determine the sources of pollution and their relative contributions. For source apportionment studies, Catalyst partner MAP-AQ (Monitoring, Analysis, and Prediction of Air Quality), co-chaired by the NSF-sponsored National Center for Atmospheric Research, is advising on emissions inventory design and source awareness data collection planning. They are also providing insights into the location of emissions sources and using modeling to predict the impacts of specific actions on air quality and exposure. With this support from the U.S. atmospheric science community, the Catalyst is improving source awareness and strategic planning for air quality management with the goal of building tailored, data-driven solutions for air quality action in Indore, Jakarta, and Nairobi.

NASA-USAID SERVIR program improves drought monitoring and forecasting in the Lower Mekong Region

[SERVIR](#) is a joint initiative of NASA and USAID, collaborating with global partners to use satellite-based Earth observation data to support weather and climate resilience, agriculture and food security, water security, ecosystem and carbon management, and air quality and health. In 2022, in the [Southeast Asia region](#), the Mekong River Commission (MRC) Secretariat adopted SERVIR drought and flood forecasting methodologies to improve the ability of the five Lower Mekong countries—Burma, Cambodia, Laos, Thailand, and Vietnam—to monitor and manage climate risks. SERVIR tools and services give policymakers access to better data to implement and adapt to the adverse impacts of climate change. MRC helps local governments and the agricultural sector with seasonal drought forecasting and in implementing short and long-term mitigation measures during and in advance of droughts. SERVIR worked with MRC to develop drought assessment methodologies that use satellite datasets and seasonal forecasts. These datasets help the MRC convey the drought forecast severity to the member countries, with the aim of developing a timely response to drought conditions.



PRIORITIES FOR FUTURE GLOBAL CHANGE RESEARCH

In Fiscal Year 2024 (FY2024) and beyond, USGCRP will focus on implementing 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 through coordination of federal climate information services efforts, the development of high-impact scientific assessments, and other efforts.

Expanding USGCRP Participation and Membership

To better meet growing information needs, USGCRP's Strategic Plan calls for increased engagement across the federal government, both by expanding in reach to existing member agencies and increased outreach to non-member agencies and departments that need global change information to serve their constituencies.

Throughout FY2024, USGCRP will continue to provide briefings on the Program and opportunities for non-member agencies to get involved in its activities, including through participation in USGCRP Interagency Groups. To date, these briefings have resulted in new members and engagement of new agencies in multiple Interagency Groups. As the operational endpoints for interagency coordination, Interagency Group membership provides networking opportunities, as well as direct access to program managers that fund research in each area.

In addition to ongoing membership, USGCRP provides access to federal expertise on a range of topics, from flooding to drought and extreme weather. Agencies outside of USGCRP are now routinely approaching the Program with requests for specialized analyses, access to experts, and briefings on a variety of climate-related topics. USGCRP sees these requests as signs of success and will continue to build its network of experts to respond to emerging needs.

Coordinating Federal Climate Information Services

The federal government has been a credible source of climate information for decades, but the speed, scale, and types of climate impacts outpace the current delivery of useful services. Federal agencies provide a range of climate services for the entire nation, including tailored products for stakeholders. The need for a more coherent strategy for federal climate services has long been recognized but is becoming more urgent as climate impacts accelerate and the demand for more useful climate services increases.

In March 2023, the interagency Fast Track Committee on Climate Services (FTAC) of the National Science and Technology Council released [recommendations for a federal climate services framework and action plan](#), based on deliberations among agencies regarding the scope, challenges, and opportunities associated with building a more cohesive and

strategic federal climate services enterprise (FTAC, 2023). FTAC's overarching recommendation is for the USGCRP to expand its research coordination role to provide national leadership in coordination and strategic planning of climate services. In response to this recommendation, USGCRP has appointed a new Deputy Director for Services charged with implementing interagency recommendations on improving federal capacity to deliver accessible, usable knowledge and information about the climate and how it is changing.

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Anticipated FY2024 activities include the following:

- Continuing to advance work that translates basic science into actionable climate information through common data platforms and decision-support tools.
- Leveraging and empowering regional applied science and service organizations to increase accessibility and usability of climate information and services and providing feedback on user needs for science planning purposes.
- Enhancing understanding of co-production processes so that climate services better incorporate communities, end users, and decision-makers, as appropriate.

Increasing Exploration of Other Global Changes

The [First National Nature Assessment](#) (NNA1), with anticipated release in 2026, will provide a comprehensive picture of the status, observed trends, and future projections of U.S. lands, waters, wildlife, biodiversity and ecosystems and the benefits they provide. USGCRP plans to conduct a collaborative development process that engages with potential users of the assessment, including Tribal Nations, and is exploring ways to move towards co-production over the course of the assessment.

In FY2024, USGCRP will develop guidance for authors and onboard leadership and author teams for NNA1 chapters. USGCRP staff will also explore opportunities for NNA1-associated activities and products, such as multimedia products, journal special issues, and technical input reports.

