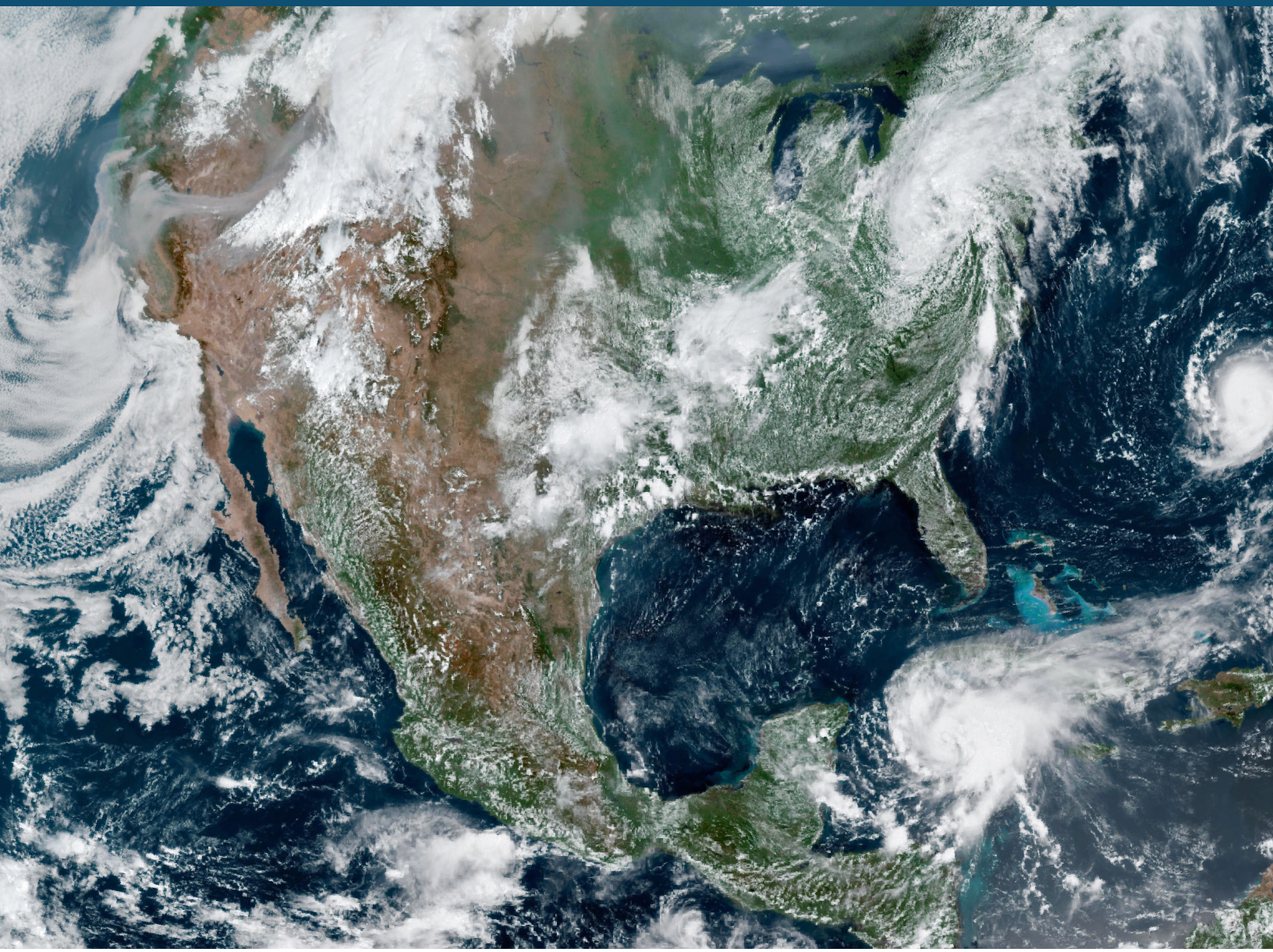
U.S. Global Change Research Program



The U.S. Global Change Research Program 2022–2031 Strategic Plan

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

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This report meets the requirements set forth in the U.S. Global Change Research Act of 1990 (Section 104) to provide a 10-year plan establishing goals and priorities for Federal global change research. It does not express any regulatory policies of the United States or any of its agencies or make any findings that could serve as predicates for regulatory action.

Image Credits

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

Page 3: Snowy mountains in western Virginia. NASA Earth Observatory image by Joshua Stevens, using Landsat data from the U.S. Geological Survey.

Page 7: Fall foliage in central Pennsylvania. NASA Earth Observatory image by Joshua Stevens, using Landsat data from the U.S. Geological Survey and data from NASA/METI/AIST/Japan Space Systems and the U.S./Japan ASTER Science Team.

Page 9: Wildfire smoke over the Pacific Northwest, July 10, 2021. NASA Earth Observatory image by Lauren Dauphin, using MODIS data from NASA EOSDIS LANCE and GIBS/Worldview.

Page 10: The Florida Keys. NASA Earth Observatory image by Lauren Dauphin, using Landsat data from the U.S. Geological Survey.

Page 19: Carrizo Plain National Monument, California. Bureau of Land Management photo by Bob Wick.

Page 23: Spring in the Tennessee Valley. NASA Earth Observatory image by Lauren Dauphin, using Landsat data from the U.S. Geological Survey.

Page 24: Rock Island Dam on the Columbia River, Washington. DOE photo by Karl Specht.

Page 28: NASA-funded researchers atop Arctic sea ice. NASA photo by Kathryn Hansen.

Page 33: Clouds over the Great Lakes in winter. NASA Earth Observatory image by Joshua Stevens, using MODIS data from NASA EOSDIS LANCE and GIBS/Worldview.

U.S. GLOBAL CHANGE RESEARCH PROGRAM

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

The U.S. Global Change Research Program (USGCRP) coordinates research across 13 Federal agencies to understand the human-caused and natural processes that influence our planet. Building on a foundation of more than $3 billion in annual investments in Federal research and development, research supported by USGCRP agencies informs the Nation to navigate the challenges of a changing environment and identify opportunities for a more resilient future.

Over more than three decades, USGCRP and its member agencies have worked together to understand the processes—particularly climate change—that are reshaping Earth's environment and capacity to support the world's people. The evidence is clear that human activities have caused unprecedented warming of the atmosphere, ocean, and land (IPCC, 2021). Communities across the country and the world are experiencing the effects of this warming, including more frequent and severe flooding, more destructive wildfires, heavier rainfall, and more extreme heat waves (USGCRP, 2018).

These and other climate changes are increasing the risk of infrastructure failure; disruption to vital public services; threats to ecosystems and species that provide benefits to people; harms to workers, industries, and the economy; and heat-related illness and death and other health impacts (USGCRP, 2018). Climate change is already causing severe disruption to essential systems—including food, water, health, energy, transportation, and natural and managed ecosystems—that help keep people safe and healthy. People who are already vulnerable due to socioeconomic inequality and past and current marginalization are disproportionately harmed by the impacts of climate change and have lower capacity to adapt (IPCC, 2022; NASEM, 2021a).

> *"Climate change is a grand challenge for society in the 21st century. The continued accumulation of greenhouse gases in the atmosphere and the growing impact of climate change on the lives of the American people increase the urgency of implementing effective, science-based policies to limit climate change and to manage its consequences. Similarly, policies are needed to address other critical global environmental changes, such as land use, biodiversity loss, and the eutrophication of Earth's ecosystem with nitrogen." (NASEM, 2021a)*

Other global changes closely associated with climate change—including biodiversity loss; urbanization and deforestation; and ocean acidification, deoxygenation, and other profound changes—compound risks to people and ecosystems. Climate change interacts with other global changes in complex ways, creating multiple cascading risks that can amplify harmful impacts. Managing climate and global change risks requires understanding complex interactions across the climate system, ecosystems, and human systems, including potential tipping points that lead to large-scale and potentially abrupt changes, and how these changes will be experienced across different social groups (NASEM, 2021a).

"Climate change is a threat to human well-being and planetary health. Any further delay in concerted anticipatory global action on adaptation and mitigation will miss a brief and rapidly closing window of opportunity to secure a liveable and sustainable future for all." (IPCC, 2022)

Together, climate and global change present an immediate and growing threat to human welfare and planetary health. Since publication of USGCRP's last decadal Strategic Plan in 2012, climate and global change-related impacts have accelerated, and actions to avoid or reduce harms have increased as more people experience more severe impacts. Demand for authoritative information to support decision-making at local to global scales is growing, and needs are becoming more specific and complex.

Near-term actions that aim to limit global warming to close to the 1.5°C target established by the Paris Agreement would substantially reduce negative impacts and costs related to climate change but cannot eliminate them all. Beyond the next few decades, the amount and rate of climate change and associated impacts depend strongly on near-term actions to reduce greenhouse gas emissions and adapt to ongoing changes (IPCC, 2022). Other aspects of global change that interact with, and often influence, climate change and how its impacts are experienced add complexity to this challenge. Preventing the worst consequences of warming will require global, transformational efforts to reduce net greenhouse gas emissions and prepare infrastructure and communities for unavoidable changes, such as continued near-term increases in destructive coastal flooding and deadly extreme heat events.

The research needed to inform responses to climate and global change extends beyond the scope of previous decadal plans and demands enhanced ambition on the part of USGCRP and its member agencies. The 2022-2031 Strategic Plan lays out a framework for meeting this expanded vision (Box 1) to better equip the Nation and the world to respond to change and manage critical risks.

Box 1. Pillars of the 2022–2031 Strategic Plan

Advancing Science. Advance scientific knowledge of interconnected natural and human systems and risks to society from global change.

Engaging the Nation. Enhance the Nation's ability to understand and respond to global change by expanding participation in the Federal research enterprise.

Informing Decisions. Provide accessible, usable information to inform decisions on mitigation, adaptation, and resilience.

