Draft Triennial Update to The National Global Change Research Plan 2012-2021

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U.S. Global Change Research Program

Draft Update to the USGCRP Research Plan:
For Public Comment and Review by the National Academies of Sciences, Engineering and Medicine

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Executive Summary

The effects of climate change are being felt in many different ways around the country and the world. Higher average global temperature, frequent high coastal storm surges, and changing patterns of precipitation and extreme weather events are becoming routine. These, in turn, have different consequences for different regions. Examples include more drought and longer fire seasons, more days needing air conditioning, fewer days needing heating, greater coastal flooding, changing distribution of agricultural pests, and sometimes the need to shift crop growth to reflect changing temperature and precipitation patterns.

The United States Global Change Research Program (USGCRP, or "the Program") provides science and information needed to understand such climate-related changes, current and projected for the future, and help the country prepare for them. Established in legislation in 1990 by the Global Change Research Act (GCRA), the USGCRP is charged with providing "a comprehensive and integrated United States Research Program to assist the Nation and the world to understand, predict, assess and respond to human-induced and natural causes of global change."

The USGCRP comprises the science arms of 13 Federal departments or agencies[1] that fund research and development in climate-related global change. The agencies leverage each other's investments to ensure that the country has strong capabilities in areas like observing, understanding, and modeling the changing climate, as well as its impacts and implications for different regions and business sectors. The USGCRP advances fundamental new research, and harvests and translates maturing research to support decision makers and communicate and educate about climate change and its impacts. The Program develops a quadrennial National Climate Assessment—a synthesis of climate change science and impacts—written for decision makers, and works with Government agencies outside the Program (Federal, regional, state and sometimes local), and with other stakeholders, to broaden and improve the use of science in developing approaches to adapting to climate change. Climate-related data from the USGCRP member agencies are freely available, and the Program is emphasizing information technology that makes these data easier to find and use.

The USGCRP focuses on those areas of global change that affect climate or are affected by it. For example, population dynamics and economic growth are major drivers of global change; the USGCRP emphases include the role they have on climate change, and vice-versa. As another example of its scope, the Program includes a focus on sea level rise and its coastal impact, along with the ocean's role in climate variability and change. The USGCRP often works with other Federal interagency groups, in areas of common interest such as the Arctic or coastal regions.

In developing this update to the Strategic Plan (formally called the National Global Change Research Plan 2012–2021), the USGCRP reviewed the framework for the 2012–2021 Strategic Plan and decided it is still highly relevant to the Program's mission and national needs. The four goals of the Strategic Plan were developed originally to more fully reflect the scope of the GCRA, and drawing upon multiple reports and recommendations from the National Research Council (now called the National Academies of Sciences, Engineering and Medicine—hereafter referred to as the National Academies).

[1] U.S. Department of Agriculture, U.S Department of Commerce, U.S. Department of Defense, U.S. Department of Energy, U.S. Department of Health & Human Services, U.S. Department of the Interior, U.S. Department of State, U.S. Department of Transportation, U.S. Environmental Protection Agency, National Aeronautics & Space Administration, National Science Foundation, Smithsonian Institution, U.S. Agency for International Development

In this Update to the Strategic Plan the four goals for the USGCRP remain:

- **Goal 1. Advance Science:** Advance scientific knowledge of the integrated natural and human components of the Earth system.
- **Goal 2. Inform Decisions:** Provide the scientific basis to inform and enable timely decisions on adaptation and mitigation.
- **Goal 3. Conduct Sustained Assessments:** Build sustained assessment capacity that improves the Nation's ability to understand, anticipate, and respond to global change impacts and vulnerabilities.
- **Goal 4. Communicate and Educate:** Advance communications and education to broaden public understanding of global change and develop the scientific workforce of the future.

In this Update the Program is able to build on some significant accomplishments. While sustaining a comprehensive and continuing network of observations remains a challenge, newly developed observing capabilities for the Arctic and for various parts of the water cycle allow a stronger focus on questions "How is Arctic change affecting Northern Hemisphere weather and climate, and global climate in general?" and "How is a changing climate affecting water cycle extremes, both drought and extreme precipitation?".

Computational and modeling advances are allowing climate models on ever-finer time and distance scales (often called "downscaling") and better integration of climate and impacts models, providing important tools for decision-making. They also create the need for USGCRP to ensure robustness in downscaling approaches and to provide guidance in helping decision makers use appropriate models. In 2014, USGCRP released the Third National Climate Assessment (NCA3), which provided climate science findings for the regions and multiple business sectors of the United States. In the first year after its release, the NCA3 website had more than 500,000 visits. In developing NCA3, the Program was able to strengthen its avenues for engaging with stakeholders and understanding their needs. Many of these USGCRP activities complement well the actions called for in the President's Climate Action Plan (PCAP), and provide underlying science called for in PCAP.

In the 2012–2021 Strategic Plan, the USGCRP also set itself some large challenges, and is working to meet them. They revolve around building an integrated program that monitors the planet's changing climate and conducts cutting-edge fundamental and use-inspired science and relevant social science research. Challenges also include building capacity to purposefully transition relevant expertise, data, tools, and model outputs into products for societal benefit, as well as for research on emerging issues. Building the kind of governmental partnerships and private sector collaborations needed to fully address these challenges is an ongoing effort.

This Update, called for in the GCRA, discusses how the USGCRP will build on progress and navigate challenges.

Chapter I: Introduction

With its National Global Change Research Plan of 2012–2021 (also referred as the "Strategic Plan"), the U.S. Global Change Research Program (USGCRP or the "Program") maintains strong research capabilities and aims to make its science more accessible and useful for decision makers in terms of their considerations and potential actions (hereafter referred to as "actionable science"). In so doing, the USGCRP is guided by its founding legislation, the Global Change Research Act of 1990 (GCRA), which tasks the Program with providing a "comprehensive and integrated United States research program to assist the Nation and the world to understand, assess, predict, and respond to human induced and natural processes of global change."

The GCRA tasking shapes the USGCRP mission, vision, and Strategic Plan goals (*see "USGCRP at a Glance" box below*). It also shapes a dual emphasis on both advancing science and its utilization for the kinds of decisions that need to be made now (for example, by resource managers and policy makers across the public and private sectors, business, and community leaders, and individuals) to prepare for the current and anticipated effects of climate change. USGCRP science is freely available via globalchange.gov and nca2014.globalchange.gov in forms that can be easily used by decision makers. As in the 2012 Strategic Plan, this Update to the Strategic Plan focuses on climate-related global change.

USGCRP at a Glance

Vision: A Nation, globally engaged and guided by science, meeting the challenges of climate and global change.
Mission: To build a knowledge base that informs human responses to climate and global change through coordinated and integrated Federal programs of research, education, communication, and decision support.

Strategic Plan Goals and Objectives:
Goal 1. Advance Science: Advance scientific knowledge of the integrated natural and human components of the Earth system.
Goal 2. Inform Decisions: Provide the scientific basis to inform and enable timely decisions on adaptation and mitigation.
Goal 3. Conduct Sustained Assessments: Build sustained assessment capacity that improves the Nation's ability to understand, anticipate, and respond to global change impacts and vulnerabilities.
Goal 4. Communicate and Educate: Advance communications and education to broaden public understanding of global change and develop the scientific workforce of the future.

There is growing recognition that the impacts of climate change are affecting many parts of the country. Climate change impacts can be societally disruptive, and science-based adaptation and mitigation actions taken in the next years will decrease longer-term costs, avoid further disruption, and create long-term economic opportunities. Having the science in place to inform decisions and actions becomes even more essential, realizing that climate change pressures will be felt more strongly in a world of increasing economic development and population growth. The U.S. Government continues to recognize climate change impacts as a significant risk to the country and the functioning of the government, as seen through a series of reports from the military (such as the 2014 Quadrennial Risk Review) and the Government Accountability Office (GAO). Similarly, many business sectors (as seen through the American Business Act on Climate

Pledge of 2015) are increasingly taking climate change into account in their planning, as are urban and coastal planners in many parts of the country.

To support the well-informed decisions the country requires, the USGCRP provides the strong and deep scientific foundation needed to understand climate-related global change and its anticipated effects. Scientific foci for the Program encompass many aspects of the climate system and their impacts—topics like ice sheet dynamics and rates of sea level rise, permafrost thawing in a warming Arctic and implications for methane release to the atmosphere, and changes in the water cycle, including both drought and extreme precipitation. USGCRP foci include fundamental understanding of topics like the potential relationships between climate change and changing patterns of extreme weather, the role of biogeochemical processes in methane production, and potential tipping points in various parts of the climate system that could affect how society adapts to change.

Progress in areas like these rests squarely on the USGCRP's programs in observing, modeling, and understanding change, reported yearly in the annual report to Congress, *Our Changing Planet*. For example, since the 2012 release of the Strategic Plan, the deployments of new space and ground-based resources and field campaigns are providing considerable new observational capabilities in key parts of the water cycle and for the Arctic, among other advances. Observational data streams, alone and especially in combination, drive new understanding, extend and challenge model abilities, and provide time series records of change that can be used for decision-making. Building on the long-term development of multi-model ensembles for North America and the data that support them, for example, the USGCRP is advancing its ability to perform and analyze seasonal climate predictions.