Delivering the National Climate Assessment

The [Fifth National Climate Assessment](#) (NCA5) was delivered in November 2023 (USGCRP, 2023). Outreach, engagement, and development of resources designed to increase usability and accessibility of the report will continue through FY2024, including translation of the report into Spanish; development of an online [NCA Atlas](#) that provides additional resources like interactive maps and climate products for each U.S. region; media training for NCA5 authors; presentations at scientific conferences, public and regional webinars, and engagement events; and development of derivative products for specific audiences. USGCRP's [Climate Engagement and Capacity Building Interagency Group](#), formed in 2023, will assist in amplifying NCA5's education, communication, and engagement efforts.

Early planning for NCA6 will also take place throughout FY2024, including appointment of an NCA6 Director and establishment of the NCA6 Federal Steering Committee. This Committee will initiate early discussion on the format, function, and timeline for NCA6.

Advancing Science: Selected Topics

Social sciences. USGCRP’s Social Sciences Coordinating Committee has held a series of discussions focused on the social science dimensions of climate adaptation and resilience. In FY2024, the group plans to continue these discussions and move towards a product that identifies priority research gaps for federal agencies. The group also looks forward to scoping new activities on urban resilience and environmental justice, in collaboration with the Subcommittee on Global Change Research.

Integrated Hydro-Terrestrial Modeling 2.0. USGCRP’s Interagency Integrated Water Cycle Group and its Coasts Interagency Group are jointly planning a workshop in October 2023, Integrated Hydro-Terrestrial Modeling (IHTM) 2.0, for U.S. federal and non-federal scientists and managers. Building on the previous IHTM 1.0 (2019) and Coastal IHTM (2020) workshops, IHTM 2.0 will accelerate applications and collaborations through the design of integrated modeling experiments and collaborative use cases that respond to societal needs, leverage existing capabilities, transition from concepts to implementation, and foster the development of a community of practice. After the workshop, the IHTM community will continue to foster collaborations designed for demonstrable progress and accomplishments over the next 3-5 years, deploying, testing, and adapting the Research to Operations to Research (R2O2R) framework with diverse stakeholders inside and outside of the federal government.

Greenhouse gas emissions monitoring. The Greenhouse Gas Monitoring & Measurement Interagency Working Group recently released its [plan](#) for a national system to measure, monitor, report, and verify greenhouse gas emissions and removals from the atmosphere (GHG IWG, 2023). As the plan is implemented, USGCRP expects to engage with and support this effort. In FY2024, USGCRP will remain engaged through the carbon cycle expertise of the Carbon Cycle Interagency Working Group and the observing expertise of the Observations Interagency Working Group.

Engaging the Nation: Selected Topics

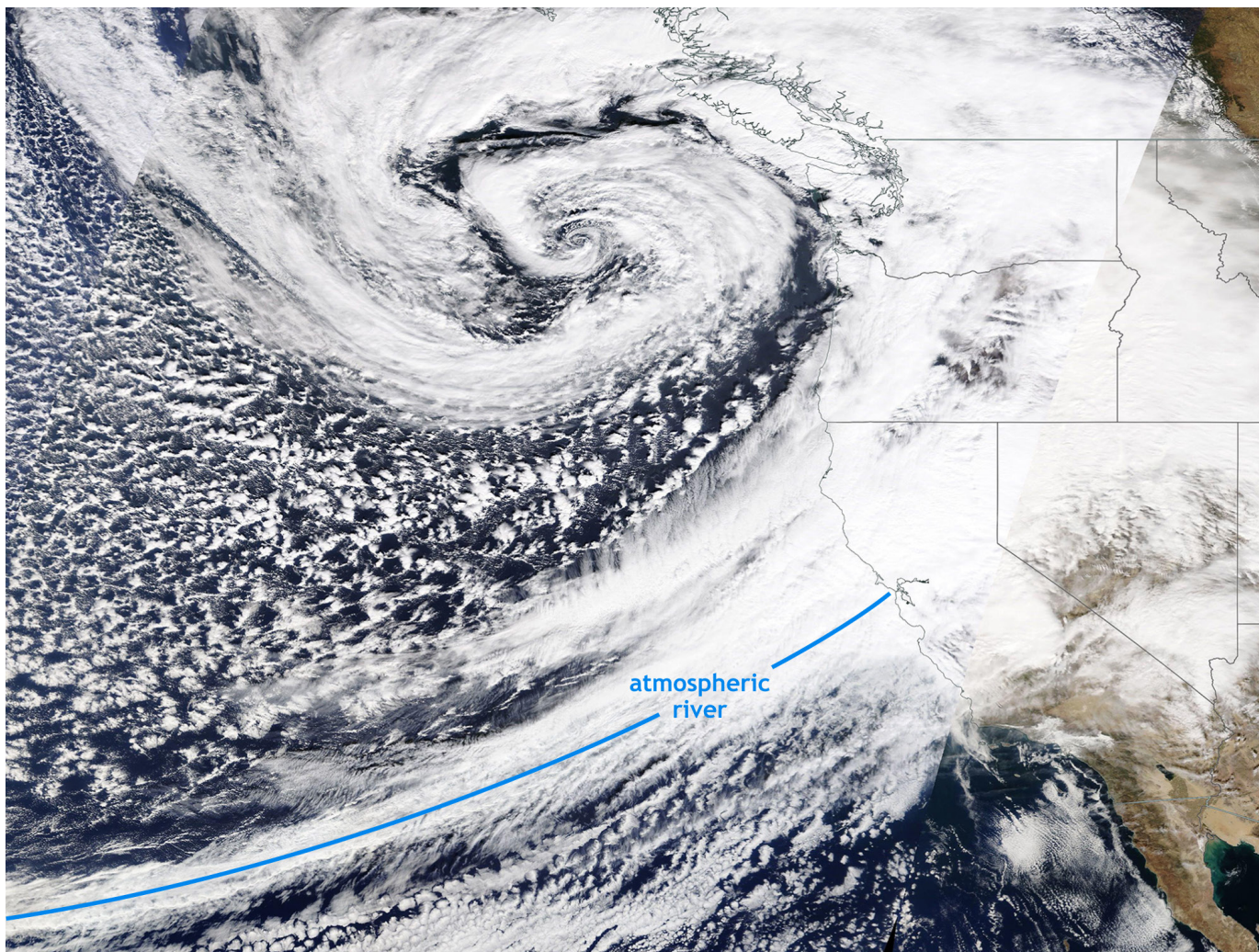
In 2023, USGCRP’s Climate Engagement and Capacity Building Interagency Group initiated an update of the 2009 interagency guide *Climate Literacy: The Essential Principles of Climate Science*, which provides a framework for formal and informal education about climate change (USGCRP, 2009). The update will ensure that the Guide reflects current climate science, engagement, and education methods and includes a focus on informed climate decisions.