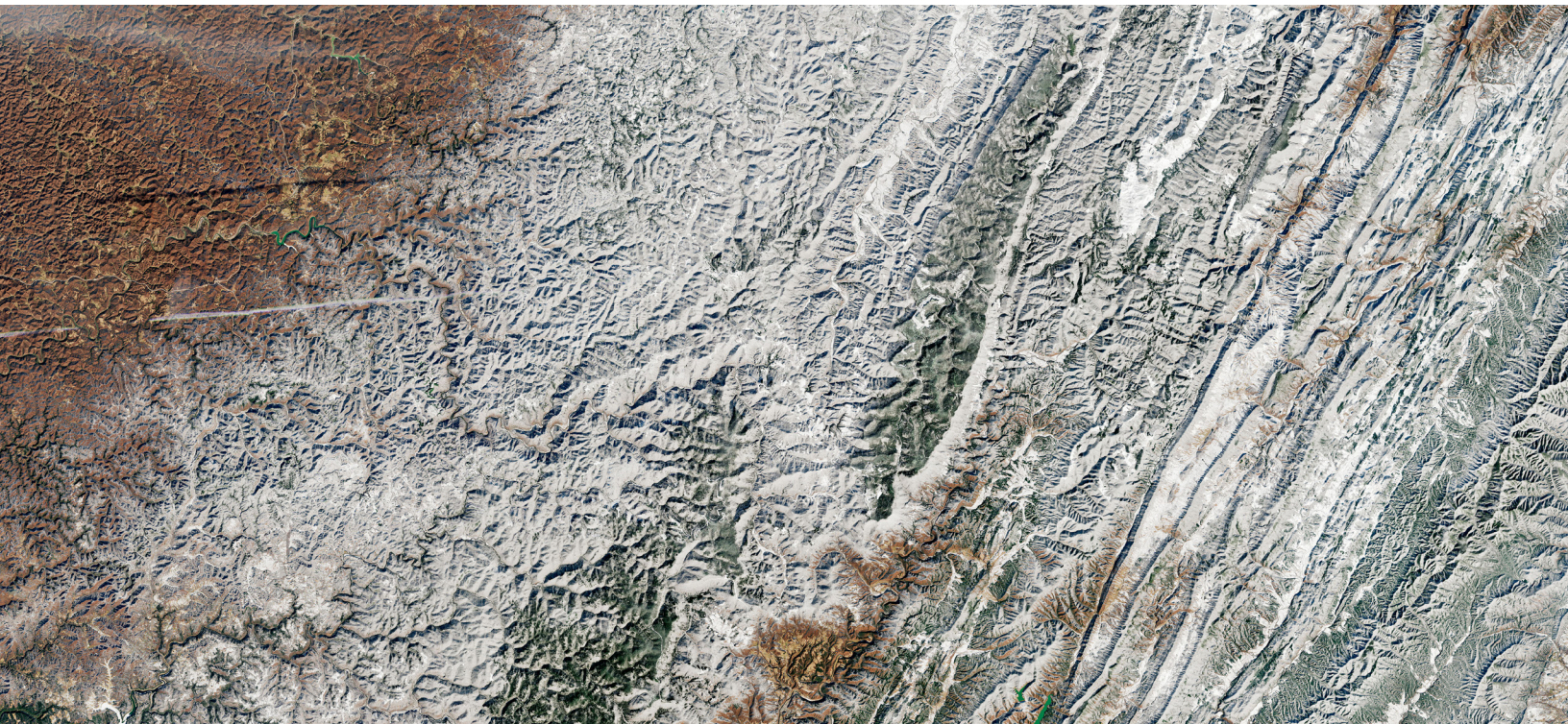
Collaborating Internationally. Build global capacity to respond to global change through international cooperation and collaboration.

Over the next decade, USGCRP agencies will develop new understanding of climate and global change risks affecting interconnected natural and human systems, how the behavior of those systems affects risks to society, and the social context and consequences of measures to reduce risks. Enhancing the integration of social and natural sciences in all stages of research, and the use of transdisciplinary approaches to collaborative research, will be critical to advancing knowledge and the ability to inform decisions.

To better understand user needs and improve the usability of information, USGCRP and its member agencies will expand participation in global change research to new audiences and prioritize engagement with populations, communities, and organizations that face higher risks from climate and global change. Increased engagement with decision-makers at various levels will enable USGCRP to better target its research and science products to the needs of different decision-making processes. As USGCRP's agencies collaborate to invest research funding and translate results into actionable information, the Program will emphasize diversity, equity, inclusion, justice, and accessibility to help ensure that Americans benefit equitably from Federal science investments.

The world faces critical challenges that affect all nations and demand solutions at a global scale. Global scientific collaboration is key to maintaining and advancing our capability to understand and communicate emerging global change issues and inform responses at local to international scales. USGCRP will expand cooperation with international organizations, initiatives, and research networks to further enhance the ability of the Nation and the world to understand, assess, predict, and respond to global change.

USGCRP's 2022-2031 Strategic Plan lays the foundation for meeting a new set of challenges and demands for useful, accessible, and inclusive data and information alongside advancements in understanding of a rapidly changing environment. As the Nation responds to these challenges, USGCRP seeks to provide the information and tools needed to inform actions to manage risks and strengthen resilience. This Plan sets a course to expand the impact of Federal global change science and better deliver this urgently needed information to the Nation and the world.



INTRODUCTION

Box 2. 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 of 1990 (15 U.S.C. § 2921) 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." The Program emphasizes research that can be used to answer critical questions about the changing Earth system and how the world can respond to those changes. USGCRP is also charged with "disseminating research information that would be useful in preventing, mitigating or adapting to the effects of global change."

Our Vision
A Nation, globally engaged and guided by science, meeting the challenges of climate and global change for the benefit of all.

Our Mission
To empower the Nation and the world to anticipate and respond to urgent risks of climate and global change by creating and providing accessible, usable knowledge.

USGCRP's membership (Figure 1) includes agencies that conduct global change research and agencies that use it to carry out their missions, creating opportunities for decision-makers to communicate information needs directly to scientists and for scientists to support informed decision-making.

Figure 1 – U.S. Global Change Research Program Member Agencies (Top) *Department of Agriculture; Department of Commerce; Department of Defense; Department of Energy; Department of Health and Human Services; Department of the Interior* **(Bottom)** *Department of State; Department of Transportation; Environmental Protection Agency; National Aeronautics and Space Administration; National Science Foundation; Smithsonian Institution; U.S. Agency for International Development.*

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 objectives described here. This document uses USGCRP (or "Program") in reference to the collective activities of the Subcommittee on Global Change Research of the National Science and Technology Council, USGCRP member agencies or bureaus, USGCRP Interagency Groups, and the USGCRP National Coordination Office.

Information on USGCRP's legal mandate, membership, and structure is available at https://www.globalchange.gov/about.

The impacts of global climate change are already causing severe disruptions to many Americans' lives and imposing high economic costs and other adverse impacts on the environment and human well-being (USGCRP, 2018). The effects of other global environmental changes—such as biodiversity loss, the spread of invasive species, and land-use change—interact with climate change and are worsening risks to people, ecosystems, infrastructure, and other services (NASEM, 2021a).

The burden of climate change is not felt equally across society. Climate-related hazards and other impacts disproportionately affect communities that are already overburdened by environmental and health risks and have lower capacity to adapt, including communities of color and low-income communities (USGCRP, 2018; NASEM, 2021a). For example, discriminatory policies such as redlining forced communities of color into the least valuable, often low-lying areas lacking green space that are now more vulnerable to adverse climate impacts, including flooding, extreme heat, and associated health impacts (Hoffman et al., 2020; Nowak et al., 2022). Responses to climate change, including adaptation and mitigation, can themselves exacerbate social inequities and enhance vulnerability for certain groups, unless their broader social implications are explicitly accounted for in response measures (NASEM, 2021a).

Box 3. Diversity, Equity, and Inclusion

The impacts of global change, and the capacity to respond to them, are interconnected with historical and current disparities and injustices. Effective solutions to global change challenges require diversity of thought, knowledge, and experience, and greater efforts are needed to evaluate risks, impacts, and responses from the perspectives and practices of equity and environmental justice. USGCRP will emphasize diversity, equity, inclusion, justice, and accessibility (DEIJA) 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. USGCRP's DEIJA statement is available at https://www.globalchange.gov/content/usgcrp-diversity-equity-justice-inclusion-and-accessibility-statement.

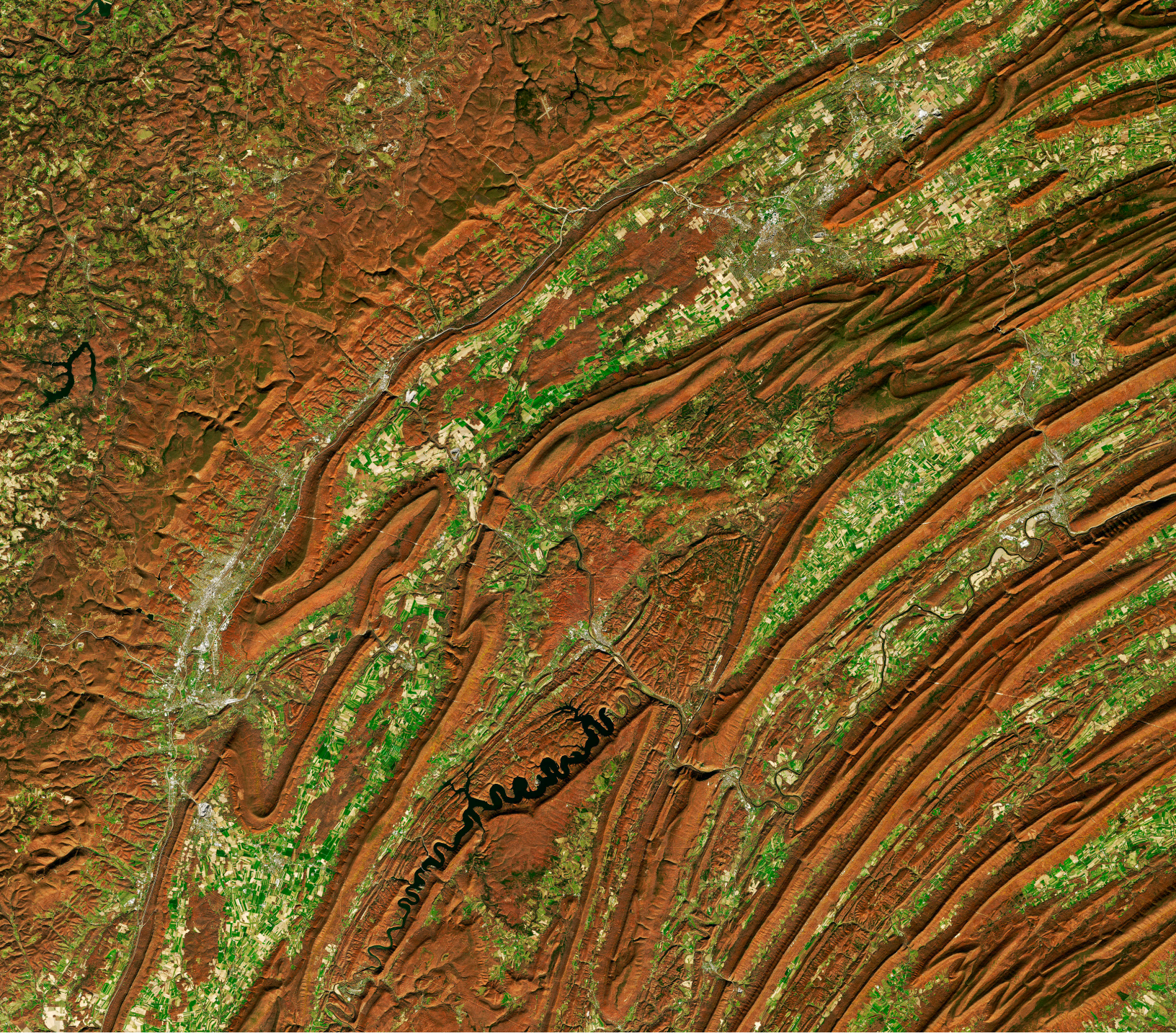
USGCRP has an important role to play in bringing together scientists and decision-makers to identify and address priority research and information needs for addressing the challenges of climate and global change. The Program will support expanded coordination across Federal agencies to design and implement research and dissemination programs that advance knowledge of climate and global change impacts, risks, and responses, including the following:

- emissions mitigation and interventions to reduce atmospheric greenhouse gas concentrations and warming[1]
- measures to adapt to the impacts of global change

1 Note: climate intervention is an evolving area of research, with interagency efforts called for in the FY22 Omnibus appropriation. USGCRP's plans for research on this topic will be informed by the development of the Congressionally mandated plan, as well as by the recommendations of the National Academies of Sciences, Engineering, and Medicine (2015, 2021a, 2021b).