The USGCRP's progress also builds on the Program's involvement in international activities by contributing to their science directions and leveraging their progress in areas such as assessments and observations. The Program also participates in and benefits from new international efforts focused on explicitly linking science advances to societal needs.

The USGCRP has made considerable progress in ascertaining user needs for science and translating research into scientific findings that are easily accessible and understandable for users of all levels of understanding. For example, within the Federal government, the Program synthesizes and distills the content from Federal Agency Climate Change Adaptation Plans and incorporates their major science needs into its planning. It also includes representatives from response-oriented non-member agencies on its working groups.

Reaching beyond the Federal landscape, the Third National Climate Assessment (NCA3) synthesized and distilled an extensive science literature for decision makers, focused on climate change and its impacts across the United States and in multiple sectors therein. The NCA3 is served through a searchable and shareable website, which had almost 500,000 visits and nearly a million downloaded reports in its first year. NCAnet, a network of more than 150 organizations and networks from both the private and public sectors, aims to understand user interests and needs while also sharing USGCRP information widely. In the interval before the fourth NCA, due out in 2018, USGCRP is developing special assessment reports on topics like climate and health, climate and food security, and state of the carbon cycle. In support of the NCA3, the USGCRP built the Global Change Information System (GCIS) to provide traceability from the NCA3's distilled science findings to the underpinning science. The GCIS will be used with the upcoming special reports and is being further developed to support the Program more widely.

The 2012–2021 Strategic Plan conveyed a decadal vision for the USGCRP that included large and challenging imperatives for the Program and its role in the Nation. They revolve around the

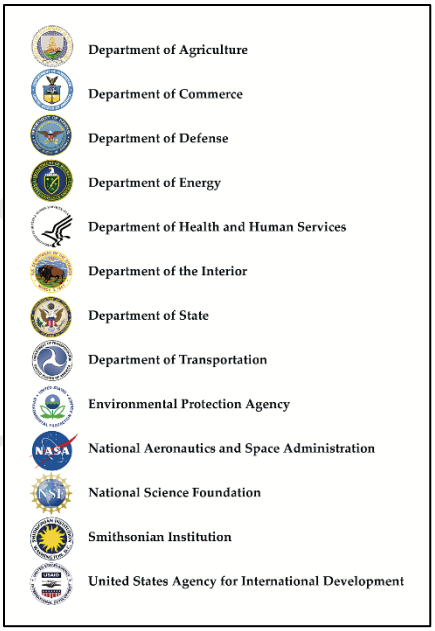
building of an integrated program that monitors the changing climate, conducts cutting-edge fundamental and use-inspired science and relevant social science research, and purposefully transitions relevant expertise, data, tools, and model outputs into products for societal benefit, as well as for research on emerging issues. A key element of this involves sustaining collaborations within and beyond the USGCRP that are committed to managing and maintaining robust observing, monitoring, modeling, prediction, and decision-support programs and systems. Another focuses on continuing to advance USGCRP capabilities in developing and sustaining integrated information systems like the GCIS that support science and facilitate effective decision support in the public and private sector, and with the Program's national and international partners. Together with advancing its strong science program, progress in meeting these imperatives better allows the USGCRP to serve as the integrating focal point for global change research across and beyond the U.S. Federal landscape.

This document provides an Update to the Strategic Plan (hereafter called the "Update"), highlighting areas where the Program is building on progress and the challenges it is navigating. The Strategic Plan itself remains the guiding blueprint for USGCRP, unless otherwise noted herein. Given the relatively short time since the release of the Strategic Plan, this Update refreshes it, and serves as the triennial revision required by the GCRA.

Chapter II: USGCRP Strategic Overview

The U.S. Global Change Research Program is three years into the implementation of its National Global Change Research Plan 2012–2021. That decadal Strategic Plan remains the continuing blueprint for USGCRP, with its strategic directions guiding the Program. There are areas, however, where the landscape has changed by virtue of significant progress, changing scientific or societal urgencies, or challenges. This Update speaks to these areas and any resulting acceleration or shift in Program efforts. It also emphasizes areas of integration across the goals of the USGCRP, made possible by recent progress.

The USGCRP was established by President Ronald Reagan shortly before leaving office in 1989, and codified by Congress in the Global Change Research Act of 1990. The 2012–2021 Strategic Plan and this Update are built around the GCRA directive to provide a "comprehensive and integrated United States research program to assist the Nation and the world to understand, assess, predict, and respond to human induced and natural processes of global change." The Strategic Plan aligns well with the science and information needs identified in President's Climate Action Plan (PCAP) released in 2013, where the USGCRP has a significant role to play in areas such as developing actionable climate science, assessing climate change impacts in the United States, and supporting the Climate Data Initiative (CDI) and Climate Resilience Toolkit (CRT). The USGCRP sees significant roles for itself in providing underlying science for areas that link to protecting our economy and natural resources in the face of climate change, including climate change and human health, water cycle extremes (both wet and dry), and methane cycling.



Guided by the White House Office of Science and Technology Policy (OSTP), the USGCRP is composed of the global change research and development arms of 13 Federal agencies (*see figure*), which share knowledge and coordinate activities to advance fundamental science and its utilization in addressing the challenges of climate-related global change. It is directed and overseen by the Subcommittee on Global Change Research (SGCR), which is chartered under the Committee on Environment, Natural Resources and Sustainability (CENRS), part of the National Science and Technology Council (NSTC). Much of the USGCRP's work is coordinated though its interagency working groups, which include participation from Federal agencies that are not formally members of USGCRP. The term "USGCRP" is used in reference to the collective global change research activities of the SGCR, the member agencies or bureaus, and the National Coordination Office, which facilitates and supports program integration. *See Chapter V for more detail about Program operations.*

Guiding the Program

The vision, mission, and goals from the 2012–2021 Strategic Plan remain the guideposts for the USGCRP (*see "USGCRP at a Glance" box in Chapter I*). These goals emphasize making scientific progress in key areas (Goal 1) and making that science accessible and actionable for decision-making (Goals 2, 3, and 4). The Strategic Plan's goals are strongly symbiotic, and emphasize both progress within each goal area and synergies across them.

The USGCRP identifies scientific focal areas that build on progress towards achieving the goals of the Strategic Plan, and on the Program's core science capabilities, discussed below. These foci spotlight areas where fundamental science advances can be made and where current and emerging science can be harvested for decision support. These areas, along with the core science capabilities, serve as a programmatic focus for several years, evolving over time as progress is made. While building on strong interagency collaboration, they may also depend on key single-agency contributions to the USGCRP, such as observations.

For Fiscal Years 2015 and 2016, the USGCRP is spotlighting the topics below, characterized as USGCRP interagency priorities. More information about progress in these areas is available through the USGCRP's annual report to Congress, *Our Changing Planet:*

- Extremes, thresholds and tipping points, with foci on 1) Arctic climate change, its regional impacts and influence on global climate; and 2) understanding the water cycle under a changing climate, including both wet and dry extreme conditions, and their impacts. These are broad scientific challenges, and build on progress in areas such as observations, attribution of extremes, scalability of Earth system processes in space and time, and understanding cascading effects and linkages between natural and human systems *(see Chapter III, Objectives 1.1, 1.2, and 1.3).*
- Predictions, with a focus on rapidly advancing the science underpinning global and regional climate modeling capabilities and systematic intercomparison methodologies, to understand and reduce uncertainties for regional climate projections, at intra-seasonal to decadal time horizons and spatial resolutions of 50 km to as fine as 10 km. This effort builds on improving model systems and infrastructure, and coordination across national modeling centers *(see Chapter III, Objective 1.4).*
- Science to inform policy making and management, with an emphasis on enhanced joint-production of actionable science between science producer and science user/decision-maker communities and expanding the utilization of USGCRP science findings, tools, or resources *(see Chapter III, Objective 1.5 and Goals 2, 3 and 4).*

The USGCRP's ability to advance both fundamental science and its use in areas of societal need is critically dependent on strong core capabilities—the ongoing development of underlying capacity that supports the breadth of the Program. Deployed through interagency cooperation and single-agency activities, core capabilities provide knowledge and methodologies on which the Program and the member agencies rely. These include: modeling, experiments and process research for science insight *(Chapter III, Goal 1);* integrated observations, both sustained time series measurements and improving capabilities in areas of Program priorities (*Chapter III, Objective 1.3);* cutting edge capabilities for information sharing and management for research and decision-making *(Chapter III, Objective 1.5);* sustained capabilities for timely synthesis and assessment of emerging science for decision makers (*Chapter III, Goal 3*); and the ability to, communicate with individuals and decision makers at a variety of organizations and multiple; scales of government, with a focus on training, engagement and education *(Chapter III, Goals 2 and 4).*

Significant Progress, Evolving Challenges

The USGCRP has made significant progress in the three years under the 2012–2021 Strategic Plan, and has needed to navigate challenges, both new and persistent. Chapter III speaks to these in more detail.

Major advances have occurred within the USGCRP on a number of fronts, as discussed in Chapter I. Advances in observing and modeling capabilities, for example, are allowing rapid

science progress in areas discussed in this Update. With its NCA3, the USGCRP has built new capacity for understanding and providing science for decision maker needs. Together, these position the USGCRP well to meet the challenges of the GCRA.