Collaborating Internationally: Selected Topics

LACI. The International Activities Interagency Working Group is continuing to support the co-development of the LACI pilot activities, aimed at building climate risk assessment capacity in the Latin American and Caribbean (LAC) region. In FY2024, the group will

begin identifying opportunities for pilots' regional scalability and will continue to provide opportunities for partnership building and peer-to-peer learning and training in climate risk assessment and response across the Americas.

Global Precipitation Experiment. In 2022, GPEX was established as a cross-World Climate Research Programme (WCRP) activity to bring the international weather, water, and climate communities together to improve precipitation science and prediction at different temporal scales and for weather, subseasonal-to-seasonal, interannual, and decadal timescales. GPEX will gather national and international initiatives already in place on precipitation science and applications from both WCRP and non-WCRP programs, and jointly plan future activities to achieve the GPEX objectives. As part of its ongoing engagement with WCRP, USGCRP's International Activities Interagency Activities Group has helped facilitate coordination with WCRP to explore opportunities in advancing GPEX. GPEX will officially launch as a new lighthouse activity at the 2023 WCRP Open Science Meeting. Member agencies of the U.S. GEWEX (Global Energy and Water Exchanges) Sub-Group under USGCRP's Integrated Water Cycle Group are supporting the domestic and international coordination of GPEX implementation as a multi-year project.



Satellite image taken on October 24, 2021. A powerful storm off the Pacific Northwest coast brought an intense atmospheric river to the San Francisco Bay region of California. An atmospheric river is a long, narrow region in the atmosphere that moves moist air from the tropical ocean to land over higher latitudes. These phenomena can produce heavy rain and snow upon landfall. Credit: NASA Moderate Resolution Imaging Spectroradiometer (MODIS/Terra satellite image taken from NASA Worldview).



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 2024 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 2022 Enacted (\$M)	FY 2023 Enacted (\$M)	FY 2024 President's Budget (\$M)
National Aeronautics and Space Administration	1,750	1,814	2,043
National Science Foundation	737	792	1,047
Department of Commerce	483	588	627
Department of Energy	354	380	394
Department of the Interior	232	252	367
Department of Agriculture	139	184	357
Department of Health and Human Services	37	179	239
Environmental Protection Agency	19	21	52
Smithsonian Institution	8	9	13
Department of Transportation	2	2	2
Total	3,761	4,221	5,140



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 around 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 [12 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)
- [Climate Engagement and Capacity Building Interagency Group](#) (CEC)
- [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) climate and global change research program anticipates the challenges faced by agriculture, forests, and natural resources, while also supporting the commitment by the land sector to address those challenges. USDA's Agricultural Research Service (ARS), Forest Service (FS), National Institute of Food and Agriculture (NIFA), Economic Research Service (ERS), National Agricultural Statistics Service (NASS), and Natural Resources Conservation Service (NRCS) work collaboratively to provide comprehensive understandings and solutions, alongside the Department's network of Land Grant and Minority Serving Colleges and Universities, Cooperative Extension, an active extramural research enterprise, and the USDA Climate Hubs. In this way, USDA's climate science program prioritizes partner and stakeholder engagement in the development of use-inspired research for immediate application.

USDA's research on greenhouse gas mitigation technologies informs implementation of the Department's climate-smart agriculture and forestry strategy. It also improves our ability to measure, monitor, and report on greenhouse gas sources and sinks in the agriculture, forestry, and natural resource sectors. USDA's research enterprise provides viable solutions and the means for quantifying outcomes in mitigative management practices to ensure that investments in greenhouse gas mitigation are having their intended impacts.