- the social context, consequences, and efficacy of various adaptation, mitigation, and intervention measures, including their impacts on equity
- complex interactions among climate and global change and human systems (e.g., food, water, and health) and the risks these interactions pose to society
- cascading and compounding events and challenges, including the potential to cross thresholds that could lead to large impacts and irreversible changes
- how communities can build resilience to climate and global changes while protecting those who are most vulnerable
- how the characteristics of global change data, information, and products affect their accessibility and use

This knowledge base, informed by engagement with science users at all levels, provides the foundation for tools and information designed to meet user needs. USGCRP and its member agencies also recognize the opportunity to build a more diverse Federal workforce, expand opportunities in the broader scientific community, and work toward a diverse research enterprise equipped to meet the challenges of climate and global change.



USGCRP 2022–2031 STRATEGIC PLAN

The 2022–2031 Strategic Plan provides a framework to accelerate systems-based research and its translation to inform decision-making to meet the challenges of climate and global change (Figure 2). This framework incorporates science to understand climate and global change risks, responses, and societal needs at scales relevant to decision-makers. It outlines a strategy for engagement across agencies at all levels of government and with the public to understand and meet knowledge and information needs and provides for enhanced collaboration with international scientific partners.

Pillars of the 2022–2031 Strategic Plan

Pillar 1. Advancing Science

Pillar 2. Engaging the Nation

Pillar 3. Informing Decisions

Pillar 4. Collaborating Internationally

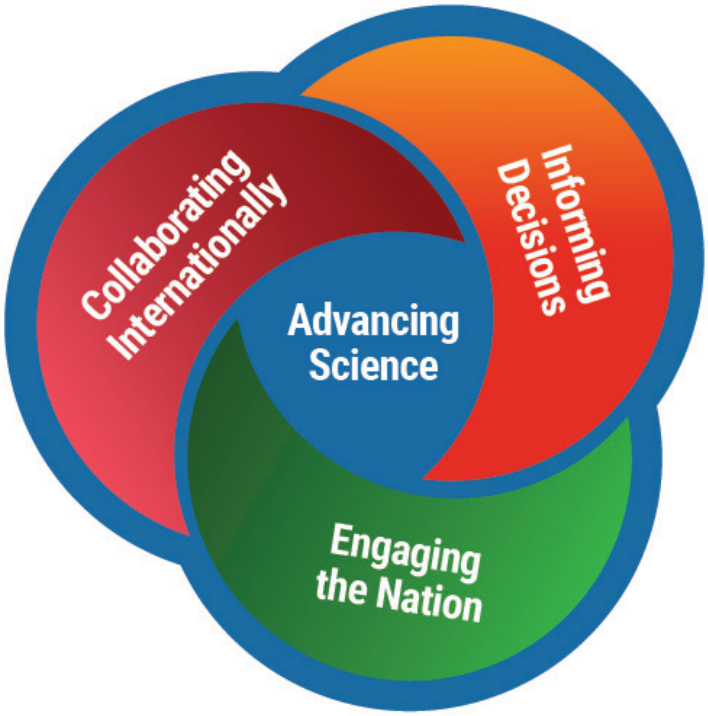
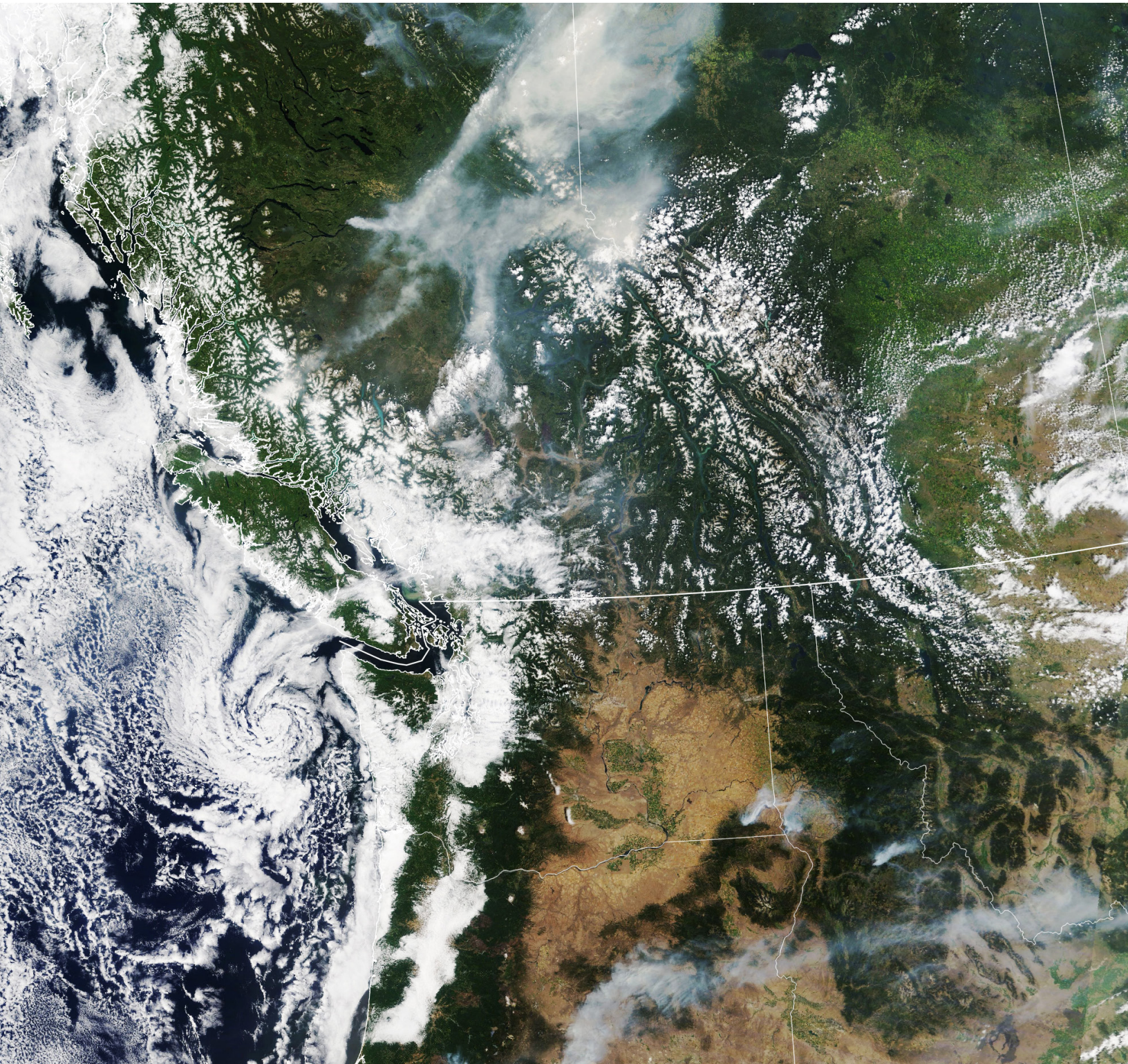
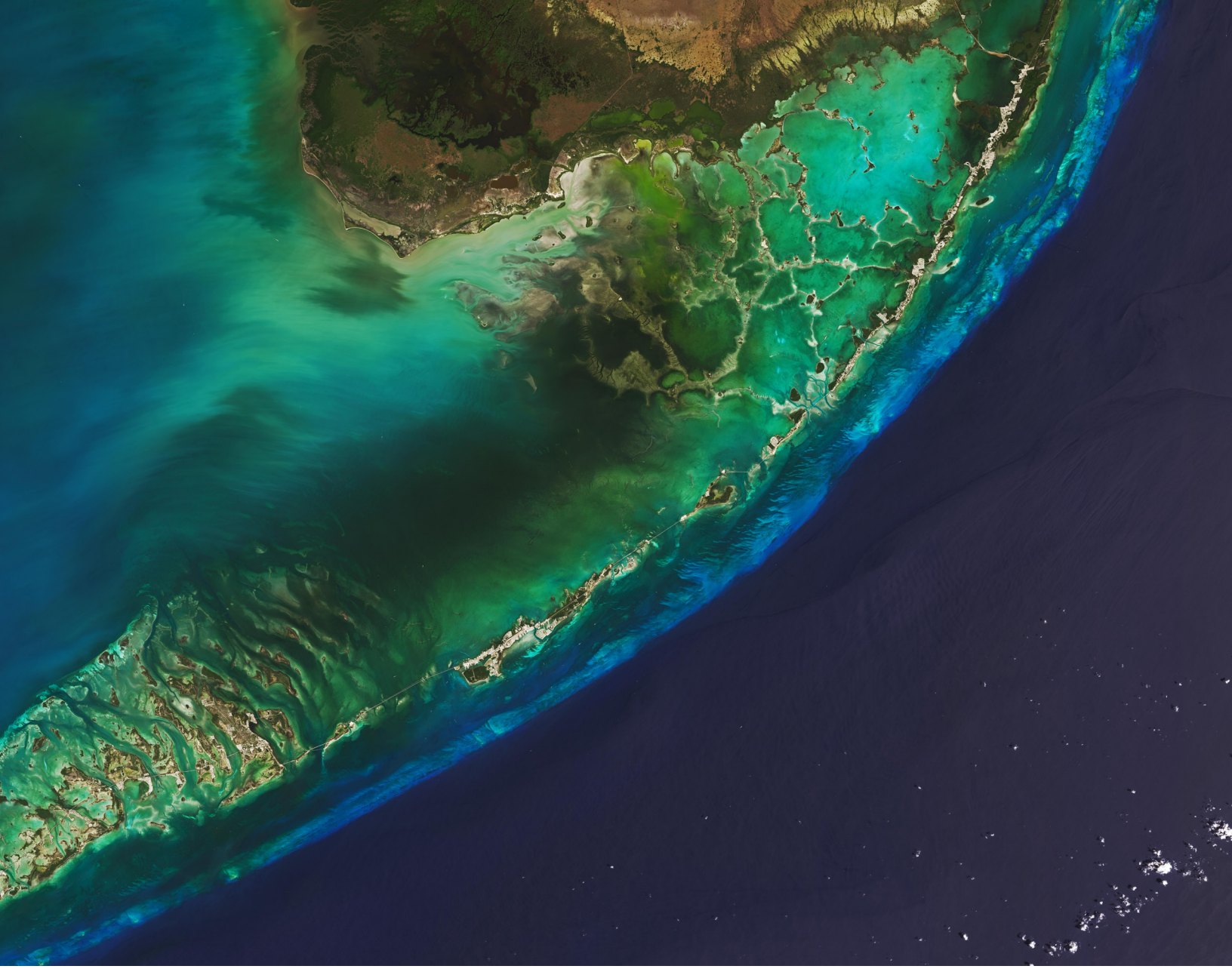


Figure 2 – This diagram illustrates the interconnections among the four pillars of USGCRP's 2022-2031 Strategic Plan.