The USGCRP is navigating new challenges, as will be discussed in Chapter III, some directly related to areas of progress. For example, the demand for ever-increasingly fine-scale climate information creates a need for rigorous and robust approaches to downscaling and for providing guidance in use of downscaled products. This is a challenge because the demand for information is broader than the USGCRP alone can provide. Although the USGCRP has made significant progress in developing science that can inform adaptation measures and planning, the Program's role in generating science for informing mitigation decisions has been less well defined. The Program also continues working to define and implement key elements of its role in connecting science providers and science users, and its relationships with other organizations that aim to do the same.

Persistent challenges remain in fully implementing the Strategic Plan. The Program has been successful in integrating the social, behavioral and economic sciences into specific activities within the USGCRP (for example in its planning for the fourth NCA), but it is still challenging to develop a broader program that combines the social and natural sciences, where appropriate, to better understand how humans drive and respond to global change. On another note, sustaining critical observations for long time series, while also improving abilities to observe and seamlessly stitch together new variables needed for comprehensive analysis, remains a perpetual challenge. These, too, are discussed in Chapter III.

USGCRP's Global Change Information System (GCIS)

The USGCRP used the NCA3 Report as a pilot project for developing phase one of the GCIS. Using semantic web technologies and persistent unique identifiers, the GCIS allows NCA readers or direct GCIS users to:

- Link to many climate change data sets, without knowing *a priori* which agency produced the data
- Track down to the underlying reference for the data, and sometimes track down to the instrument used for data collection
- Link out to other repositories for climate change information

The USGCRP will use the GCIS to provide data transparency and provenance in upcoming special assessments, like that for climate and human health. GCIS code is open source and can be modified for other uses. The USGCRP is working with the U.S. Government's Climate Data and Tools Interagency Working Group to demonstrate the GCIS ability to link USGCRP assessments to data in the Climate Data Initiative and Climate Resilience Toolkit.

Climate Change and Human Health

Since the release of the decadal Strategic Plan, the USGCRP has made substantial advancements on understanding the human health risks from climate change. In support of the President's climate Action Plan, the draft report *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment* synthesizes in-depth science and modeling on the observed and projected health impacts of climate change in the United States. In addition, the USGCRP released the Metadata Access Tool for Climate and Health (MATCH) and coordinated the health input for the U.S. Climate Resilience Toolkit and the Climate Data Initiative.

Looking ahead to the remainder of this Update, Chapter III centers on the four goals of the Strategic Plan, emphasizing areas of progress on which to build and challenges to navigate. Chapter IV provides an updated view of USGCRP's role in international cooperation, building from guidance in the GCRA, and reflecting a rapidly changing international landscape for global change science. Chapter V provides an update on USGCRP's strategies for implementing the remaining years of the 2012–2021 Strategic Plan.

Chapter III: USGCRP Goals and Objectives

Goal I: Advance Science

Goal 1. Advance Science: Advance scientific knowledge of the integrated natural and human components of the Earth system.

- ***Objective 1.1. Earth System Understanding:*** Advance fundamental understanding of the physical, chemical, biological, and human components of the Earth system, and the interactions among them, to improve knowledge of the causes and consequences of global change.
- ***Objective 1.2. Science for Adaptation and Mitigation:*** Advance understanding of the vulnerability and resilience of integrated human-natural systems and enhance the usability of scientific knowledge in supporting responses to global change.
- ***Objective 1.3. Integrated Observations:*** Advance capabilities to observe the physical, chemical, biological, and human components of the Earth system over multiple space and time scales to gain fundamental scientific understanding and monitor important variations and trends.
- ***Objective 1.4. Integrated Modeling:*** Improve and develop advanced models that integrate across the physical, chemical, biological, and human components of the Earth system, including the feedbacks among them, to represent more comprehensively and predict more realistically global change processes.
- ***Objective 1.5. Information Management and Sharing:*** Advance the capability to collect, store, access, visualize, and share data and information about the integrated Earth system, the vulnerabilities of integrated human-natural systems to global change, and the responses to these vulnerabilities.

The objectives of Goal 1 work together, with the intent to: 1) Foster fundamental scientific knowledge of the integrated natural and human Earth system, and 2) Advance essential science needed to reduce vulnerability to global change through increased resilience and managed risk. Although discussed individually for clarity and to reflect the depth of work across the USGCRP, scientific progress requires linkage across the objectives.

Several common themes, emerging from implementation of the Strategic Plan, connect across Goal 1 objectives, highlighting the cohesion and synergy needed for strong continuing progress. There is increasingly deep interplay amongst observations, process research, and modeling at all scales, on topics such as the dramatic decline of Arctic sea ice area or the need to better understand aspects of known climate variability, such as global surface temperatures. The scientific community is capitalizing on improved observational systems and more readily accessible data sets to drive rapid progress in fundamental understanding, efforts that are leading to Earth System Model (ESM) improvements and increased foresight about future changes.

Another common theme is integration across the traditional boundaries between communities working on different aspects of Earth System Models. A proliferation of Model Intercomparison Projects (MIPs) since 2012 address new topics such as ScenarioMIP, which explores how potential future forcing pathways of greenhouse gases (GHG) affect climate extremes, regional sea level rise, water availability and biospheric feedbacks, and how the effects will influence mitigation and adaptation options. Communities such as agriculture (AgMIP), which have deep

process-level understanding and capacity to assimilate observational data, are connecting with Earth System Models to understand climate change impacts. This outgrowth of the central Coupled Model Intercomparison Project (CMIP) process is providing an expanded capacity for rapid analysis of models, development of new projections, exploration of uncertainties, and generation of feasible policy-relevant scenarios. The MIPs are thus breaking down barriers across research, impact, and adaptation communities. They also bring the challenge of managing the proliferation of activities and integrating the new knowledge.

Since release of the Strategic Plan, the USGCRP has matured its priority-setting approach, as reflected in the annual report to Congress (*Our Changing Planet*). Certain research topics serve as prime priorities for USGCRP, integrating across the Program. For example, understanding the causes and impacts of rapid changes in the Arctic, and using that knowledge to inform decision-making, draws from all four goals of the Strategic Plan. Similarly, the USGCRP's research on the water cycle and drought links to development of decision support tools and to education, through member agency activities and programs. The USGCRP is adapting to the increased demand from non-USGCRP agencies and entities for insightful understanding and knowledge. A major challenge in meeting this demand remains effective engagement of social scientists.

The Advance Science goal underpins and supports the other three; these three in turn inform science planning and priorities. From working to provide deeper understanding of extreme events or changes in the Arctic, to providing leadership on evaluating the applicability of climate models and downscaling approaches for decision makers, the USGCRP interagency teams work to align their respective agency efforts to collectively advance all the goals in a deliberate manner.

Objective 1.1: Earth System Understanding

Maintaining Directions

The USGCRP advances scientific understanding of the changing Earth system by considering natural, and increasingly social, drivers and their interdependencies as part of one integrated research effort. These drivers interact at various spatial and temporal scales and involve departures from recent historical climate conditions, a condition scientifically described as non-stationarity This objective, and the following one on science for adaptation and mitigation, focus on scientific insight from process research and experimentation, which draw from the USGCRP investments in areas such as observations (Objective 1.3), modeling (Objective 1.4), and data management and harvesting (Objective 1.5). Due to the international nature of science and global change, USGCRP will continue to coordinate with related and complementary science programs in the international sphere, discussed in more detail in Chapter IV.

Building on Progress

Since the writing of the 2012–2021 Strategic Plan, significant developments in science conducted or funded by the USGCRP agencies have occurred, some capturing the attention of policymakers and the media. Drawing on advances in Goal 1 objectives, this section showcases examples of how the Program is building in the area of Earth System understanding.

Tipping Points and Thresholds. A USGCRP interagency priority for fiscal years 2013 through 2016, recent research has focused on factors that contribute to tipping points or thresholds in the climate system that could result in a system quite different from that currently or historically observed. Advances in characterizing such non-linear behavior are informed by new scientific

understanding that is fueled by an ever-growing set of observational data, which is being transformed from a loose collection of data from observing systems into systematic records of global change. These data sets are now available over unprecedented temporal and spatial scales (Objective 1.3). New observational data sets have been utilized with more sophisticated modeling and theoretical understanding (Objective 1.4), providing improved insight into prediction and uncertainty analyses. Looking ahead, indications of change are also being developed using theoretical and empirical approaches, with the potential to greatly increase the ability to anticipate and respond to changes on all scales. Some general advances in the framework of tipping points, often informed by paleoclimate data, are nascent in their development, and will be a continuing focus for the USGCRP. The potential for complex feedbacks within and between different parts of human and natural systems, related to threshold behavior, is a significant source of uncertainty in formulating future scenarios, and is a focus for the USGCRP.

Using Long Data Records to Understand Earth's Climate Variability. Seamless integration, validation, and interpretation of paleoclimate data, together with those from the instrumental observing record, are critical for research into Earth's longer-term record of climate non-stationarity, nonlinearities, and variability. Stitching together high quality, high-resolution, long time series (from decades to millions of years), from both active observing systems and paleoclimate information (e.g. from ice cores, corals, tree rings, stalactites and stalagmites, and marine and lake sediments) provides great potential for robust analyses of variability and change at global, regional, and local spatial scales. Such records can include very high temporal resolution (hourly) from instrumental observing systems to lower temporal resolution at annual to centennial or greater timescales from paleoclimate data. They can constrain variability in key features of the global climate, such as continental-scale temperature and hydroclimate, the cryosphere, surface CO_2 forcing, various manifestations of major climate variations, such as the El Niño-Southern Oscillation, and the behavior of the ocean's overturning circulation.