USDA's Climate Hubs connect land managers and decision-makers to the Department's scientific resources. The Climate Hubs and their partners develop tools and resources to increase the resilience of working lands and communities to extreme weather events and changes in climate that support decision-making at a local level. The Climate Hubs convene groups of partners and stakeholders with activities such as the [Caribbean Drought Learning Network](#), the [Southwest Drought Learning Network](#), and regional drought engagements. Through these and other types of engagements, the Climate Hubs conduct assessments and demonstrations and develop tools to support science-based, climate-informed decisions and to improve adaptation, mitigation, and production outcomes.

USDA's Climate Change Program actively develops scientific understanding across the workforce so that employees, extension professionals, and stakeholders understand how climate and global change influence the Department's mission and their day-to-day work. The program coordinates across agencies and mission areas to plan, execute, engage, and learn from applied research efforts and incorporate that information into programmatic activities.

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 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 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 develop mobility and infrastructure advancements that reduce energy demand and increase resilience and capabilities in the Arctic and other environments in line with their 2022 Climate Strategy and Implementation Plan.
- 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 Department of the Air Force published its Climate Action Plan (DAF CAP) in October 2022 and in July 2023 finalized 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 change hazard exposure 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). The DoD Regional Sea Level (DRSL) database tool provides projections of sea-level change and extreme water levels globally for DCAT and is also [publicly accessible](#). DoD is enhancing DCAT and expanding the installations included in the tool to assess exposure as well as vulnerability (including adaptive capacity and sensitivity) to climate change and weather impacts.
- Two years ago, at the Climate Leaders' Summit led by President Joseph R Biden Jr., Honorable Secretary of Defense Lloyd J. Austin III committed to produce tailored versions of DCAT for six allies: Australia, Germany, Italy, Japan, Republic of Korea, and the United Kingdom. On April 20, 2023, the Pentagon hosted a Climate Assessment Tool Ceremonial event with embassy staff from the allies to mark the successful development of these tools. DoD continues to develop additional tailored versions of DCAT for other partner nations and allies.
- The Strategic Environmental Research and Development Program (SERDP) and the Environmental Security Technology Certification Program (ESTCP) are DoD's environmental, resilience, and installation energy and water research programs, investing in and harnessing the latest science and technology to improve DoD's overall resilience to environmental threats, extreme weather and climate change impacts. Since 2009, SERDP-ESTCP has sponsored nearly 50 projects in the climate projection temporal space including these recent applicable studies: Linked Rainfall and Runoff Intensity-Duration-Frequency in the Face of Climate Change and Uncertainty; Changes in Climate and its Effect on Timing of Snowmelt and Intensity-Duration-Frequency Curves; Exploring the Basis for Skillful Projections of Decision-Relevant Climate Normals; Developing an Experimental Predictive Framework for Climate Regime Shifts and Their Impacts Within a 2-20 Year Outlook Window; Fit for Purpose? An Integrative Assessment of State-of-the-Science Downscaling Methods for DoD Infrastructure Planning; Development of a Decision Support Aid System Connecting Climate Model Downscaling and DoD Infrastructure; Updated International Climate Change Data for DOD Climate Assessment Tool (DCAT).

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 Homeland Security

As a new member of the USGCRP, the [Department of Homeland Security](#) (DHS) seeks to serve as a bridge between researchers and resilience practitioners to ensure that the USGCRP research agenda is aligned with U.S. hazard mitigation and climate adaptation priorities drive national action through climate change data and science. DHS will continue to share evidence and best practices with the American people and partners across the Nation to promote change at all levels of government and in the private sector.

An informed nation is a resilient nation, and a prepared nation is a safe nation. The Department of Homeland Security is working to inform the American people about climate-related risks, including extreme heat, flooding, wildfire, and drought, and to provide them with clear information about how to reduce those risks. Emergency response is also a DHS priority and key mission. The Department seeks not only to respond to disasters, but also to empower American communities to prevent them before they occur.

The Federal Emergency Management Agency (FEMA), the United States Coast Guard (USCG), the Department of Homeland Security (DHS) Science and Technology Directorate (S&T), Cybersecurity and Infrastructure Security Agency (CISA), and Customs and Border Protection (CBP), comprise DHS's participation in USGCRP.

The changing climate brings more intense storms, floods, droughts, and temperatures to places that historically experience these events, and poses new threats to communities across the nation. FEMA is supporting community climate action through risk information, preparedness, hazard mitigation, response and recovery, grants, and field operations. FEMA programs help communities understand the climate and hazard related risks they face, assess their greatest vulnerabilities, and plan for critical preparedness and adaptation measures. The goal is to reduce vulnerability and support safer, more climate-resilient communities. FEMA will leverage the expertise of our federal partners and the research from USGCRP by incorporating climate data into emergency management programs, grants, and decision-making tools to advance resilience.

The S&T Directorate is an essential component of the Nation's efforts to address global challenges, particularly those related to climate change. Established in 2003 as the science lead and primary research and development arm of DHS, the S&T Directorate focuses on enhancing resilience and safeguarding infrastructure against the impactful threats of climate change. As part of its mission, DHS S&T collaborates with various federal agencies, including USGCRP, to better leverage scientific advancements in technology and research that support homeland security objectives and contribute to the global fight against climate change. DHS S&T is committed to enhancing resilience, safeguarding infrastructure, innovating climate technologies, supporting disaster response and recovery, as well as mitigating the impacts of global change on the Nation's security.