The final section of the Plan, Fulfilling the Vision, briefly presents perspectives on overarching issues facing USGCRP. These issues emphasize the approaches that USGCRP and its member agencies will take in conducting the science discussed in the four pillars and include other aspects related to the infrastructure that enables research and research coordination.

The 2022–2031 Strategic Plan was developed by representatives of USGCRP's 13 member agencies, drawing upon the advice of the National Academies of Sciences, Engineering, and Medicine (NASEM) Committee to Advise USGCRP; feedback from public comment periods; input from Federal agencies and USGCRP Interagency Groups; input from public sessions on select topics convened by NASEM; and USGCRP's mandate under the Global Change Research Act. The Plan was approved by USGCRP's member agencies through the Subcommittee on Global Change Research of the National Science and Technology Council, which serves as the leadership team for the USGCRP.





Pillar 1: Advancing Science

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

Over the next decade and beyond, USGCRP agencies will develop new understanding of global change processes and how they affect and are affected by natural and human systems in ways that can cascade through society. Building on this knowledge, USGCRP agencies will advance user-driven science needed to address climate and global change risks affecting interconnected natural and human systems and their impacts on society (Lubchenco, 2021; NASEM, 2021a).

Earth system change

USGCRP agencies maintain core scientific and technical capabilities in understanding Earth system change:

- ***Observations*:** USGCRP agencies conduct Earth system observations at various spatial and temporal scales through satellite remote sensing and surface-based, in-water (the ocean, lakes, rivers, and streams), and airborne networks. Agencies leverage observations from state and private networks, coordinate through USGCRP Interagency Groups and with international partners, and employ emerging technologies and approaches.
- ***Modeling*:** USGCRP 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.
- ***Data access and management*:** USGCRP agencies make data freely available to the public and the private sector in forms that are accessible to and usable by decision-makers and scientists. A growing international commitment to open science, timely data access, and advanced online search capabilities helps USGCRP agencies ensure that data are consistent with the FAIRER (Findable, Accessible, Interoperable, Reusable, Equitable, and Responsible) Principles.

USGCRP agencies will build upon this foundation to advance understanding of climate and global change processes that pose critical risks to society and nature. The six foci described in this section are representative of some of the key issues being addressed by USGCRP agencies.

Extreme events

Advance understanding of the processes driving extreme events and their impacts on society.

Changing patterns of extreme weather (such as storms and heat waves) and climate-related events (such as droughts) can affect public health, national security, the economy, infrastructure, and other essential systems. Extreme events can interact and build on each other, creating multiple stressors that make it difficult to plan and improve preparedness.

USGCRP agencies will conduct fundamental research on factors that can improve the estimation of human and natural influences on extreme events, including the following:

- attribution (i.e., identifying the physical, biogeochemical, and human causes of extreme events)
- characterizing and constraining uncertainty
- improving observations
- improving model representation and accuracy
- improving climate projections

USGCRP agencies will also conduct research to improve understanding of impacts and risks from extreme events to society. Topics include the following:

- frameworks to facilitate connections between climate models and models of specific economic sectors
- differential impacts of extreme events across social groups
- implications of these impacts for mitigation and adaptation strategies

Tipping points

Improve understanding of the potential for abrupt, widespread changes in physical, natural, and human systems.

Tipping points occur when Earth system changes become irreversible, leading to large-scale shifts in the Earth system that can have significant impacts on society or the natural world. One example is the potential collapse of the West Antarctic Ice Sheet due to increased warming in the ocean and atmosphere, which would lead to greater than projected sea level rise (USGCRP, 2017). Understanding tipping points is critical to informing risk management strategies (NASEM, 2021a).

USGCRP agencies will continue to conduct research, develop models, and design observational systems to advance understanding of potential tipping points in the Earth system, emphasizing the complex interactions between physical and social systems that could help identify thresholds and the potential onset of tipping points. It is likely that some interactions are known but cannot yet be quantified, while others may exist that are currently unknown, leading to potential surprises (USGCRP, 2017).

Biodiversity

Monitor and assess the relationships among climate and global change and the distribution, productivity, and diversity of species.

The impacts of climate and global change are causing disruptions in life cycles, food webs, and the ecological connectivity of species across the land surface and ocean. These effects are projected to accelerate with continued climate change. Changes in biodiversity can also contribute to climate change by altering land cover and the carbon and nitrogen cycles. By considering climate change and biodiversity as part of a single global challenge, decision-makers can develop solutions that avoid maladaptation and maximize beneficial outcomes (Pörtner et al., 2021).

USGCRP agencies will continue to document biodiversity loss, global trends, and potential future losses in marine, freshwater, and terrestrial ecosystems—and the interaction of these trends with climate change—through the following research activities:

- remote sensing and in situ observations
- field campaigns
- biological monitoring networks
- modeling of species and ecosystem responses to changing environmental conditions

- model–observation experiments to better understand the processes at work and patterns of change
- development and provision of tools and synthesis products that inform actions to conserve biodiversity and employ nature-based solutions to address multiple threats

USGCRP will continue to contribute to global and regional assessments of changes in biodiversity. These efforts include the Intergovernmental Science–Policy Platform on Biodiversity and Ecosystem Services, the international Group on Earth Observation's Biodiversity Observation Network, and Future Earth.

Land and ocean change

Understand trends in and future evolution of human-driven changes to Earth's land and ocean.

Human activities are altering Earth's land and ocean. Land cover and land-use change driven by urbanization, agriculture, deforestation, and other processes is one of the primary drivers of global change. Ocean activities including oil, gas, and mineral exploration and extraction; fishing; shipping; renewable energy generation; habitat destruction; and pollution also impact global change. These land and ocean changes are also affected by climate change, in turn affecting the carbon and water cycles, climate, air and water quality, the rate of biodiversity loss, and the capacity of the environment and society to cope with disasters.

USGCRP agencies will continue to use multiple approaches to characterize land and ocean changes:

- large-scale satellite monitoring carried out through the Landsat program (ongoing since 1972), ocean pattern and process monitoring, and compatible land-imaging satellites of domestic and many international partners
- in situ measurements
- collaboration with an increasing number of commercial entities that collect very high-resolution data
- modeling to characterize ongoing changes, their origins, and potential future evolution
- studies conducted by individual investigators and interdisciplinary teams in both natural and social sciences
- emerging techniques in artificial intelligence and machine learning to extract all possible information from available data sources and approaches

Data and results from these efforts are routinely shared among a wide range of research and applications users in the United States and globally.

Climate sensitivity and carbon cycle feedbacks

Reduce uncertainties in estimates of future climate system behavior.

Climate sensitivity is a measure of how Earth's average temperature will respond to changes in atmospheric greenhouse gas concentrations. However, humans control greenhouse gas emissions, not concentrations; the relationship between emissions and concentrations is determined by feedbacks in the carbon cycle that act to

enhance or reduce the warming effect of human emissions. Both carbon cycle feedbacks and climate sensitivity must be understood to predict the effects of emissions on global temperature.

Physical feedbacks in the climate system—such as changes in cloud cover or sea ice extent—play a major role in climate sensitivity. Models and observations currently indicate a range of possible sensitivities, resulting in a range of projections for future climate change even under the same emissions scenario. To improve estimates of climate sensitivity, USGCRP agencies will conduct the following activities:

- maintain observational networks and extend existing observation time series
- use the latest generation of models, new statistical and theoretical approaches, paleoclimate reconstructions, and new observational data

Key research objectives include the following:

- improve the ability to model feedbacks in the climate system, including changes in cloud cover, atmospheric water vapor, and ocean circulation, and accelerated warming in the Arctic
- understand Earth's climate history and how natural systems have responded to climate forcing through geologic time

To date, carbon cycle feedbacks have lessened the warming effect of human greenhouse gas emissions. Climate warming is expected to alter the efficiency of the land and ocean carbon sinks, resulting in a greater fraction of future emissions remaining in the atmosphere and increasing global temperature. Understanding the processes governing how the land and ocean carbon sinks respond to warming is an urgent research priority.

Uncertainty

Advance quantification of uncertainty in Earth observations and modeling.

Uncertainty in model predictions consists of uncertainties due to observational error, data assimilation assumptions, simplifications with parameterizations, and numerical methods in modeling. Model uncertainty is an important contributor to uncertainty in climate projections. Characterization of uncertainty is a critical component in determining the validity of climate projections and related decisions for risk management.

USGCRP agencies will use improved representation of processes in models, machine learning, and artificial intelligence to more rapidly advance quantification of uncertainty. Activities will include the following:

- integration of uncertainty quantification directly into the model development and intercomparison process, using advanced statistical techniques
- development of integrated uncertainty frameworks, incorporating climate change research, feedbacks, and applications

Risks to coupled human–natural systems

Climate change is already causing severe disruptions to human systems—those designed, built, and operated by people—including health, agriculture, fisheries, aquaculture, food, water, energy, transportation, built infrastructure, the economy, national and international security, communities, institutions, and culture. These systems affect and are affected by natural systems that include the physical climate system and ecosystems (both unmanaged and managed, such as croplands). Disruptions to these systems are expected to grow in magnitude, extent, and type, demonstrating the urgency of improving our understanding of these changes and ways to respond to them. To meet the needs of decision-makers for knowledge and data to inform mitigation, adaptation, and resilience measures, USGCRP agencies will build upon Earth systems research to expand existing and begin new research on the interactions between natural Earth systems and human systems that support society—or coupled human–natural systems.

USGCRP agencies maintain core capabilities to understand diverse, dynamic, and complex human systems:

- ***Observations*:** USGCRP agencies observe the status of and changes in diverse and dynamic human systems through land use, health, economic and other social activity, resource development and use, and other measures. USGCRP agencies work with other Federal agencies to incorporate additional observed data related to human systems, such as population, workforce, and housing.
- ***Modeling and analysis*:** USGCRP agencies develop and use integrated assessment models and social and physical science methods that apply and analyze observational data to understand how natural and human systems interact now and how those interactions may change in the future.