Ensuring combined long-term data sets that are free of time dependent biases is a research activity for the USGCRP and related national research programs. The knowledge to be gleaned from new methodologies and extended records is essential to distinguishing anthropogenic influences from natural variability. It also helps define the baseline from which extreme events can be distinguished. Looking ahead, study of key time intervals in the past, such as the Little Ice Age, Medieval Warm Period, and Last Glacial Maximum, is necessary for better understanding how the climate system behaves under a wide range of forcing conditions (with opportunities to revolutionize the understanding of how the ocean, atmosphere, and solid earth are linked in modulating the Earth's carbon cycle). Syntheses of large regional and global data are now possible. Further integration of these data sets with models (Objective 1.4), and novel applications of numerical techniques, will help to focus new data collection on key areas of uncertainty. Conversely, new data are helping to improve and challenge model simulations. In sum, the long-term data sets help scientists understand the continuum of timescales of variability and sensitivity of Earth's climate system. Building on progress in this area requires that there be good coordination among member agencies that support data set development across observing systems, including paleoclimate data. Research on seamless integration of data and data archiving is paramount to building on these advances (Objective 1.5).

Attribution. A key intersection of Earth system understanding and actionable science lies in ascertaining the extent to which current and future climate change is associated with anthropogenic (i.e. human-caused) drivers interacting with natural variability. For example, examining human versus natural contributions to potential changing patterns in future extreme weather events (e.g., their probabilities, geographic distribution, intensity, and return intervals) is especially critical. The USGCRP continues to build on advances in, and growth of, research on

the respective influences for climate phenomenon affecting society (such as the 2013 Boulder, CO floods, the 2013 Australian heat wave, the 2013–2014 United Kingdom floods, Typhoon Haiyan, Superstorm Sandy, or the 2012–2015 California and Central United States droughts). Approaches to isolating the climate signal from natural variability—termed 'attribution science'—are currently under development, with this being a significant research activity for USGCRP. They rely on increased mechanistic understanding grounded in adequate observations and improved modeling that are part of USGCRP's core mission. The USGCRP will continue to build this capacity, which leads to a greater ability to inform decisions based on improved clarity about future risks.

The Global Warming "Hiatus." Another timely, priority question on the relative roles of anthropogenic change and natural variability regards the so-called global warming "hiatus" or slowdown in the rate of increase in the Earth's globally averaged surface temperature since 1998. The hiatus question spurred numerous USGCRP-agency supported studies examining the global energy balance and evaluating competing mechanisms (e.g., El Niño-Southern Oscillation, internal ocean variability, volcanic activity, and aerosol radiative effects) that could be responsible for decadal timescale variations that depart from the long-term anthropogenic climate change trend. Ascertaining the duration, magnitude, and even existence of a hiatus is an ongoing challenge being debated within the science community. A recent analysis suggests that the rate of global warming over the first fifteen years of this century is indistinguishable from that of the second half of the 20th century, suggesting that a hiatus has not occurred in the global surface temperature record. Other analyses find the hiatus to be entirely real in other measures, with a discernable abatement of surface warming during the period, concurrent with shorter periods of estimated increases in ocean heat storage. The USGCRP will promote the systematic evaluation of time-series analyses and process-based interpretation of decadal and multi-decadal temperature trends in the context of the long-term trends. It will also promote further evaluation (through observations and modeling) of the impacts of various natural and anthropogenic internal and external factors affecting the climate system. Such research plays into larger USGCRP questions regarding the impacts of temporal and spatial resolutions and scales on models of the global climate system.

Rapid Arctic Change. There is growing awareness of the rapid changes in the Arctic, which is a USGCRP interagency priority. In addition to impacts of climate change within the Arctic region itself, ongoing 'attribution science' research is investigating the plausible role that changing Arctic conditions have in global climate and in various extreme weather events elsewhere. In concert with international science programs, such as the World Climate Research Programme (WCRP), the USGCRP will continue rapidly to improve understanding in a variety of topics. These include physical and chemical changes in permafrost, sea- and land-ice; rates of ice loss; feedback between permafrost processes and the carbon cycle; and aerosols and clouds and their impacts on the surface energy budget, with feedbacks to ice and snow cover. The USGCRP's Arctic priority will continue to focus on these physical processes while deepening its investigations into ecosystem and socioeconomic responses. Coupled interactions between the Arctic Ocean and the Northern Pacific and Atlantic oceans will be further explored to investigate their Arctic impacts and feedbacks to regional and global climate. The U.S. chairmanship of the Arctic Council (May 2015 through April 2017) provides an opportunity to leverage the Program's efforts to enhance observational capacity (including Traditional Environmental Knowledge/Indigenous Knowledge) and integrate the new findings into models at all scales to support appropriate adaptation and (impact) mitigation actions (Objective 1.2). The USGCRP works closely with its sibling Committee on Environment, Natural Resources, and Sustainability (CENRS) subcommittees the Interagency Arctic Research Policy Committee (IARPC) and the

Subcommittee on Ocean Science and Technology (SOST) to make optimal use of the Nation's science and scientists working on critical Arctic issues.

Carbon Cycle and Ecological Modeling. There have been many recent cross-disciplinary advances in the science of biogeochemical cycles and biodiversity, upon which the USGCRP is helping to build. In terms of the carbon and hydrologic cycles, there is now much better understanding of the effect of new energy developments on water requirements, as well as on net methane emissions and their role in the global carbon cycle budget. The contribution of urban areas to the regional carbon cycle is also emerging as an important area for the USGCRP, conveying with it information that may be used by non-USGCRP agencies in mitigating urban emissions. Recent comparisons of multiple models for the exchange of carbon between land and the atmosphere use improved empirical data to better represent terrestrial processes below ground, and are allowing improved quantification of terrestrial carbon sequestration rates and biogeochemical cycling. Combining these and other advances in observational and modeling capabilities is leading to new estimates for carbon sources and sinks nationally and globally, an area in which the USGCRP will continue to focus attention.

Integrating Earth observations with ecological models is allowing, for the first-time, global assessments that track biodiversity condition and trends, using datasets of global extent but landscape grain sizes (e.g., 10m to 50m resolution). Increasingly, non-satellite information goes beyond species to include genetic data, promoting the relatively new field of landscape genetics as a partner to information on species occurrence and population ecology. Improved remote sensing capabilities capture observations of ecological traits and other aspects of phylogeny, enabling greater characterization of the components of ecosystems and how they are processing energy and elements. The parallel developments of improved observation networks across spatial scales, bioinformatics tools that link cross-scale observations, and recent theoretical understanding captured in models, will allow the USGCRP to build testable ecological forecasts. We can now assemble predictions of the impacts on ecosystems, species, and populations resulting from changes in climate, human land/water/energy use, and other drivers. The last three years have seen an acceleration of this trend, as well as the advent of new satellite and other remote sensors (e.g. airborne drones, camera traps, sound recordings, enhanced tracking/tagging devices, and environmental DNA). The ability to integrate observations across scales is leading to predictions that will underlie the USGCRP's increasing ability to make assessments of the regional to local impacts of changing climates on the living systems upon which we all depend.

Research for Identifying Gaps in the Climate Observing System. Advancing scientists' ability to address clearly articulated, testable scientific hypotheses that bear closely on key areas of societal need is central to the country's ability to plan for, and respond to, the impacts of climate and global change. Doing so will require both advances in observational capabilities and improved integration of existing capabilities. This includes bridging gaps between, for example, *in situ* and remotely sensed observations, and between models and observations. The opportunity exists to research, modify, and apply approaches such as Observing System Simulation Experiments (OSSEs, commonly used for improving weather prediction systems) to climate and global change scientific-societal questions, particularly in the USGCRP priority areas such as water cycle extremes, perturbations to the global methane cycle, and climatological and ecological tipping points in the Arctic. Such approaches would identify key questions within the topic areas, measurements essential to answering the questions, and the observing system characteristics (e.g. sensor distribution, measurement frequency, precision, and duration) needed for robust answers.

Cloud Regime Transitions and Aerosol Chemistry. Uncertainties in these key aspects of climate models (e.g., precipitation formation, cloud amount and lifetime) can lead to biases in the water cycle and radiative energy balance in both seasonal coupled models and annual mean climate forecasts. Recent concerted multi-agency observational efforts (e.g., the CalWater 2 field campaign, the ARM Cloud Aerosol Precipitation Experiment (ACAPEX), and the Cloud-Aerosol Transport System (CATS)) are aimed at improving understanding of cloud and aerosol processes. Modeling efforts are currently focusing on incorporating the improved process-level knowledge into climate models for the purpose of seeing the impacts on climate scenario projections. Knowledge gained from these recent observational efforts has the potential to be applied to other cloud regimes that have strong climate feedbacks and/are poorly represented in climate models, such as clouds in the Arctic and Southern Ocean.