S&T's role, as DHS's scientific representation to USGCRP, involves bridging the gap between scientific research and practical applications for homeland security. Through ongoing collaboration, DHS S&T gains access to cutting-edge climate science and data, allowing the development of technology-driven solutions to tackle climate-related challenges. The Directorate focuses on enhancing resilience by investing in climate adaptation strategies, vulnerability analysis, and risk assessments. Additionally, DHS S&T supports disaster response and recovery efforts by analyzing climate data to improve preparedness and coordination during climate-induced disasters.

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 mitigate the impact of aviation on the climate. The FAA is following a whole of government approach described in the [United States Aviation Climate Action Plan](#) to put the aviation 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 procedures. The FAA is also working through their university partners to understand the impacts of aviation activity on the climate and to evaluate and mitigate the effects of climate change on FAA infrastructure and the National Airspace System. The FAA also funds a range of airport infrastructure initiatives that will improve the efficiency, sustainability, and resilience of U.S. airports.

- 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 while improving mobility. FHWA and FTA are supporting transportation agencies through ongoing programs that include assessing vulnerabilities; considering resilience and sustainability in the transportation planning and project funding processes; incorporating resilience in asset management plans; incorporating resilience and greenhouse gas emissions considerations in project development and design; optimizing operations and maintenance practices; planning for transit-oriented development; and deploying alternative fuel vehicles and associated infrastructure. FTA and FHWA are also working to ensure that resilience is considered when rebuilding damaged transportation infrastructure after a natural disaster. Additionally, both agencies have launched climate challenges that support efforts to curb transportation sector greenhouse gas emissions. FTA's Sustainable Transit for a Healthy Planet Challenge encourages transit agencies to develop climate, sustainability, or electrification or zero-emission transition plans that include strategies with measurable goals to achieve GHG emission targets. FHWA's Climate Challenge provides funding and technical assistance to quantify greenhouse gas emissions from materials and practices for the design, construction, and maintenance of pavements. Further, FHWA is implementing a number of new funding programs under the Infrastructure Investment and Jobs Act (Public Law 117-58), also known as the Bipartisan Infrastructure Law, targeted at mitigating the impacts of climate change and increasing the resilience of the surface transportation system. These programs include the Carbon Reduction Program, the National Electric Vehicle Infrastructure Formula Program, the Charging and Fueling Infrastructure Discretionary Grant Program, the Promoting Resilient Operations for Transformative, Efficient, and Cost-Saving Transportation (PROTECT) Program, and the Reduction of Truck Emissions at Port Facilities Grant Program.
- The Federal Railroad Administration (FRA) challenged the rail industry to meet net-zero greenhouse gas emissions by 2050, including working with the rail industry to find solutions to transition from diesel fuel for locomotives to zero emissions technologies. FRA's activities include coordinated research into the safety of zero-emission locomotive technologies, developing pilot projects to test new 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 a low-carbon emissions option for intercity transportation. FRA is conducting research into 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 incorporated climate change and sustainability considerations as an evaluation factor in its reviews of applications seeking grant funding for port infrastructure development projects 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 has established a Climate Change Research and Technology Program to advance greenhouse gas emissions mitigation, resilience, and climate adaptation research initiatives. The program is investing in research to support understanding and implementation of multi-modal transportation decarbonization strategies. Further, the program is working in partnership with FHWA and three Metropolitan Planning Organizations—Hampton Roads, Hillsborough, and Houston Galveston—to implement the [Resilience and Disaster Recovery \(RDR\) Tool Suite](#). The tool suite assists transportation agencies in infrastructure investment planning and prioritization across a range of uncertain future hazards. Further, the program 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's) global change research program is to develop scientific information that supports policy makers, stakeholders, and society at large as they respond to climate change and associated impacts on human health, ecosystems, and socioeconomic systems. EPA's research is driven by the Agency's mission 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)'s global change activities span the entire Earth Science Division (ESD), from satellite observations and technology development to research and analysis and 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 July 2023, NASA's portfolio includes 23 missions in operation, the combined measurements of which enhance our understanding of our changing planet. 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. The portfolio also includes programs to develop capacity to use these tools in both the United States and developing nations. NASA's effort to increase the use of Earth science data in addressing societal issues has been expanded in the past year for all missions and programs under the "Earth Science to Action" strategic framework. Highlighting this focus, NASA—with its interagency founding partners EPA, FEMA, NOAA, USAID, USDA, and USGS—opened an Earth Information Center (EIC) at its Mary W. Jackson Headquarters (HQ) building in Washington, DC, to allow visitors to engage with data, visualizations, and dashboards about our changing planet, as well as to enter an immersive experience that demonstrates the power and scope of Earth science remote sensing observations. The EIC at NASA HQ acts as a testbed for content development that will be pushed to several other EIC public exhibits. Another EIC focus is the development of a companion virtual site that will combine Earth data from across the seven founding agencies. The site will contain an interactive mapping application to help visitors easily access and use data about agriculture, air quality, biodiversity, water resources, disasters, energy, greenhouse gases, sea level rise, and

wildfires to make decisions about their lives and livelihoods.