Understanding how coupled human–natural systems interact with global change requires integrating these components to understand systems as a whole. Advancing the science of coupled human–natural systems requires integrating the social and natural sciences at each phase of the research process, from defining the problem to communicating results.

Complex, adaptive, interconnected systems

Understand how the dynamics of coupled human–natural systems affect vulnerability and risk.

The relationships between human and natural systems are being increasingly affected by global change, leading to growing vulnerabilities and risks to both. USGCRP agencies will conduct research to understand the behavior of interconnected human and natural systems as they respond to global change, accounting for a wide range of other physical and societal issues that affect vulnerability, risk, and the capacity to respond. Human systems, the physical climate system, and ecosystems are interdependent and interact with one another in complex ways. These interactions include dynamics within one or more natural systems, within one or more human systems, and processes through which natural and human systems affect one another. Dynamic, coupled systems can exhibit behaviors that differ from the behaviors of each system independently.

Understanding how the dynamics of such systems affect vulnerability and risk is an increasingly urgent research need that is critical to our ability to inform effective response decisions.

Research topics include the following:

- ***Nonlinear changes in complex systems:*** USGCRP agencies will investigate the potential for unexpected and nonlinear changes to conditions that are very different from what would be expected by studying individual systems in isolation. This research will expand upon existing modeling research that focuses on understanding complex natural systems and incorporate what are now largely separate economics-based models to evaluate societal decisions. USGCRP Interagency Groups will emphasize coordinated efforts across USGCRP agencies to develop and evaluate improved model processes and integration.
- ***Tipping points:*** USGCRP agencies will apply research on tipping points and state changes described above to understand how societal risks are affected by the dynamics of interdependent systems, including the potential for beneficial tipping points (Sharpe & Lenton, 2021).
- ***Transdisciplinary approaches:*** USGCRP agencies will apply transdisciplinary approaches to understand how the dynamics of interdependent systems affect vulnerability and risk. Transdisciplinary research aims to develop solutions to real-world challenges by engaging nationally and internationally to combine scientific, stakeholder, and traditional knowledge, as illustrated by USGCRP's efforts in Latin America and the Caribbean (Watson et al., 2022). The general design of transdisciplinary research entails three steps that engage stakeholder groups: co-design, co-production, and co-dissemination. Transdisciplinary efforts (for example, participatory scenario development) produce model results and other research outputs that are usable by diverse audiences.
- ***Justice and equity:*** USGCRP agencies will conduct research that evaluates the consequences for justice and equity related to vulnerabilities to global change and risks caused by unexpected and unintended responses of complex, interconnected systems.

Global change impacts, risks, and vulnerability

Understand dynamics affecting the vulnerability of human–natural systems to global change impacts.

USGCRP agencies will conduct research to understand and assess the global change-related impacts, risks, and vulnerability of people and human systems and how they vary across different social groups. This requires understanding changes in Earth systems in combination with how those changes affect, and are affected by, human systems in the context of non-environmental factors that affect risk and vulnerability. Understanding the dynamics of these interacting and interdependent systems increasingly requires a transdisciplinary research approach. As one example, the One Health approach uses a transdisciplinary lens to understand how global change impacts the interconnections among people, animals, plants, and their shared environment. By considering the full scope of risks, this approach supports development of more effective strategies to reduce negative impacts on human health.

USGCRP agencies will conduct research using an integrated systems-based approach to understand the vulnerabilities of coupled human–natural systems to the impacts of global change by coordinating efforts through USGCRP Interagency Groups, several of which have been formed since the previous decadal Strategic Plan in response to increasingly urgent needs to inform policy actions. USGCRP and its member agencies are also coordinating with other interagency groups, including those focused on understanding the impacts

of global change on geopolitical security. Activities that aim to increase knowledge and data about impacts, risks, and vulnerabilities include the following:

- improving observational and projected climate change information at local scales
- understanding the distribution of impacts across regions, ecosystems, and populations
- evaluating the impacts of global change in the context of other local changes and pre-existing conditions, such as population or economic changes
- understanding cascading risks, or risks related to a chain of impacts that result in increased risks or failures in other systems or locations
- evaluating cumulative impacts, or impacts from multiple causes leading to effects that can be greater than the sum of the individual impacts

Social drivers, impacts, and responses

Use social science insights and methods to understand global change risks, opportunities to build resilience, and effective delivery of global change information.

USGCRP agencies will increase research into the behavioral, societal, economic, and cultural aspects of global change to meet the critical, pressing needs voiced by decision-makers to improve our understanding of risks and ability to develop effective responses to global change. This includes elevating different ways of knowing to define, conduct, and evaluate research—including Indigenous Knowledge—to inform effective decisions. In the context of coupled human–natural systems, research to inform effective responses needs to integrate considerations of and practices that support equity, social justice, and community welfare, among other social components. Coordinating these efforts through the USGCRP Interagency Groups and incorporating practices identified in Pillar 2. Engaging the Nation and Pillar 3. Informing Decisions are among the approaches USGCRP will take to enhance the effectiveness of these efforts.

USGCRP agencies will explore the following topics:

- the role of human systems as drivers of and feedbacks to global change, including in specific social contexts (e.g., urban areas) through initiatives such as the DOE Integrated Field Laboratories
- how human systems affect and are affected by the risks and impacts of global change
- the social context of understanding and responding to global change information, data, and knowledge
- different ways of understanding culturally important practices and resources affected by global change, including the recognition and inclusion of Indigenous Knowledge (see Pillar 3. Informing Decisions), and methods to incorporate that understanding into decision analyses
- the political economy of developing, adopting, and implementing responses to global change
- approaches for local decision-making under uncertainty
- methods for communicating, engaging, and collaborating with communities and research users to understand how scientific information can be most effectively translated for use in decision-making

Response measures

Evaluate the effectiveness, social context, and consequences of actions to manage climate and global change risks.

Responses to climate and global change include measures to 1) adapt to the impacts of global change; 2) reduce the drivers of climate change through emissions mitigation and reductions in atmospheric greenhouse gas concentrations; and 3) stem global loss of biodiversity. As decision-makers accelerate development and application of response actions, understanding potential actions and their consequences—and effectively communicating that understanding—becomes increasingly important and requires research that integrates insights from the natural sciences, engineering, social sciences, and the humanities. Responses are inherently social actions, requiring an understanding of the social context and consequences of response actions, including the justice and equity consequences of those actions. Building this understanding is crucial, given the potentially transformative nature of the large-scale technological and societal changes associated with transitions to low-emission energy, urban, and other systems.

USGCRP agencies will conduct research, analyses, and modeling that will help inform decisions aimed at managing and mitigating risks associated with climate and global change. Examples of USGCRP mitigation-related science and focal topics include the following:

- the benefits, costs, trade-offs, and path dependencies of and interactions among actions taken to manage risks from climate and global change
- evaluation of mitigation scenarios and outcomes, including the level of mitigation that is needed based on our knowledge of Earth system behavior
- analysis of competing risks (e.g., risks of global change impacts relative to the risks posed by responses)
- research on how human systems may respond to and be affected by alternative adaptation, mitigation, and intervention[2] actions and analyses of the differential consequences of response actions across social groups
- how ecological systems can affect and be affected by different options
- approaches for effective engagement and communication with the users of scientific information
- methods for decision-making under conditions of uncertainty

USGCRP agencies will increase efforts to understand community-level needs, information use, impacts, and responses. This will require active engagement and cooperation with affected communities, expanded reliance on social sciences and transdisciplinary approaches, and a recognition of past and current disparities and injustices experienced by many of the most vulnerable communities. Involvement of communities in all stages of global change research can result in more inclusive research that recognizes and includes diverse community needs and capabilities, including Indigenous Knowledge, and contributes to more just, effective, and sustainable responses (see Pillar 2. Engaging the Nation and Pillar 3. Informing Decisions).

2 Note: climate intervention is an evolving area of research, with interagency efforts called for in the FY22 Omnibus appropriation. USGCRP's plans for research on this topic will be informed by the development of the Congressionally mandated plan, as well as by the recommendations of the National Academies of Sciences, Engineering, and Medicine (2015, 2021a, 2021b).

Pillar 2. Engaging the Nation

Enhance the Nation's ability to understand and respond to global change by expanding participation in the Federal research enterprise.

An open, inclusive, and transparent process for creating scientific knowledge enhances the salience, credibility, and usability of information for decision-making. USGCRP and its member agencies will continue to expand participation in Federal science and contribute to a research enterprise that meets the needs of users, particularly those most affected by global change. Over the next decade, USGCRP agencies will expand their ability to foster meaningful engagement among scientists, affected communities, and decision-makers.

Many decision-makers may not yet recognize how climate and global change information can be useful in their operations or have the capacity to use it. They may also be limited in their ability to provide input on needed information through engagement with science producers. Efforts that demonstrate the value of climate and global change information in decision-making can help establish the credibility, utility, and applicability of USGCRP data, science, and products, while improving science literacy and public trust in science. Long-term investments in collaboration will help ensure that communities find USGCRP's engagement efforts meaningful and valuable. USGCRP and its member agencies will expand upon existing avenues for engagement with decision-makers and integrate insights from the social sciences on what makes engagement successful.

Organizations

Expand engagement with organizations that develop and use global change information to identify science needs.

Federal Agencies and Departments. USGCRP will increase engagement with non-USGCRP Federal agencies and departments that need global change information to serve their constituencies. Means of engagement will include activities such as collaborative workshops, risk- and vulnerability-framing exercises, and direct discussions. Bi- or multi-directional platforms will be used to provide information where it is most needed and to help design future Program investments.

To increase Federal capacity for managing sectoral portfolios, USGCRP agencies will conduct scientific workforce development to better connect Federal leaders and employees with appropriate global change information and tools. A focal point of this effort will be training Federal employees on the available information and tools that are appropriate to agency sectors and stakeholders, including for application on Federal lands.

Federal Regional Science Organizations. USGCRP will maintain a liaison with Federal Regional Science Organizations (RSOs) external to USGCRP via the relevant agencies' Subcommittee on Global Change Research Principals to address needs for climate science research and decision support via trusted, ongoing relationships with regional stakeholders, as well as to facilitate cross-institutional and sectoral partnerships. USGCRP will amplify collaborative activities among the RSOs and cooperate in those activities as invited and appropriate. RSOs include NOAA's Climate Adaptation Partnerships[3] teams, DOI's Climate Adaptation Science Centers, and USDA's Climate Hubs. The Program will work with the RSOs, as invited and appropriate, to explore technical, educational, and interpretive activities for maximizing engagement potential. USGCRP will prioritize standardized, centralized, and built-to-purpose climate information, tools, and services as determined through its collaboration with the RSOs.

Other regional agency office capabilities that link scientific capacity with regional needs will be developed and used to meet evolving needs. Additional partners (such as the Joint Fire Science Program and Cooperative Extension Service) will also be consulted regarding potential collaborations.