Water Cycle Research. The U.S. droughts of 2012–2015 and research related to climate trends on decadal time scales are helping drive USGCRP research on the dynamics of the water cycle and the related land-ocean-atmosphere interactions. With a USGCRP interagency priority focused on both wet and dry extremes in the water cycle in the face of a changing climate, there is emphasis on the understanding, observations, and modeling that improve forecasting of the water cycle. An example is new understanding of the ocean's influence on North American climate, based on better knowledge of the variability over time in El Niño events and the range in their effects on precipitation. Similarly, recent research highlights the importance of moisture-laden atmospheric currents (atmospheric rivers) off the Pacific Coast in influencing precipitation patterns. Understanding the thermodynamics associated with the causes of changes in extreme precipitation events at local, regional, and global scales are of fundamental importance, both practically and theoretically. Going forward, the USGCRP will continue to investigate such phenomena as part of efforts to improve drought and extreme precipitation predictions, projections, and monitoring. Utilizing recent advances in observations and modeling, the USGCRP is also improving its ability to better integrate groundwater into its understanding of the water cycle, continuing its efforts towards quantifying groundwater flows and extending its progress in incorporating such flows into climate models of various resolutions and scales. Together with a larger CENRS effort, there is a compelling and urgent need to understand, model, and manage the climate related aspects of the interconnected food-water-energy system, which incorporates natural, social, and human-built components.

Navigating Challenges

A number of USGCRP research areas, such as understanding the interplay of multiple stressors (natural and human) and the potential impacts of climate system tipping points on social systems, require closer integration of social, natural, and engineering sciences. Although member agencies do provide funding opportunities for human dimensions of global change, systematic incorporation of the social sciences into appropriate parts of USGCRP research remains a challenge. A new USGCRP Social Sciences Coordinating Committee is entraining social scientists from the member and non-member agencies[2] to identify ways to strategically incorporate social sciences into the Program. For example, the USGCRP interagency priorities in Arctic change and water cycle extremes include topics like vulnerability and risk assessment, making them targeted opportunities for integrating the social sciences through agency activities and academic research. Continuing progress in this area is important to the Program, which will continue to work with the National Academies of Sciences, Engineering and Medicine and the member agencies to identify high priority areas of global change science as opportunities for

[2] National Academies of Sciences, Engineering, and Medicine. *Enhancing Participation in the U.S. Global Change Research Program*. Washington, DC: The National Academies Press, 2015. doi:10.17226/21837

longer-term integration of natural and social systems. These areas will aim to incorporate research from the growing cadre of trans-disciplinary young scientists interested in working at this interface.

Another challenge is the surge in demand for climate data at very high resolution (to the community and plot scale) and short time scales, often challenging the Program's ability to provide such information. The USGCRP will pursue this challenge through research, education, and communication avenues. With a focus on high-resolution data, research will continue in quantifying uncertainty across multiple time and distance scales, to advance the USGCRP's capabilities in responding to this surge of user-demand. The Program will continue to offer high-resolution products with reliable information about their applicability to a variety of temporal and spatial scales, including major river basins. The USGCRP will provide guidance in use of select high-resolution products (Goal 2). Educational and communication efforts (Goal 4) will emphasize the scientific meaning of "uncertainty" in their use.

Objective 1.2: Science for Adaptation and Mitigation

Philosophically, the USGCRP sees a complete continuum from its basic climate science, through climate impacts and vulnerabilities, to translation and provision of this information and knowledge needed to inform responses to climate change, such as adaptation and mitigation. Science for informing adaptation and mitigation builds from the USGCRP's core capabilities in areas like observations, regional and global scale modeling, decision-scale scenario development, and increasing understanding of the carbon cycle (including natural and anthropogenic sources and sinks). In the context of climate change, science that can inform adaptation contributes to enabling adjustments in natural or human systems to a new or changing environment, allowing either beneficial opportunities or helping to moderate negative effects. The USGCRP Strategic Plan defines mitigation as intervention to reduce the sources or enhance the sinks of GHG and other climate warming agents. In this arena, USGCRP research focuses on understanding the carbon cycle and its ecosystem connections, including the climate impacts of different emission scenarios and science that underpin carbon sinks and natural system carbon reduction approaches. It also includes modeling capabilities for decision support relative to mitigation. Mitigation approaches that include the development of engineering technologies or devices for energy generation, tailpipe or power plant emissions control, or active/direct carbon capture are carried out by various Federal agencies, outside the scope of USGCRP.

Maintaining Directions

The USGCRP reaffirms the commitment made in the Strategic Plan to use-inspired science to inform adaptation and mitigation. To enhance understanding of the vulnerability and adaptation of social, ecological, and human-natural systems, the USGCRP will continue to implement the Strategic Plan, including its crucial research on (1) national-to-local-scale consequences of gradual global change (e.g., increasing temperatures, changing water availability, agricultural shifts, sea level change); (2) similar scale consequences of changing patterns of extreme weather events (e.g., drought, floods, heat waves, storms); and (3) the potential impacts and consequences of large-scale rapid global change (e.g., permafrost loss, sea ice and glacial melt, destruction of major infrastructure). The USGCRP will further advance its efforts in achieving an integrated understanding of GHG sources, sinks, and emissions data and models, and their implications for mitigation. The USGCRP will continue to explore potential synergies and trade-offs between implementing adaptation and mitigation strategies and the impact that these two modes of response, if implemented together, have on the environment, economy, and society. Goal 2

speaks more directly to how this underlying science will be used to inform and support adaptation and mitigation decisions and actions.

Building on Progress

The USGCRP will further bolster its scientific frameworks for informing and assessing adaptation and mitigation options and strategies to better understand their potential effects (including in lightly- and significantly-managed ecosystems) including risks, benefits, synergies and co-benefits. In addition, the USGCRP is providing the scientific underpinnings for areas outlined in the President's Climate Action Plan (PCAP) that support the Federal Government in reducing carbon pollution and enhancing resilience domestically and internationally. Such efforts will draw on observing and modeling capabilities discussed under Objectives 1.3 and 1.4. Some specific areas in which the Program will build include areas of science need identified in Federal Agency Climate Change Adaptation Plans. Research on relevant social, behavioral, and economic sciences (e.g., decision-making under uncertainty, iterative risk management, effective communication approaches, costs of action vs. inaction) to improve understanding of human responses to climate change continue to be an important, and challenging, area for the Program. The USGCRP will continue making progress towards the Strategic Plan, including the areas discussed below.

Models for Decision-Making. Often basic scientific understanding about the changing climate needs to be interpreted in a regional context, accounting for the local topography and climate conditions, and other kinds of future changes, for example in demographics and land use. While general circulation models (GCM) provide foresight into future climate conditions, they do not account for this more localized context, nor do they necessarily integrate these parallel drivers of change. For the former, a range of statistical and modeling techniques have been developed, collectively termed 'downscaling,' to bridge the gap between processes and scales simulated by global models and information needs for finer-scale changes. The USGCRP member agencies are providing leadership to the rapidly expanding effort in downscaling by fostering research evaluating the efficacy of these techniques and clarifying best practices for choosing appropriate datasets. For the latter, research on future demographic shifts and patterns of land-use is being incorporated into the next generation of impacts and vulnerability modeling and assessment to foster a more comprehensive, consistent, and cohesive vision of potential future conditions; these will assist adaptation planning in sectors such as water resources, farming, and transportation. Overall, a range of approaches is being developed and used to better integrate climate models and their output into planning and decision support around key regional and sectoral information needs and to improve understanding of the complex human and natural system interactions driving and modulating change. For example, recent advances in Integrated Assessment Models (IAM) will allow improved understanding of the interplay of natural processes and human activities in areas key for developing robust adaptation responses, such as water and energy. Looking ahead, the USGCRP is focusing on developing or enhancing multi-scale and multi-sector representations, model interoperability, uncertainty quantification, and their representation within impact, adaptation, and vulnerability (IAV) models. These advances will aim to better support assessment, scenario planning, and in general the co-production of usable information about future global change risks.

The application of USGCRP modeling capabilities in support of decision-making is also highly relevant in a mitigation context. In particular, the USGCRP will expand efforts to assess what levels of broad-scale mitigation are necessary to avoid a range of adverse outcomes in the United States. A key outcome of this type of model-guided analysis is a clear assessment of the extent to which risks can be avoided over longer time frames by mitigation. Another outcome is

identification of risks that are unlikely to be avoided in the short-term by immediate mitigation actions and would therefore require adaptation responses. Other outcomes include evaluation of the potential need for additional emissions mitigation as a consequence of natural releases of GHG due to climate change and assessing the implications, in terms of adverse impacts avoided, of expected GHG reductions from significant mitigation actions.

Resilience and Vulnerability Research. Accurately assessing risks and vulnerabilities is essential to understanding and managing the societal, sectoral, and systemic impacts of a changing climate. A baseline assessment of climate-related risks to populations, natural resources, infrastructure, supply chains, etc., facilitates the incorporation of adaptation and resilience strategies into decision-making processes. Consistent with several Executive Orders[3] on Federal sustainability and adaptation in the face of climate change and on climate-resilient international development, the USGCRP and its member agencies are engaging in scientific research to support adaptation decisions in these areas. Regional and sectoral assessment tools and location-specific research, developed by the USGCRP agencies conducting such investigations, help to inform decision makers and climate preparedness efforts. The USGCRP agencies will continue to build on this research, developing tools and resources to assess climate-related vulnerabilities at a national-, regional-, and state-scale. Such tools should reflect social science dimensions, for example incorporating social science research findings about how people perceive and make decisions about climate impacts. The application of new scientific research for vulnerability assessments will provide more refined perspectives on climate change impacts at various spatial and temporal scales, enabling the development of more effective resilience solutions over the long term.