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 is committed to open-source science to accelerate scientific discovery, broaden and diversify user communities, and increase transparency and reproducibility across Earth science disciplines. NASA Earth Science satellite and sub-orbital data are made widely and freely available through the Earth Science Data System, and efforts are underway for full migration to the cloud to increase the utility of Earth Science data by leveraging cloud-native computing for data visualization and analysis.

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) has provided its first data, with "first light" products released on March 24, 2023, not long after its launch 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.

The Earth Surface Mineral Dust Source Investigation (EMIT), launched to the International Space Station (ISS) on July 14, 2022, has entered routine operation and has made significant progress towards its primary goal of mapping the properties of desert surfaces that provide the mineral desert dust in the atmosphere in order to inform forecasts of its role in the radiative forcing (warming or cooling) of the atmosphere. EMIT has also demonstrated its capability to measure distributions of the greenhouse gases (GHGs) such as carbon dioxide and methane in source regions, with a particular emphasis on methane emission point sources for which data are now being made routinely available. EMIT data, together with data from several other NASA and partner satellites, most notably NASA's two Orbiting Carbon Observatory instruments, will be part of the information to be provided at a U.S. Greenhouse Gas Center currently under development by NASA together with three interagency partners (EPA, NIST, and NOAA). Science integration is a critical component of the GHG Center's effort to provide actionable, authoritative GHG information to a variety of end users through a coordinated data system. Three initial demonstration areas include: 1) providing more accessible anthropogenic emission inventories, 2) improving understanding of natural sources and sinks of methane and carbon dioxide, and 3) demonstrating the ability to reliably observe and estimate point source GHG emissions.

In May 2023, NASA selected the latest in its series of Earth Venture satellites, the Polarized Submillimeter Ice-cloud Radiometer (PoISIR) mission to study ice clouds that form at high altitudes throughout tropical and sub-tropical regions, with a focus on determining why they change throughout the day. PoISIR will provide crucial information about how to accurately simulate these high-altitude clouds in global climate models. The mission will involve a pair of CubeSats, flying in orbits separated by between three and nine hours. The principal investigator for PoISIR is Ralf Bennartz at Vanderbilt University in Nashville, TN. NASA's Goddard Space Flight Center will provide the project management team that builds the two instruments, while science operations will be conducted by the Space Science and Engineering Center at the University of Wisconsin-Madison. The two spacecraft will be built by Blue Canyon Technologies in Lafayette, CO.

A recent satellite launch for NASA's Earth Science program was Tropospheric Emissions: Monitoring of Pollutants (TEMPO) on April 7, 2023. The TEMPO instrument is a UV-visible spectrometer and is 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 flies aboard a commercial geostationary communications satellite (Intelsat 40E integrated by Maxar) as a hosted payload, with launch provided by a SPACE-X Falcon-9 rocket.

Also launched in 2023 were the four satellites that constitute the Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS) mission. TROPICS measures 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 was launched by Rocket Lab USA (two spacecraft each on May 8, 2023, and May 26, 2023) as part NASA's Venture-class Acquisition of Dedicated and Rideshare (VADR) launch services contract.

The next satellite launch for NASA's Earth Science Division is the Plankton, Aerosol, Cloud Ecosystem (PACE) satellite, currently planned for early 2024. PACE will extend and improve NASA's over 20-year record of satellite observations of global ocean biology, aerosols, and clouds. It will advance the assessment of ocean health by measuring the distribution of phytoplankton, tiny plants and algae that sustain the marine food web. It will also continue systematic records of key atmospheric variables associated with air quality and Earth's climate. PACE has three instruments, the Ocean Color Instrument (OCI), which will be the most advanced instrument of its type ever flown by NASA, and two multi-angle polarimeters, one of which was developed by a Dutch consortium consisting of SRON Netherlands Institute for Space Research (SRON) and Airbus Defence and Space Netherlands (Airbus DS NL), supported by optical expertise from the Netherlands Organisation for Applied Scientific Research.

NASA has continued the process of moving forward with the Earth System Observatory (ESO). This observatory comprises an integrated set of missions that includes the Designated Observables identified by the National Academies of Sciences, 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 early 2024. Individually, these missions deliver important environmental measurements. The NISAR Mission will measure Earth's changing ecosystems, dynamic surfaces, and ice masses providing information about biomass, natural hazards, sea level rise, and groundwater, and will support a host of other applications. The Surface Biology and Geology (SBG) mission will provide high-resolution (i.e., at the human scale) measures of climate impacts on terrestrial and aquatic ecosystems, as well as the feedbacks of hydrological, geological, and biological surface processes to climate. The Atmospheric Observing System (AOS) will increase our quantitative understanding of and ability to model aerosol particles, clouds, their interactions, and their impact on weather and climate; storm dynamics; the processes controlling precipitation; and the impact of aerosol particles on air quality. The Mass Change mission will continue the critical mission of measuring the movements of mass within and between Earth's atmosphere, oceans, land, and ice sheets, as well as below Earth's surface, enabling monitoring of groundwater and ice sheet changes. 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 (announcement of opportunity released May 6, 2023) involving competitive opportunities for medium-sized instruments and missions. Formulation (Phase A) continues for the ESO missions (SBG, AOS and Mass Change).