External organizations. USGCRP and its member agencies will seek out opportunities to interact with external organizations to better understand their needs, decision-making frameworks, and the timescales relevant to the communities they represent. Engagement will be conducted via existing legal structures that allow

3 Note: the FY22 Omnibus renamed the NOAA Regional Integrated Sciences and Assessment program to Climate Adaptation Partnerships.

for transparent Federal relationship-building with state and local governments, non-governmental organizations (NGOs), private entities, foundations, and businesses, and government-adjacent services (such as Cooperative Extension). To accomplish this goal, USGCRP will create an engagement management system that invites, manages, prioritizes, and responds to potential engagements. USGCRP will use capacity within its Interagency Groups to explore models and modes for engagement for large programs that adhere to relevant legal frameworks to recommend an appropriate system, as well as for developing, implementing, and managing engagement.

Engagements with boundary organizations that facilitate collaboration between researchers and decision-makers represent a specific focus of this Plan. USGCRP and its member agencies will prioritize a range of geographical and topical engagements that can be sustained throughout the research-to-decision support process—and the feedback from decision-making to research—while minimizing the time and energy investment of stakeholders. The Program will prioritize people- and place-based engagements that can be scaled up and scaled out to inform a broad range of activities.

Frontline communities

Proactively engage with and learn from communities that face higher risks from climate and global change and may have lower capacity to adapt.

USGCRP will prioritize inclusion of the needs, decision frameworks, and capacities of community organizations and emergency response organizations in the Program's workflow, with a focus on underserved communities. The Program will also recognize and include Indigenous Knowledge in Programmatic activities, including the National Climate Assessment (see Pillar 3. Informing Decisions and Box 4. National Scientific Assessments). Research training via academic institutions, Tribal Colleges and Universities, Minority-Serving Institutions, and citizen science activities will increase the capacity and diversity of the scientific pipeline and, over the long term, increase the Program's ability to provide scientific services and interact with disproportionately affected communities.

Community-based adaptation efforts could include providing materials to facilitate peer-to-peer learning, capacity building, and identification of best practices for adaptive implementation, depending on local needs and circumstances. Alternative research and presentation techniques that result from these interactions will be developed and used to make the Program's findings more accessible, applicable, interoperable, and reusable.

Workforce

Advance development of a more inclusive scientific workforce.

USGCRP will contribute to multi-level educational efforts to create a more inclusive workforce. USGCRP's scientific efforts are becoming broader and more complex as the challenges from climate and global change become more evident and urgent. Specific needs and challenges vary by community, requiring a workforce that better reflects this complex and diverse Nation. These challenges require the best talent, which is found across all social identities and socioeconomic backgrounds, but has historically been less visible, selected, and elevated within the scientific community. Limited diversity across the scientific enterprise narrows the available skill, insight, and potential modes of engagement for the Program.

Research design

Enhance user participation in the research design process to improve information on critical risks for decision support.

USGCRP will expand dialogue with partners to understand decision points, capacities, and modes of decision-making, building on existing trusted partnerships to inform collaborative research design. Applied science based on community-level adaptation will help ensure the applicability and adoption of the Program's activities and outputs.

Rapid assessment and science synthesis products that are responsive to emerging stakeholder needs will be crucial to involvement of and engagement with communities facing higher risks. Activities discussed throughout Pillar 2 will each be a step towards the goal of enhanced user engagement in research design.

Box 4. National Scientific Assessments

USGCRP's most high-profile product has been the periodic assessment of the science of climate change and its impacts on the United States mandated by the Global Change Research Act (15 U.S.C. § 2936), known as the National Climate Assessment (NCA). USGCRP has released four NCAs that have informed national policymaking and provided useful scientific information to decision-makers. The Fifth NCA is under development, with anticipated release in 2023. The NCAs are synthesis products and therefore draw from and integrate across all four pillars described in this Plan.

USGCRP has also initiated an assessment of the condition of nature within the United States. The National Nature Assessment (NNA) 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, global change, society, and the economy.

USGCRP assessments are written by hundreds of experts from across the country, who help ensure that the findings are accessible, relevant, and usable by the widest possible audience. USGCRP agencies contribute to assessments through individual expertise as authors; production of scenarios, development and use of Earth system models, indicators based on Federal data, and other tools that contribute to the ongoing assessment of the state of the climate and other impacts; and scientific review. Public engagement processes help ensure that assessments are relevant to users.

USGCRP and its member agencies have also produced assessment reports on topics including health, food security, and the carbon cycle that contribute to the NCA and support decision-makers at local, state, and national levels.

Pillar 3. Informing Decisions

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

Over the next decade, USGCRP will focus on informing key mitigation and adaptation decisions at various scales to avoid or reduce risks from climate and global change. Increased engagement with decision-makers will enable USGCRP-supported research and USGCRP science products to better identify and address data, information, and product needs. A number of USGCRP agencies will provide these services, including climate model projections and impact assessments at relevant scales, as well as social science research to better understand the context within which a range of decisions are made, to support state, local, and sector-specific decision-making. USGCRP will support agencies' efforts to incorporate knowledge and information from research into the agencies' operational activities.

The Paris Agreement aims to keep global temperature rise this century to well below 2°C above preindustrial levels and pursue efforts to limit the temperature increase even further to 1.5°C. Stabilizing global temperature requires net cumulative carbon dioxide emissions to eventually approach zero, along with deep reductions in other greenhouse gas emissions. Achieving net-zero emissions of carbon dioxide would lower all future risks associated with warming and would require global transformation across all greenhouse gas-emitting sectors. As the IPCC emphasizes, every fraction of a degree matters (IPCC, 2021). The effects of a changing climate and the societal transformations needed to at least meet the Paris Agreement goals have implications for society's objectives related to biodiversity, land-use, and human welfare.

To inform policies designed to achieve net-zero emissions and inform decision-making related to other aspects of global change, USGCRP research and products will provide information on the following:

- trends in atmospheric greenhouse gas levels
- improved estimates of greenhouse gas emissions from domestic and international sources that have been difficult to quantify
- estimates of natural sources and sinks of greenhouse gases, including the role of the ocean and terrestrial systems
- future climate projections based on anthropogenic emission trends and Earth system feedbacks
- the feasibility, carbon removal potential, and risks and benefits of various carbon removal strategies, including the potential for and implications of significantly scaling up these measures—particularly for biodiversity and land use

USGCRP will continue to ensure that the best-available science produced by the Federal Government is accessible to inform adaptation actions to enhance resiliency at local to national to international scales. USGCRP research and products will provide decision-makers with information on the following:

- the changing nature and frequency of extreme events
- the evolving risks of crossing tipping point thresholds, possibly indicating abrupt and large-scale change
- varying levels of risk over time under different warming and associated socioeconomic scenarios, with greater geographic granularity and improved quantification of risk
- how these risks may affect underserved communities
- the benefits and costs—taking equity into account—of measures implemented to date and proposed options moving forward

Data and tools

Enhance usability of and public capacity to use Federal data, information, and analysis tools for decision-making.

USGCRP will help coordinate agency activities to sustain and improve existing online tools and develop new tools that allow decision-makers to engage with and find, tailor, and use relevant Federal data, software, and information, consistent with the FAIRER (Findable, Accessible, Interoperable, Reusable, Equitable, and Responsible) Principles, as a means of informing decisions and improving science literacy. USGCRP is undertaking a new initiative in 2022 that aims to make USGCRP and other relevant Federal data, tools, and information more findable, usable, and customizable, in combination with non-Federal and localized data, so that users can package and generate information at low cost for their specific decision contexts.

USGCRP will also work with its member agencies to train and increase the capacity of a range of users to engage in the use of USGCRP-produced models and information. In turn, USGCRP will use experiences with these practitioners to inform future USGCRP research, as well as how USGCRP information can be tailored and communicated to a range of different decision-makers.

Scientific assessment

Assess global change science and risks to society to support decision-making.

USGCRP will explore the use of more targeted assessment reports (i.e., on particular topics, sectors, or regions) to meet the needs of various stakeholders, while continuing to ensure that the National Climate Assessment (NCA; see Box 4. National Scientific Assessments) is an authoritative reference on current and future climate risks for the United States. USGCRP will use these products to inform mitigation and adaptation decisions at regional, national, and international scales.

USGCRP will support a U.S.-focused scenario effort that would complement the Intergovernmental Panel on Climate Change (IPCC) scenarios used in both IPCC and NCA reports, emphasizing changing socio-demographics and regional climate change, to facilitate research on regional and localized risk analysis and inform adaptation actions at various scales.

In addition, USGCRP will evaluate the implications of developments in coupled human–natural systems research for the structure and scope of future NCAs. The Fifth NCA includes chapters on complex systems and human social systems, but further adjustments may be needed to ensure that the report effectively evaluates and communicates the science of coupled human–natural systems and implications for risk management.

USGCRP assessment processes will continue to seek to ensure that decision-makers' information needs, including information on the equity dimensions of global change impacts and responses, are addressed. USGCRP will expand efforts to support research to evaluate risks from the perspective of equity and environmental justice.

Engagement to improve decision support

Enhance user engagement in the research design process to ensure that key risks are addressed, and information meets the needs of decision-makers.

USGCRP will enlist its member agencies and their existing programs and networks to enhance partnerships with stakeholders in sectors facing urgent global change risks. These partnerships will be used to better understand user needs across key sectors so that USGCRP research, products, and communications can be better targeted and tailored to decision-maker needs.

USGCRP will also engage with more Federal agencies, or parts of agencies, that are current or potential users of USGCRP information. USGCRP and its agencies will also work to engage more with underserved communities, tribal governments, and Indigenous communities to ensure that USGCRP-supported research and its products integrate and more fully meet their needs.

Indigenous Knowledge

Elevate Indigenous Knowledge in the global change research enterprise.

USGCRP will continue progress made to date in considering and including Indigenous Knowledge in the NCA and other key products, responding to an increasing call for Indigenous Knowledge holders to become true partners in climate and global change research and assessments (e.g., IARPC, 2021). USGCRP recognizes Indigenous Knowledge as one of the many important bodies of knowledge that contribute to our understanding of and ability to respond to global change.

USGCRP will explore developing special reports and/or pilot studies entirely focused on, and driven by the needs of, Indigenous Knowledge holders. Further, USGCRP will encourage member agencies to foster partnerships and facilitate co-production mechanisms with Indigenous Knowledge holders for the range of USGCRP research and products, and to support research that explicitly calls for co-production with Indigenous Knowledge.

Evaluation

Measure the effectiveness of assessments and decision-support efforts.

USGCRP will undertake more formal mechanisms to evaluate how widely, and for which purposes, the NCA and other major USGCRP products are used. These evaluations will seek to understand how USGCRP's products are being used, who the users are, and to what degree decisions are being informed by USGCRP's information.