Translational Research to Inform Adaptation and Mitigation Decisions. The USGCRP agencies have long supported translating basic research into more actionable science that can be applied to the needs of decision-makers. Traditional ecological knowledge is also often available from indigenous people or those who have spent generations in a locale. The USGCRP is building on this core of applied research by leveraging existing agency mechanisms and supporting new approaches at the regional level. The NCA and the USGCRP's sustained assessment effort (Goal 3) are major sources for translational research, as are the regional research hubs supported by member agencies. The Program is accelerating its work in translational products like scenarios, which are a coherent description of a potential future situation that serves as input to more detailed analyses or modeling, intended to support the information needs of regional decision makers. Prior research based on current climate conditions now needs to be reconsidered in light of new understanding of local climate change, using new tools and consistent future scenarios of climate, population, and land-use across the Federal agencies.

Urban Opportunities for Adaptation and Mitigation. Dense populations, community-wide planning, and large collective carbon footprints in and from urban communities make them a natural focus for adaptation and mitigation actions. Rising interagency (and private sector) focus is driving research on reducing emissions from natural and engineered infrastructure while simultaneously increasing resilience to natural disasters and future climate change via place-based, large-scale adaptation measures. The USGCRP agencies, in cooperation with the Executive Office of the President (EOP), have initiated efforts to improve estimates, observations, and projections of carbon emissions and stocks. Multiple areas of improvement are needed in this area, These include quantifying and understanding underlying processes, dynamics, and future scenarios of carbon flows, stocks and sequestration at the urban scale, and translating

[3] Executive Orders: 13693 (2015), 13690 (2015), 13677 (2014), 13653 (2013), 13547 (2010), and 13514 (2009)

these into global-scale anthropogenic flux estimates within a truly integrated research sphere, including the natural, social, and engineering sciences. Viewing urban areas as whole systems is vital to inform decisions and promote successful preparedness and resilience. The USGCRP is catalyzing such efforts through its working groups and their coordination with related Federal efforts (see, for example, the U.S. Carbon Cycle Science Program).

Carbon Cycle Research. The USGCRP's carbon cycle research is essential to understanding natural carbon sources, the fluxes among them, and their interactions with anthropogenic emissions. Understanding natural biological and geological carbon reservoirs is also important for possible carbon sequestration, a key strategy for enhancing carbon removal from the atmosphere. One area receiving growing attention is the importance of coastal ecosystems in biological carbon sequestration (as well as other ecosystem services), by characterizing coastal wetland processes as key drivers of land-ocean carbon exchanges, and identifying significant quantitative and qualitative data gaps. There is limited data availability and data quality for coastal carbon distribution, properties, and processes. With the rising recognition that carbon in coastal ecosystems needs to be better understood, the science of coastal zone management for carbon sequestration and associated conservation, restoration, and adaptation benefits is gaining momentum via research coordination under the USGCRP auspices, through the Carbon Cycle Science Program.

Methane Cycling. The USGCRP research will include relevant aspects of the science needs identified in the "Strategy to Reduce Methane Emissions" announced in 2014 as part of the President's Climate Action Plan. The Program is fostering the combination of newly-available and continuing data streams produced from local, regional, and global scale measurements and observational platforms (including airborne platforms, flux towers, and global satellite based CO_2 measurement capabilities) across land, air, water, and ecosystem interfaces, and their integration into the evolving suite of global biogeochemical models. The USGCRP will further advance research on processes governing natural methane emissions and their interplay with anthropogenic emissions. The goal is to integrate improved observations and insight into large-scale models that can be used to project future atmospheric methane concentrations and their impacts. A key aspect of this effort will be in the Arctic, where warming temperatures could lead to permafrost thawing and methane release to the atmosphere. Utilizing data from new airborne platforms (e.g., DISCOVER AQ and CARVE), and climate projections, potential future emissions of methane from soils and sediments in high, mid, and low latitudes will be further studied (e.g., rice agricultural fields, peatlands, and coastal ecosystems). Both long- and short-term monitoring efforts that are fundamental to developing models for understanding and predicting atmospheric methane flows will be expanded by building upon existing USGCRP coordinated research efforts, networks, and infrastructure. Results from this work will be critical input in any U.S. Government policy on reducing methane emissions.

Navigating Challenges

The USGCRP faces continuing challenges to provide the best available science to inform adaptation and mitigation actions. The Program's goal is to provide global, national, regional and, via the NCA, state-scale information on key climate and global change variables in accessible and usable formats, and interact appropriately with user groups so they can customize information to their needs *(see Goals 2, 3 and 4)*. Over the past few years, the USGCRP has been collaborating with various non-USGCRP agencies (e.g., the General Services Administration, Department of Homeland Security) to improve its understanding of decision-maker information needs, at a range of scales, using regional and jurisdictional exercises to play out a variety of future conditions and identify research needed now to inform key future decisions. In the adaptation realm, user needs

for climate information (e.g., the risks and impacts that call for responsive adaptation actions) and models range from the Federal to the state and municipal level, and therefore can exceed the USGCRP's capabilities. The USGCRP's climate information is most useful for local use when its products, like the NCA, climate models, scenarios, and data streams, are used and leveraged by other groups (non-governmental organizations, state and local governments, the private sector) to provide customized information at the local and community scale. The U.S. Climate Resilience Toolkit is a good example of such leveraging. Adaptation issues are also complex in that they involve multiple types of decision makers (e.g., farmers, water managers, wildfire managers, community planners) and issues, all with potentially conflicting needs and varying levels of climate expertise of decision makers. The USGCRP is building experience in addressing these issues, and is working to integrate the social sciences to better meet user needs. There is a need to increase engagement with decision makers on what is known and not known about various impacts from a changing climate that might affect local and regional needs (for example, the effects of changing precipitation patterns on local horticulture and agriculture or of increasing heat waves on human health). Such engagement can help decision makers prepare now, using a mix of simple models, scenarios, and associated projections, as appropriate, to inform decision-making.

For mitigation, the Program will maintain awareness of emerging mitigation technologies and management practices, and will work to identify research needed to understand how interactions between mitigation activities and the underlying processes of Earth system behavior might result in potential impacts or unintended consequences. The monitoring, reporting, and verification of emissions, conducted by agencies to evaluate the impacts of mitigation approaches and adaptation measures, will require enhanced spatial and temporal precision across multiple geographic scales within and beyond the United States. Multiple data streams (e.g., satellites, inventories, social indicators, process models) will need to be included and harmonized in a comprehensive approach to optimally constrain estimates of carbon fluxes on land, in oceans, and connecting surface waters. National and international cooperation using observational and modeling platforms will assist the USGCRP to address and inform adaptation and mitigation objectives.

The SGCR is in the early stages of considering the topic of climate intervention, including the recommendations to the USGCRP in the National Research Council (NRC) reports *Climate Intervention: Carbon Dioxide Removal and Reliable Sequestration* and *Climate Intervention: Reflecting Sunlight to Cool Earth*. Regarding carbon dioxide removal, the NRC recommends, among other things, a coordinated approach that draws upon the historical strengths of the various agencies involved and uses existing coordination mechanisms, such as USGCRP. Regarding albedo modification, the NRC report included in its recommendations that the USGCRP could provide oversight and coordination to ensure that aspects of the research that are of benefit to both basic climate science and understanding of albedo modification are taken into account. Because of the preliminary nature of the SGCR's consideration of this topic, this is an area where public comment and input during the public comment period for this Update could be particularly helpful.

Identifying successful adaptation actions remains a very challenging research area, given the long response time of the climate system to perturbation. The USGCRP, with its Social Sciences Coordinating Committee and Adaptation Science Working Group, will work to identify and advance promising research pathways. This critical information will help provide a means to assess the progress of adaptation and mitigation measures, and to help decision-makers gauge whether the Nation is on the right path or is in need of an adjusted course.

Objective 1.3: Integrated Observations

Maintaining Directions

The USGCRP reaffirms the importance of sustaining and strengthening integrated observations of the natural and human systems involved in climate-related global change. Observations are essential to advancing integrated Earth system science. They are central to constructing the knowledge base for documenting and evaluating change, establishing the scientific basis for global change research, fostering model evaluation and development, and undertaking risk management and response. The Program promotes the deployment of observations taken at various spatial and temporal scales through multiple means, including remote sensing, non-satellite networks, and combinations thereof, including via field campaigns. Such integrated observations also contribute to global change monitoring and assessment efforts of national and international significance. Since the publication of the Strategic Plan, assets have been deployed which, in concert with existing ones, allow the USGCRP to address some new areas of global change research, and monitor changes in the Earth system. The USGCRP will continue to advance the Strategic Plan, including in the areas highlighted below.