NASA continues to conduct numerous field campaigns using surface-based measurements, aircraft, and ships and to support several surface-based measurement networks. In 2023, NASA completed field campaigns from the third Earth Venture Suborbital solicitation, with the final deployments for the Investigation of Microphysics and Precipitation for Atlantic

Coast-Threatening Snowstorms (IMPACTS) and Sub-Mesoscale Ocean Dynamics Experiment (S-MODE) campaigns.

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. Another goal of the STAQS campaign is to improve temporal estimates of anthropogenic, biogenic, and greenhouse gas emissions. The STAQS campaign is being implemented together with NOAA's Atmospheric Emissions and Reactions Observed from Megacities to Marine Environments (AEROMMA) campaign. The STAQS data will complement and correlate with the TEMPO data that will become available during that time. NASA also plans to fly the Biodiversity Survey of the Cape (BioSCape) airborne campaign in southwestern South Africa, October–November 2023. BioSCape will feature 17 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.

In 2023, NASA also began a significant addition to several of its surface-based measurement networks (AERONET, PANDORA, precipitation monitoring) as part of the Increasing Participation of Minority Serving Institutions in NASA Earth Science Surface-Based Measurement Networks. Instruments are beginning to be installed at the proposed locations for the fifteen selected institutions.

NASA continues to purchase commercial satellite data through its Commercial Smallsat Data Acquisition (CSDA) program, with the aim of making these data available to NASA and U.S. Government-funded researchers. These data have the potential to add new information to the scientific research and applications that are already of focus in the Earth Science Division. In 2023, CSDA completed the evaluation of two vendors—Airbus (synthetic aperture radar data only) and Blacksky. Additionally, the evaluation process has started for three additional vendors—GeoOptics, GHGSat, Capella Space, and ICEYE U.S.

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

Global change research and public education at the [Smithsonian Institution](#) (SI) is primarily conducted by the National Air and Space Museum, the National Museum of Natural History, the National Zoo and Conservation Biology Institute, the Smithsonian Astrophysical Observatory, the Smithsonian Environmental Research Center, the Smithsonian Tropical Research Institute, and the Smithsonian Libraries and Archives. At the core of SI's global change research are diverse themes, encompassing atmospheric processes, ecosystem dynamics, and observing natural and human-induced environmental change across different time scales. Scientists delve into historical artifacts, geologic records, and long-term observations to gain insight into our planet's past and present. Through the Smithsonian's Global Earth Observatories, networks such as ForestGEO and MarineGEO explore the dynamics of forests and coastal marine habitats over decadal time frames, providing invaluable data for understanding our rapidly changing ecosystems.

Collaboration lies at the heart of SI's efforts. Researchers from various disciplines unite to address joint challenges. From estimating volcanic emissions, understanding and sustaining biodiversity, monitoring and mitigating the human encounters of animal migrations, characterizing working landscapes and seascapes, or studying emerging infectious diseases in wildlife and humans, these endeavors ensure a holistic understanding of our planet's interdependent systems. SI's paleontological research documents and interprets the history of terrestrial and marine ecosystems spanning millions of years while scientists analyze the impacts of historical environmental change on the ecology and evolution of species, including humans. Archaeobiologists examine early human impacts on planetary ecosystems through their domestication of plants and animals, shedding light on our role in shaping the environment. The Smithsonian Astrophysical Observatory built and operates NASA's TEMPO mission to monitor pollution by tropospheric emissions. SI also leads vital work in green carbon in forests and grasslands and blue carbon in the Coastal Carbon Network.

Underpinning these efforts is SI's Our Shared Future: Life on a Sustainable Planet initiative, which combines research, collections, partnerships, and public outreach to foster sustainable communities, address social justice, slow and reverse climate change, and conserve Earth's ecosystems and biodiversity. Incorporating history and art from units 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 Smithsonian Design Museum, SI explores human responses and resilient adaptations to global change within diverse communities and through artistic expression. SI outreach and education programs share scientific and social understanding of our changing planet through exhibits and public programs, annually reaching nearly 14 million visitors in-person and 170 million online. SI's trust status allows it to leverage private funds for additional research, education, and outreach programs.

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 plastic 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

CDC: Centers for Disease Control and Prevention

CCHHG: Interagency Crosscutting Group on Climate Change and Human Health

CCIWG: Carbon Cycle Interagency Working Group

CMIP: Coupled Model Intercomparison Project

CMRA: Climate Mapping for Resilience and Adaptation

CoastsIG: Coasts Interagency Working Group

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

FrEDI: Framework for Evaluating Damages and Impacts

FY: Fiscal Year

GCRA: Global Change Research Act

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

IWCG: Interagency Integrated Water Cycle Group

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

MRC: Mekong River Commission

NASA: National Aeronautics and Space Administration

NCA: National Climate Assessment

NCO: USGCRP National Coordination Office

NIDIS: National Integrated Drought Information System

NIST: National Institute of Standards and Technology

NNA1: First National Nature Assessment

NOAA: National Oceanic and Atmospheric Administration

NPS: National Park Service

NSF: National Science Foundation

ObsIWG: Observations Interagency Working Group

ONR: Office of Naval Research

OSTP: Office of Science and Technology Policy

SGCR: Subcommittee on Global Change Research

SI: Smithsonian Institution

SCCC: Social Sciences Coordinating Committee

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

USFWS: U.S. Fish and Wildlife Service

USGCRP: U.S. Global Change Research Program

USGS: U.S. Geological Survey

WCRP: World Climate Research Programme

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White House Office of Science and Technology Policy: <https://www.whitehouse.gov/ostp/>