These evaluations will be used in turn to inform USGCRP research activities, product development, and communications. Over the next 10 years, USGCRP will explore different metrics to evaluate effectiveness in supporting decisions.

Pillar 4. Collaborating Internationally

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

Understanding, assessing, predicting, and responding to global change are inherently international in scope. The risks we face as a Nation are affected by how other countries respond to their own global change-related challenges, as theirs are affected by our actions. The urgency of response is unevenly shared, however, due in part to the disproportionate impacts experienced by the poorest and most marginalized nations and communities. Risks associated with global change range from endurable to existential because of differences in exposure, vulnerability, and adaptive capacity. Climate change is already exposing millions of people to acute food and water insecurity, especially in Africa, Asia, Central and South America, small island nations, and the Arctic (IPCC, 2022).

Global change research has become increasingly collaborative over the past three decades, driven in part by the widespread recognition that societal action, and therefore research, is needed across multiple scales and disciplines. The move towards collaboration across international boundaries is fostered by the growth of transdisciplinary science, capacity for producing integrated global change assessments and models, and the provision of accessible and useful science to decision-makers—work that is difficult for any nation to tackle alone. The United States has developed strong linkages with institutions around the world that are advancing the basis for understanding and responding to global change. Public policymaking at national and global scales is increasingly linked with international scientific consensus that has been made possible through such collaboration.

The Global Change Research Act (GCRA) provides explicit guidance to USGCRP agencies with respect to international collaboration. In particular, the GCRA emphasizes U.S. leadership in promoting international cooperation on global change research, building global change research and decision-support capacity in developing countries, and coordination on the development of energy technologies. The four flagships of USGCRP international collaboration during 2022–2031, described below, address USGCRP's legal mandate to collaborate internationally and build upon its long history of coordination with other international global change research programs.

Assessments

Participate in developing international scientific consensus on global change.

Since the mid-1980s, the U.S. Government has played a pivotal role in the establishment of international scientific bodies that produce assessments of global change processes and impacts at a planetary scale. USGCRP agencies have been engaged in programs such as the International Geosphere-Biosphere Programme (1987–2015), the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES; 2012–present), and the World Climate Research Program (WCRP; 1980–present).

The Intergovernmental Panel on Climate Change (IPCC), founded in 1988, provides policymakers with regular assessments on the state of scientific knowledge about climate change. IPCC assessments had a profound influence on the negotiation of the United Nations Framework Convention on Climate Change (UNFCCC; 1992), its Kyoto Protocol (1997), and the Paris Agreement (2015). U.S. experts, with the endorsement of the U.S. Department of State and financial support from USGCRP agencies, have coauthored every IPCC assessment to date. USGCRP has hosted Technical Support Units (TSUs), which produce reports on behalf of the IPCC Working Groups, for five of the six IPCC assessment cycles.

USGCRP agencies will contribute to international global change assessments, under the leadership of the Department of State, in the following areas:

- Coordinate work with and provide support to IPCC TSUs. During times that there is U.S. leadership of one or more IPCC Working Groups, USGCRP will provide space and staff needed by the respective TSU(s).
- Nominate and support U.S. experts to participate as Lead Authors and Review Editors of IPCC Assessments and Special Reports. Support U.S. leadership at the IPCC Bureau level.

- Facilitate U.S. Government review of IPCC reports via expert panels and public review.
- Contribute to and facilitate coordination across the USGCRP agencies for other scientific assessments of global change (e.g., IPBES, Interagency Arctic Research Policy Committee (IARPC)).

Contributions to these international assessment efforts will help inform and complement components of the U.S. National Climate Assessment (NCA; see Box 4. National Scientific Assessments). The Fifth NCA, scheduled for release in 2023, will include chapters that address the systemic and cascading nature of climate-related risks across national boundaries, U.S national security implications, and other international linkages.

Enhancing collaborations

Enhance international science collaborations that strengthen global capacity to understand and respond to Earth system change.

Effective transboundary research to support policymaking involves co-production of knowledge with science users and a focus on knowledge exchange. Knowledge co-production and exchange are also foundational to transdisciplinary research (see Pillar 1. Advancing Science), a key component of transboundary science.

USGCRP will continue to build international science collaborations that foster transboundary, transdisciplinary research. These collaborations advance USGCRP agency priorities, link to USGCRP's domestic program areas, and leverage agency investments and resources. As USGCRP facilitates and enhances engagement with other institutions (see Pillar 2. Engaging the Nation), lessons learned about what makes engagement successful will be extended to the Program's international work.

USGCRP's objectives include the following:

- Strengthen existing relationships in collaborative efforts that foster international climate research, advance modeling of the global climate system, and enhance capacity for transdisciplinary science (e.g., Future Earth, START, WCRP).
- Establish new collaborations through other international activities (e.g., the Belmont Forum, the Inter-American Institute for Global Change Research, the Americas Group on Earth Observations (AmeriGEO), the World Meteorological Organization (WMO), and Arctic Council Working Groups) to pursue collaborative research actions.
- Coordinate or facilitate new observations of atmospheric, ocean, aquatic, coastal, and terrestrial systems, including land and ocean ecosystem structure and function and other physical, biophysical, and biogeochemical processes (e.g., Sustaining Arctic Observing Networks and the Global Climate Observing System).
- As the Program develops a U.S. strategy for climate intervention research, involve social scientists and engage with international partners to evaluate the impacts and governance dimensions of proposed climate intervention technologies.[4]

4 Note: climate intervention is an evolving area of research, with interagency efforts called for in the FY22 Omnibus appropriation. USGCRP's plans for research on this topic will be informed by the development of the Congressionally mandated plan, as well as by the recommendations of the National Academies of Sciences, Engineering, and Medicine (2015, 2021a, 2021b).

- Support the development of institutional collaborations and alliances that can provide a relevant and accessible scientific basis for decision-making.
- Establish partnerships that foster collaboration on emerging global change issues where international expertise could benefit the U.S. research enterprise and enhance resilience and sustainability nationally and globally.
- Pursue coordinated initiatives to understand the nature of and interactions among processes relating to global change, such as biodiversity loss, changes in land use and the ocean, and changes in the global nitrogen cycle.

Capacity strengthening

Share practices that improve the capacity of developing countries to understand, assess, and respond to global change risks.

USGCRP will facilitate greater bilateral and multilateral cooperation between the United States and key partners around the world to share knowledge that supports research, data collection, and assessment capabilities in developing countries.

USGCRP's objectives include the following:

- Support climate risk assessment efforts conducted by other countries, with a focus on the needs and capacity strengthening of lesser/least developed countries that are especially vulnerable to climate change.
- Support more equitable access to the tools of climate science and assessment—namely datasets, models, and adequate computing—in lesser/least developed countries.
- Pool USGCRP agency expertise to co-design training and other types of capacity development for climate research and climate risk assessments (Canada, Latin American and Caribbean partners, and potentially others).
- Work with international partners to engage developing country researchers in scientific leadership training and "train the trainer" programs at universities.
- Help advance diversity in international global change research; work where possible to engage Indigenous peoples and other underrepresented groups in USGCRP's international work.
- Facilitate research activities with other countries that enable exchange of climate research and assessment methods and approaches developed by USGCRP agencies and by other countries.
- Facilitate coordination of U.S. agencies with international global change research institutions that have also focused on capacity building, such as the WCRP Academy, Future Earth, START, and the Inter-American Institute for Global Change Research.

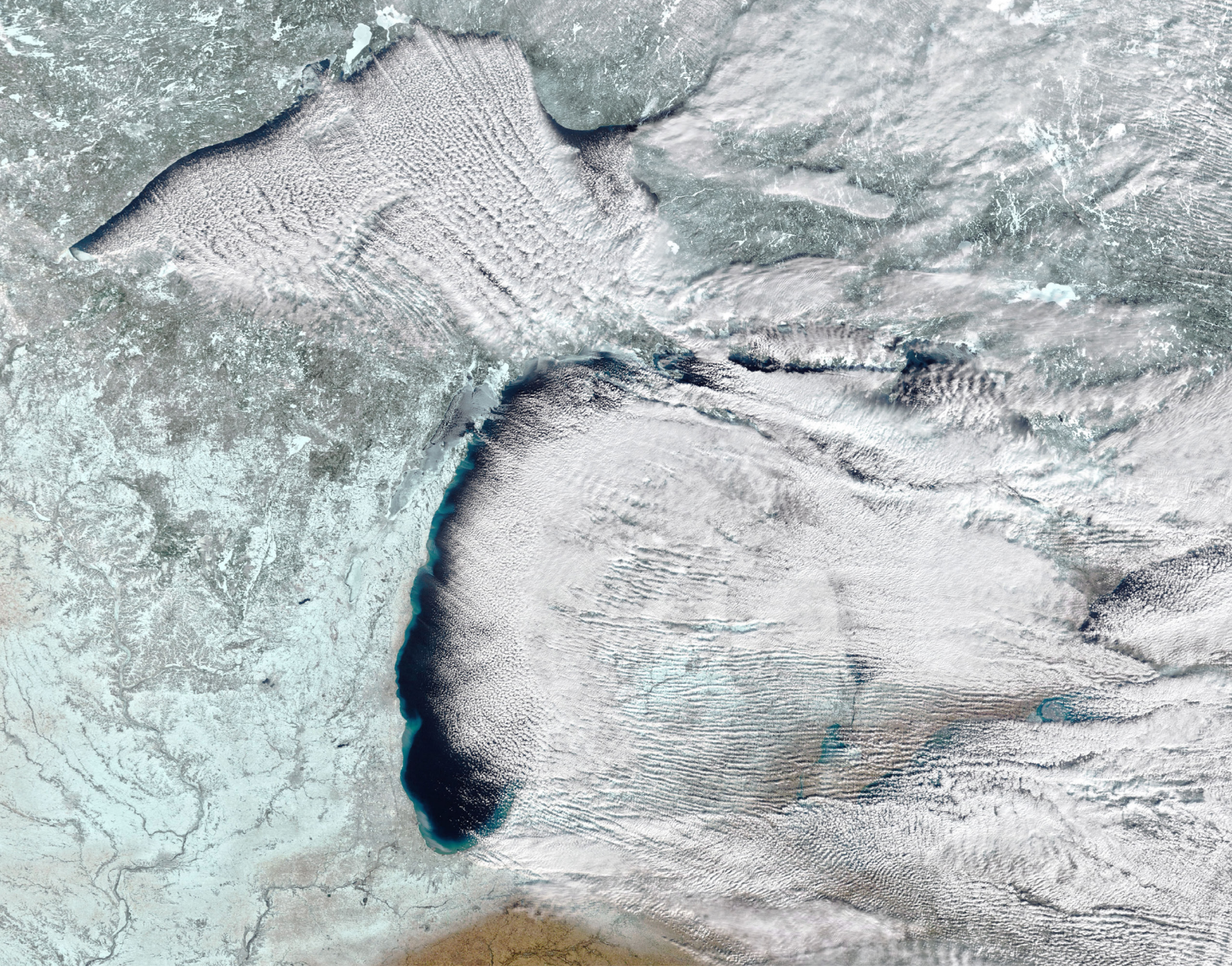
Informing policy

Provide relevant observations, science, and information to support international policymaking.