Building on Progress

New observational assets and the increases in temporal, geographic, and vertical coverage they provide will enable the Program to build on recent progress, answer more science questions, and pose new ones. Recently launched and planned U.S. Earth science satellite missions will fill some of the observational gaps identified in the Strategic Plan, including providing key observations of the global distributions of atmospheric carbon dioxide, ocean salinity, precipitation, and soil moisture. The improvement in non-satellite observations will address needs for more comprehensive and higher-quality sampling, complement and validate satellite information, constrain and validate models, and provide insight into critical processes leading to improved modeling and prediction capabilities (for other scientific topics, non-satellite capabilities are deteriorating, as discussed under challenges below). It will also facilitate more complete global sampling to validate satellite measurements in locations such as deep oceans and the poles, which can be more difficult to address with traditional remote sensing methods. Integrated satellite and non-satellite data sets offer great promise, but are institutionally and disciplinarily challenging. For example, the longer records of paleoclimate data and the shorter records of satellite observing systems are dominated by subject matter experts who have spent much of their careers within one of these specialty areas. Multi-agency field campaigns (for example, using simultaneous airborne and satellite coverage to understand the impact of sea ice retreat on Arctic climate, or simultaneous ship, remote sensing, and aircraft measurements to investigate the role of atmospheric rivers and aerosol processes on extreme precipitation in California) aim to accelerate progress in topics like natural climate variability and teleconnections; cloud and aerosol processes; coupled ocean-atmosphere processes; and carbon cycle processes. By their very nature, field campaigns tend to be local and temporary, while other ground-based assets may be global and deployed over long time periods. Effective communication pathways between short term field campaigns and sustained large-scale observing system programs/networks, will be critical to sharing information on observing system requirements across diverse spatial and temporal scales and frequencies. For instance, the USGCRP will build upon emerging and existing long-term non-satellite research to further advance comprehensive observations of ecosystem processes, changes, and interactions with human and natural systems, as well as to increase scientists' knowledge of the flow of carbon among sparse to densely settled human societies.

Autonomous Platforms. Advances in autonomous platforms, such as Unmanned Aerial Systems (UAS) and Autonomous Underwater Vehicles (AUVs), and their sensors are opening up new observational and science opportunities. Ongoing evaluation of the deployment and use of new technologies, including miniaturized sensors, should be embedded in observing system programs to identify opportunities to augment the current system or inform its redesign, and to take advantage of more economically feasible approaches. As an example, new and emerging AUV technology, such as Deep Argo floats and deep-sea gliders could potentially enable wide-ranging ocean observations at depths below 2000m, advancing understanding of ocean-climate interactions. In addition, there have been recent demonstrations of the utility of UAS platforms, including rotorcraft and small fixed-wing aircraft for making routine atmospheric and terrestrial observations, with large fixed-wing aircraft being used for long-duration (24 hour) flights. Despite the growth in opportunities resulting from the proliferation of UAS, there are significant operational hurdles for them due to operational restrictions. It is not yet clear whether it will become easier or more difficult to operate UAS for scientific purposes.

Integrated Observations and Models. New information products are made possible by integrating observational data and models. Improvements in producing finer-scale, gridded, reanalyzed atmosphere and ocean data products are enabling investigations of climate variability and change. Various improvements in reanalysis (e.g. the representation of inter-annual variability of the atmospheric state, and advances in the quality of stratospheric wind fields) enable analyses at finer scales using new observations and assimilation approaches. Ongoing efforts are needed to evaluate the strengths and limitations of these reanalyses and to identify opportunities to make improvements. Moving forward, USGRCP will expand reanalyses to include land, ice, and biogeochemistry data sets. The USGCRP will advance a strategy for integrated Earth system analyses to obtain optimal state estimates of the full Earth system to study interaction among its different components, and to assess the ability of fully coupled approaches to provide more internally consistent estimates. Furthermore, the emergence of new global observational capabilities (such as the second ice, cloud, and land elevation (IceSat-2), Landsat 8, and Orbital Carbon Observing (OCO-2) satellites), when combined with existing observations and models, will enable new land, groundwater, ice, and carbon synthesis data sets to improve monitoring of drought, changes in land and sea ice, and carbon budget tracking.

Leveraging International and National Partnerships. The USGCRP will continue to leverage numerous existing bilateral and multilateral international partnerships, providing highly productive avenues for coordination and cooperation on both satellite and non-satellite observations. There are many examples of the USGCRP leveraging these partnerships to reap the research results of global networks through relatively small investments. As discussed in Chapter IV, partnerships are important components in furthering observing systems worldwide, including shared instrument development among research organizations in different countries. Major coordinating mechanisms like the Committee on Earth Observation Satellites (CEOS), Group on Earth Observations (GEO), the Global Climate Observing System (GCOS), and World Climate Research Programme (WCRP), and the Network for the Detection of Atmospheric Composition Change (NDACC) will help facilitate better global coverage in future observing systems. The USGCRP also works closely with other groups under the Committee on Environment, Natural Resources and Sustainability (CENRS), such as the Subcommittee on Ocean Science and Technology (SOST), and the Interagency Arctic Research Policy Committee (IARPC), to ensure coordinated observations in areas like the ocean's role in climate and the Arctic.

Lastly, there is a particular need to continue U.S. leadership in ocean and cryosphere observations since these are inherently global yet important to U.S. climate observations within and beyond the Nation's borders.

Navigating Challenges

Sustaining critical observations and enhancing essential new capabilities, a key focus of the Strategic Plan, remains a challenge. Many of the observing systems essential to understanding the physical climate system are aging or have reached the end of their designated life expectancies. Often, these climate-quality observations are made by research satellites, which have finite lifetimes and typically have no planned follow-ons. These include systematic measurements of aerosols, for which the lack of a follow-on could result in a gap of crucial data. Some polar wind measurements and surface wind observations are also at risk due to deteriorating quality of surface wind monitoring stations. The continuity of profile ozone observations is needed to understand its long-term change in response to reductions in ozone-destroying substances mandated by the Montreal Protocol. Atmospheric limb sounding of the lower stratosphere, which is important for climate studies, also faces a potential gap. Precipitation observation systems, which are important for understanding climate drivers and impacts, are key for all nine GEOSS Societal Benefit Areas. Another crucial, near-term risk in continuity of essential observations is the U.S. stream gauge network, developed for other purposes (e.g., flood monitoring, water use), but essential for climate observations. Additionally, the USGCRP agencies are utilizing existing observation capabilities of many types for periods longer than for which they have been designed.

Sustaining critical observations is a persistent challenge for the Program, which is using strategies like those below to partially address the problem. The USGCRP agencies are participating in a number of studies aimed at identifying critical observing needs and gaps. These include the forthcoming National Academies' second decadal survey of Earth Observations, which aims to: assess progress in addressing the major scientific and application challenges outlined in the 2007 Earth Science Decadal Survey; develop a prioritized list of top-level science and application objectives; and recommend approaches to facilitate the development of a robust, resilient, and appropriately balanced U.S. program of Earth observations from space. The agencies are also working with the U.S. Group on Earth Observations (USGEO) on its second Earth Observations Assessment. The assessment will evaluate current U.S. Government non-classified observing systems to foster coordination and maximize scientific and societal benefit, and therefore inform future mission design and scope, heavily taking Data Management implications (Objective 1.5) into account. The USGCRP Integrated Observations Interagency Working Group enhances awareness of extant, nascent, and upcoming observing capabilities, including in selected topical areas, such as for methane observing. The Program will both contribute to the prioritization efforts and incorporate their results in its science planning and prioritization.

Partnership opportunities for observations exist with defense agencies, the private sector, and non-governmental organizations. Such partnerships have both strengths and limitations, but overall represent a potential opportunity for additional coordination. Major strengths of public-private partnerships include the ability to leverage individual national resources toward common goals, and sharing of data and expertise. A major challenge for the future is in overcoming differences in data and metadata standards, data sharing and data policy, and access to currently restricted data in both the non-satellite and satellite realms (Objective 1.5). Additionally, there are multiple data portals that provide data in many formats to best meet original user needs. Coordinating across the portals in cost-effective ways that meet user needs remains a challenge. Potential leveraging opportunities of various kinds are possible, including measurements for precipitation, winds, clouds, ozone and its precursors, GHG, soil moisture, and ocean acidity. Any specific actions with non-governmental partners would need careful consideration with regard to benefits, recognizing the need for continuity in measurements.

Using Earth observations to address societal needs both enhances the relevance of the observations and improves society's resilience to changes in the climate system. To more fully realize this goal, observational data must be collected, stored, and delivered in ways that meet both societal and scientific user needs. The USGCRP provides an effective venue to systematically engage end users in a sustained and structured way to obtain requirements that inform earth observation system development and operation. In addition, the observations community must determine how best to integrate or otherwise connect with socioeconomic, demographic, and other non-traditional data sources needed to understand the emerging societal challenges. In particular, the climate and health community is poised to tackle this challenge by working closely with its academic, user, and observation communities to institutionalize a process for regularly collecting and communicating observational requirements for health needs. In addition, observations relevant to vulnerable communities and necessary for environmental justice are often missing, and efforts need to be enhanced to collect these data and observations. Citizen science can help to systematically collect and analyze data and plays a growing role in science endeavors.