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Integrated Observations Interagency Working Group: <https://www.globalchange.gov/our-work/interagency-groups/obsiwg>

compendium of federal Earth observation activities: <https://www.globalchange.gov/our-work/interagency-groups/obsiwg/observations-compendium-2024>

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monthly seminar series: <https://www.youtube.com/playlist?list=PLDV9DpMRYpUQ6PTDZMSDIhcm24xEh9rLq>

Coasts Interagency Group: <https://www.globalchange.gov/our-work/interagency-groups/coastsig>

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International Activities Interagency Working Group: <https://www.globalchange.gov/our-work/interagency-groups/iaiwg>

LACI: <https://www.globalchange.gov/our-work/laci>

U.S. Group on Earth Observations: <https://usgeo.gov/>

AmeriGEO: <https://www.amerigeo.org/>

Inter-American Institute for Global Change Research: <https://www.iai.int/>

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Local3030 Islands Network: <https://www.islands2030.org/partners>

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Clean Air Catalyst: <https://www.cleanaircatalyst.org/>

measure air pollution levels: <https://www.airnow.gov/international/us-embassies-and-consulates/>

SERVIR: <https://www.nasa.gov/servir/>

Southeast Asia region: <https://servir.adpc.net/about/about-servir-sea>

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NCA Atlas: <https://atlas.globalchange.gov>

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plan: <https://www.whitehouse.gov/wp-content/uploads/2023/11/NationalGHGMMISStrategy-2023.pdf>

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World Climate Research Programme: <https://www.wcrp-climate.org/>

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Program website: <https://www.globalchange.gov/>

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Subcommittee on Global Change Research: <https://www.globalchange.gov/about-us/organization>

White House Office of Science and Technology Policy: <https://www.whitehouse.gov/ostp/>

Interagency Groups: <https://www.globalchange.gov/our-work/interagency-groups>

Carbon Cycle Interagency Working Group: <https://www.globalchange.gov/our-work/interagency-groups/cciwg>

Climate Engagement and Capacity Building Interagency Group: <https://www.globalchange.gov/our-work/interagency-groups/cec>

Coasts Interagency Group: <https://www.globalchange.gov/our-work/interagency-groups/coastsig>

Federal Adaptation and Resilience Group: <https://www.globalchange.gov/our-work/interagency-groups/farg>

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Indicators Interagency Working Group: <https://www.globalchange.gov/our-work/interagency-groups/indiwg>

Integrated Observations Interagency Working Group: <https://www.globalchange.gov/our-work/interagency-groups/obsiwg>

Interagency Crosscutting Group on Climate Change and Human Health: <https://www.globalchange.gov/our-work/interagency-groups/cchhg>

Interagency Group on Integrative Modeling: <https://www.globalchange.gov/our-work/interagency-groups/igim>

Interagency Integrated Water Cycle Group: <https://www.globalchange.gov/our-work/interagency-groups/iwgc>

International Activities Interagency Working Group: <https://www.globalchange.gov/our-work/interagency-groups/iaiwg>

Social Sciences Coordinating Committee: <https://www.globalchange.gov/our-work/interagency-groups/sscc>

Sustained Assessment Working Group: <https://www.globalchange.gov/our-work/interagency-groups/sawg>

U.S. Department of Agriculture: <https://www.usda.gov/>

Caribbean Drought Learning Network: <https://caribbeanclimatehub.org/projects/caribbean-drought-learning-network/>

Southwest Drought Learning Network: <https://dln.swclimatehub.info/>

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National Oceanic and Atmospheric Administration: <https://www.noaa.gov/>

National Institute of Standards and Technology: <https://www.nist.gov/>

Department of Defense: <https://www.defense.gov/>

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publicly accessible: <https://drsl.serdp-estcp.org/Site>

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Department of Energy's: <https://www.energy.gov/>

Office of Science: <https://www.energy.gov/science/office-science>

U.S. Department of Health and Human Services: <https://www.hhs.gov/>

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Department of Homeland Security: <https://www.dhs.gov/>

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U.S. Geological Survey: <https://www.usgs.gov/>

Department of the Interior: <https://doi.gov/>

Department of State: <https://state.gov>

Department of Transportation: <https://transportation.gov>

United States Aviation Climate Action Plan: https://www.faa.gov/sites/faa.gov/files/2021-11/Aviation_Climate_Action_Plan.pdf

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Resilience and Disaster Recovery (RDR) Tool Suite: <https://volpeusdot.github.io/RDR-Public/>

Environmental Protection Agency: <https://epa.gov>

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National Aeronautics and Space Administration: <https://nasa.gov>

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National Science Foundation: <https://nsf.gov>

Smithsonian Institution: <https://si.edu>

U.S. Agency for International Development: <https://www.usaid.gov/>



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