Effective U.S. cooperation with other governments to manage climate and global change risks relies on sustained global capacity to observe, predict, assess, and communicate Earth system change. USGCRP will enhance its participation in cooperative global scientific efforts that inform policymaking and emphasize opportunities to build capacity for effective communication of policy-relevant science.

USGCRP's objectives include the following:

- Enrich the development of global observation systems that can effectively contribute to improving greenhouse gas emissions data through enhanced cooperation with organizations such as the Global Climate Observing System and the Committee on Earth Observing Satellites.
- Coordinate or facilitate collaboration with international science programs, as well as greenhouse gas observation and analysis activities (e.g., the International Methane Emissions Observatory, the Copernicus Atmosphere Modeling Service, and the WMO Integrated Global Greenhouse Gas Information System).
- Facilitate the development of a rigorous scientific basis for the UNFCCC Global Stocktake processes and other technical dialogues.
- Collaborate with the intergovernmental Group on Earth Observations and the U.S. Group on Earth Observations to assess the availability of observations needed for climate adaptation and mitigation.
- Strengthen attention to non-carbon dioxide greenhouse gases; provide relevant data and analytics that help advance the incorporation of non-carbon dioxide emissions reduction in climate mitigation strategies.
- As an element of the other three international flagship activities, emphasize bilateral (country-specific) and regional efforts that help build capacity for the effective communication of science to ensure policy relevance, accessibility, and usefulness.



FULFILLING THE VISION

The urgent, transformative nature of global change requires a Federal research enterprise equipped to meet the challenge. Since publication of the last decadal Strategic Plan, climate and global change-related impacts have intensified, and implementation of actions to avoid or reduce them has increased. Demand for information to support decision-making is growing, and needs are becoming more complex, more specific, and more immediate. The research needed to inform responses to climate and global change risks extends beyond the scope of previous decadal Plans and demands enhanced ambition on the part of USGCRP and its member agencies.

Over the next decade, USGCRP agencies will develop new understanding of climate and global change risks affecting interconnected natural and human systems, how the behavior of these systems affects risks to society, and the social context and consequences of measures to reduce risks. Enhancing the integration of social and natural sciences in all

stages of research, and the use of transdisciplinary approaches to collaborative research, will be critical to advancing knowledge and the ability to inform decisions. Expanded collaboration with international scientific partners will help maintain and advance global capacity to understand, assess, predict, and respond to global change.

USGCRP and its member agencies will expand participation in global change research to better understand user needs and improve the accessibility, relevance, and usability of information for decision-making. USGCRP will emphasize diversity, equity, inclusion, justice, and accessibility as its agencies collaborate to invest research funding, build capacity and a more diverse scientific workforce, engage with frontline communities, and translate results into useful and actionable information.

This expanded participation will enhance and extend the efforts USGCRP has long undertaken to continually update and improve the Federal global change research portfolio. USGCRP and its member agencies will continue to work with external advisory bodies, solicit public input on agency-specific and interagency research strategies and major research products, and update and revise research plans on a periodic basis in response to user and scientific community input. Engagement and dialogue with users and developers of global change research will guide USGCRP and its member agencies in their efforts to provide global change science that is as useful to as many users as possible.

Challenges and opportunities

Addressing the expanded range of research topics needed to understand coupled human–natural systems and the associated implications for risk management will require involvement of Federal agencies and programs beyond those historically participating in USGCRP. This expanded scope will also require increased participation in and co-production of research by a broad range of science users, from government agencies and non-governmental organizations to industry and the public. Effectively addressing information needs for risk management requires research to understand the relative consequences, benefits, and tradeoffs of policy alternatives, while remaining dedicated to producing research that is policy neutral.

The growing demand for scientific information to support responses to climate and global change is outpacing USGCRP's ability to deliver that information. Even so, the challenge of meeting a diversity of information needs provides an opportunity to build stronger collaborations with boundary organizations within and external to the Federal Government that can facilitate collaboration among researchers and decision-makers to better serve user needs. This also provides the opportunity to expand the Program's perspectives by bringing in new expertise, particularly in the social sciences.

The growing emphasis on understanding risks to society and connecting human systems with USGCRP's historical focus on natural systems presents additional challenges and opportunities. These include the need to evaluate the agency and interagency institutional structures and mandates that define and manage Federal global change research programs and activities. This evaluation could also incorporate more general research on the ability of institutions to respond to global change impacts and responses.

The scope of research on coupled human–natural systems involves diverse expertise and perspectives, which requires a workforce that is equally diverse in multiple dimensions—e.g., race, socioeconomic status, experience, gender, educational discipline, ethnicity, geography, culture, and sexual orientation. USGCRP and its member agencies recognize the opportunity to build a more diverse Federal workforce, expand opportunities in the broader scientific community, and work towards a research enterprise with the capabilities and capacity to meet the challenges of global change.

Conclusions

Over the past three decades, the agencies and Interagency Groups that we collectively refer to as USGCRP have made enormous progress in meeting the mandate set forth in the Global Change Research Act to understand, assess, predict, and respond to human-caused and natural processes of global change (NASEM, 2017). The Program's successes to date have enabled us to recognize the growing complexities of global change, its impacts, and our responses. We face an expanded set of scientific problems, challenges, and opportunities in continuing to meet the Act's mandate to assist the efforts of the Nation and the world to respond to global change.

In 10 years, USGCRP envisions a more robust and inclusive understanding of the changing Earth system and how it affects, and is affected by, people and human systems. Making the information and tools associated with this greater understanding more accessible to a broad suite of knowledge users will move us toward the goal of a more informed Nation better equipped to respond to and manage the critical risks of global change. The strategy described in this Plan provides broad guidance and flexibility to meet those demands and sets the foundation for the Nation's global change research for the coming decade.

GLOSSARY

Adaptation: adjustment in natural or human systems to a new or changing environment that takes advantage of beneficial opportunities or moderates negative effects.

Biodiversity: the diversity of life on Earth, from genes to species to ecosystems.

Boundary organization: institutions that serve as brokers, negotiators, and translators between scientists and practitioner stakeholders or the public. Boundary organizations facilitate relationships between information producers and users, and integrate user needs with the activities of information producers.

Cascading risks: risks related to a chain of impacts that result in increased risks or failures in other systems or locations.

Climate change: a change in the state of the climate that can be identified by changes in the mean and/or variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions, and persistent human-driven changes in the composition of the atmosphere or in land use.

Co-production: a form of knowledge production based on dynamic interactions among scientific knowledge producers and knowledge users.

Coupled human–natural systems: systems with interconnected, interdependent, and complex interactions among human systems, the physical climate system, and ecosystems. These interactions include the dynamics within one or more natural systems; the dynamics within one or more human systems; the processes through which the natural systems affect the human systems; and the processes through which the human systems affect the natural systems.

Environmental justice: the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income, with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies.

Equity: the consistent and systematic fair, just, and impartial treatment of all individuals, including individuals who belong to underserved communities that have been denied such treatment, such as Black, Latino, and Indigenous and Native American persons, Asian Americans and Pacific Islanders and other persons of color; members of religious minorities; lesbian, gay, bisexual, transgender, and queer (LGBTQ+) persons; persons with disabilities; persons who live in rural areas; and persons otherwise adversely affected by persistent poverty or inequality.

Feedback: an interaction in which a perturbation in one climate quantity causes a change in a second and the change in the second quantity ultimately leads to an additional change in the first. A negative feedback is one in which the initial perturbation is weakened by the changes it causes; a positive feedback is one in which the initial perturbation is enhanced. The initial perturbation can either be externally forced or arise as part of internal variability.

Frontline community: communities or populations that have experienced systemic socioeconomic disparities, environmental injustice, or another form of injustice and are highly vulnerable to and will experience disproportionately high adverse impacts from environmental and climate injustice and inequitable climate actions.

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.

Human systems: systems designed, built, and operated by people to meet specific societal needs, including economic, food, health, water, energy, and transportation systems.

Indigenous Knowledge: the ongoing accumulation of knowledge, practice, and belief about relationships between living beings in a specific ecosystem that is acquired by indigenous people over hundreds or thousands of years through direct contact with the environment, handed down through generations, and used for life-sustaining ways.

Intervention: measures that alter the energy balance of the Earth through means other than reduction or removal of heat-trapping gases.[5]

Land cover: the physical characteristics of the land surface, such as crops, trees, or concrete.

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

Mitigation: measures that reduce the amount and speed of future climate change by either reducing emissions of carbon dioxide, methane, and other heat-trapping gases or removing carbon dioxide from the atmosphere.

Natural systems: the physical climate system and ecosystems (both unmanaged and managed, such as croplands), whose dynamics are governed by biological and/or physical processes.

Open science: the movement to make scientific research and its dissemination accessible to all levels of society.

Resilience: the capacity to anticipate, prepare for, respond to, and recover from significant multi-hazard threats with minimum damage to social well-being, the economy, and the environment.

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

Risk management: plans, actions, strategies, or policies to reduce or respond to the likelihood and/or consequences of risks.

Scenario: coherent, internally consistent, and plausible descriptions of possible future states of the world.

Tipping point: a level of change in system properties beyond which a system reorganizes, often abruptly, and does not return to the initial state even if the drivers of the change are abated. For the climate system, it refers to a critical threshold when global or regional climate changes from one stable state to another stable state.

Transdisciplinary: research that crosses disciplinary boundaries and aims to develop solutions to real-world challenges by combining scientific, stakeholder, and traditional knowledge.

Vulnerability: the degree to which physical, biological, and socioeconomic systems are susceptible to and unable to cope with adverse impacts of climate change.

5 Note: climate intervention is an evolving area of research, with interagency efforts called for in the FY22 Omnibus appropriation. USGCRP's plans for research on this topic will be informed by the development of the Congressionally mandated plan, as well as by the recommendations of the National Academies of Sciences, Engineering, and Medicine (2015, 2021a, 2021b).

ACRONYMS

AmeriGEO: Americas Group on Earth Observations

DEIJA: diversity, equity, inclusion, justice, and accessibility

GCRA: Global Change Research Act

IARPC: Interagency Arctic Research Policy Committee

IPBES: Intergovernmental Platform on Biodiversity and Ecosystem Services

IPCC: Intergovernmental Panel on Climate Change

NASEM: National Academies of Sciences, Engineering, and Medicine

NCA: National Climate Assessment

SGCR: Subcommittee on Global Change Research

TSU: Technical Support Unit

UNFCCC: United Nations Framework Convention on Climate Change

USGCRP: U.S. Global Change Research Program

WCRP: World Climate Research Program

WMO: World Meteorological Organization

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