Objective 1.4: Integrated Modeling

Maintaining Directions

Improving the varied USGCRP modeling endeavors requires maintaining progress in several scientific directions. Sustaining the scientific emphasis on all scales of models, from process models to reduced complexity models to global General Circulation Models (GCM) and Earth System Models (ESM), continues to rely heavily on participation across the modeling community to maximize collaboration, co-development of models, and coordination of integrated research. The Program will continue to promote understanding of interconnected phenomena with different characteristic timescales, from diurnal and seasonal to multi-decadal and centennial. The emphasis on interconnections includes developing classes of models incorporating the human system (e.g., Integrated Assessment Models) with the natural system models historically within the Program's purview. Underpinning this model development and validation process is continued active iteration and strong integration between observational sciences, improved science understanding, and enhanced knowledge management.

Building on Progress

The USGCRP will continue to advance the Strategic Plan, including in the areas highlighted below.

Spatial Resolution. Increased computational capacity and abilities continue to permit improvements in the spatial resolution in global models, which in turn allows incorporation of new, finer-scale physics and geographic features. Incorporating smaller scale processes, such as atmospheric turbulence and deep convection to improve model realism, are now on the verge of permitting better representation of extreme weather that will lead to a capacity to better understand and forecast extreme events. This will be an important area for the USGCRP in future. Improved interplay of geographic features such as mountains, coastlines, or water bodies with atmospheric physics is critical to skillful forecasting of important phenomena, and will allow exploring the potential of these dynamic projections to support decision makers at more local scales. The USGCRP is already working across its Interagency Working Groups to plan how best to capitalize on these improvements in dynamical downscaling and to develop evaluation techniques for them, along with the more available statistical downscaling products, to better understand their utility for decision-makers.

Model Intercomparisons. The field of model intercomparison has recently expanded—from its role as an experimental protocol for global general circulation models (the Coupled Model Intercomparison Project or CMIP) – to a greatly expanded suite of topically focused Model Intercomparison Projects (MIPs). Among the ongoing individual MIPs is AgMIP, which studies agriculture response to climate change, and Obs4MIPs that facilitate model data comparison with observational datasets. The MIPs all drive new understanding in Earth system science, assess how different approaches add realism, and develop appropriate metrics. The USGCRP will continue to foster these efforts to build on the progress being made in linking the climate community with experts on components of the natural or human systems. This includes agriculture, where deep knowledge exists about responses of crop plants to current conditions, to gain foresight into responses under future climate conditions.

USGCRP's Climate Modeling Summit

As recommended in a recent NRC report, the USGCRP convened the first annual meeting of the six modeling centers supported by the USGCRP agencies (February 2015). The Summit:

- Identified areas of cooperation and unique contributions across the centers.
- Adopted practices for significant improvements in efficiency, value, and capability of climate models
- Identified important areas of need for computing infrastructure improvements and for modeling advances, including gaps in physical climate models and seamless predictions at weather-to-climate time scales.
- Started planning for a meeting focused on models for decision makers, including development of a new class of finer resolution assessment capabilities that bring together Integrated Assessment (IA) and Impact, Adaptation, and Vulnerability (IAV) Models.
- Recommended increased and coordinated interaction with climate model stakeholder communities.

Integrated Modeling and Observations. Recently observed changes in the Earth system are driving new research efforts. The dramatic decline in Arctic sea ice, the mass loss and surface melting of ice sheets in Greenland, and instability of West Antarctic ice sheets are unsettling examples of changes observed from satellite systems. Such observations have motivated planning for expanded non-satellite observing networks, necessary to document and build understanding of the underlying mechanisms causing these changes. Other more complex phenomena reflect combinations of climate modes that reflect inherent climate variability. Changes in the annual minimum Arctic sea ice extent and "hiatus" (mentioned in Objective 1.1) are two examples that have stimulated research by USGCRP scientists to improve understanding of their underlying mechanisms. The USGCRP's ability to detect these phenomena reflects strong observing capabilities, but also its deep capacity to coordinate and combine research to improve understanding of the underlying physical processes leading to skillful models of the critical parameters. The improved mechanistic understanding of interconnected phenomena with different characteristic spatial and temporal scales then helps bridge scales leading to improvements in the global models. The USGCRP is capitalizing on improved observational assets and the detection and attribution techniques being developed in the science community, to build deeper understanding into the integrated modeling framework. It will also emphasize the use of new observational data and reanalyses (Objective 1.3) to improve model representations.

Temporal Resolution. Increased computational resources, observational assets, and deeper understanding of climate dynamics have led to the realistic possibility of an improved capability

to forecast Earth system anomalies from a few weeks to a few seasons ahead of time. The USGCRP is working to leverage improved understanding of key phenomenon and improved understanding to develop and test multi-model systems that explore forecasts for conditions such as drought, atmospheric rivers, and the El Niño-Southern Oscillation.

Earth and Human Systems. The USGCRP efforts are beginning to enrich models that better capture both human and Earth system components. Recent progress is also motivated by mitigation actions domestically and internationally. New observations (such as for global carbon) and modeling efforts, to understand progress by nations reporting for United Nations Framework Convention on Climate Change (UNFCCC) requirements, are already improving modeling of carbon storage sinks and sources, which can be used to inform decision-making. The USGCRP agencies have continued to explore how to address the economic issues of mitigation in models (e.g. costs of impacts associated with not mitigating emissions) and build cohesive frameworks to explore economic costs within the context of the CMIP5 ensemble[4]. The USGCRP will support efforts underway to advance energy and water sector models relevant to global change scenarios, analyze climate impacts on human systems under different RCP (Representative Concentration Pathways) scenarios, and build on work in behavioral modeling. Recent USGCRP workshops on demographic and land use scenarios are leading to efforts across agencies to align land use/land cover modeling efforts and deliver findings to decision makers. Another example of recent progress across the USGCRP is the collaboration between human health and climate science modeling evidenced in the recent draft for public comment of the forthcoming report *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment* that was developed as part of the sustained assessment.

Navigating Challenges

Clear progress has been made across the Federal modeling enterprise as the USGCRP adjusts to the changing landscape—from increasing computational capacity, to improved scientific understanding, to responding to startling new discoveries. Still, challenges remain to be navigated in the near-term. Fuller integration among models of human systems is needed to assess tradeoffs in many cross-sectoral areas, such as between energy, water, and land use. Other aspects of global change such as pollution and human population increase along with a changing climate. Coupling models of human systems (e.g., land-use change) and natural systems remains difficult, yet modeling advancements are needed to improve the understanding of multi-dimensional interactions within and between human and natural systems. For instance, USGCRP efforts to deepen the interplay between Earth System and Integrated Assessment Model communities are underway to better frame the decision space for mitigation and adaptation. The community is also challenged to support the numerous MIP activities, including coordinating with international efforts for the forthcoming Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report. Improved characterization of uncertainty for decision-making calls for increasing the transparency of model assumptions, enhancing model reproducibility, and developing a capacity to characterize model integrity. Decision-makers are demanding clear guidance on best practices for use of climate model outputs, such as downscaled climate data, requiring USGCRP leadership in clarifying how to scientifically assess Atmosphere-Ocean General Circulation Models and the quality of downscaling techniques.

[4] World Climate Research Program's Coupled Model Intercomparison Project

Objective 1.5: Information Management and Sharing

Maintaining Directions

Since 2012, there have been continual increases in storage, availability, volume, and variety of global change data. Simultaneously, curation methods and practices have improved and the USGCRP agencies have continued to build capacity to store and serve global change data. Most of these data are now available online, and web-based services allow researchers, decision makers, and other users to obtain data tailored to their needs. The USGCRP agencies will continue to support improvements to curation methods and practices to enhance scientific investigations and transparent information sharing consistent with the Information Quality Act, emphasizing a "high degree of transparency about data and methods to facilitate reproducibility of disseminated scientific information."

Climate Data and Tools (CDAT)

Launched in 2014 in support of the President's Climate Action Plan, the Climate Data Initiative (CDI) and the Climate Resilience Toolkit (CRT) are overseen by the Climate Data and Tools (CDAT) Interagency Working Group of the President's Council on Climate Preparedness and Resilience. USGCRP agencies participate on the CDAT Working Group, help lead the development efforts and contribute data and tools to both CDI and the CRT.

The USGCRP agencies have continued to integrate across networks to provide improved access and interoperability, a process greatly enhanced by the Climate Data and Tools effort (*see "Climate Data and Tools (CDAT)*").

Topic-specific portals bring together information from multiple agencies, as well as from non-Federal sources, to address important community-specific needs such as drought or sea level rise. These efforts demonstrate how improved data access and interoperability enable communities to adapt to climate change challenges. These Federal efforts complement and enable regional and local efforts to understand and address current and future global change impacts.

The USGCRP will continue to provide integrated knowledge to stakeholders. Agency portals will continue to provide information in multiple data formats for both science and non-science stakeholders. Users will continue to have the ability to customize information to their needs by putting more emphasis on application rather than data pre-processing. The emergence of multi-agency data portals and cross-publishing of datasets from multiple portals will foster the development of tools that tap into common data sources for stakeholder convenience. Additionally, interactive web-based maps will continue to provide visualization capabilities that do not require end-user processing.

Building on Progress

Data Volume. Technological advances continue to increase the ability to capture, aggregate, and process an ever-greater volume and variety of data. The USGCRP agencies will continue to take the lead in addressing this growing data volume challenge by maintaining, expanding, and evaluating existing collaborative, virtual data sharing environments and portals. New and innovative ways to do so, such as data alliances, partnerships, and research agreements, have made large collections of global change and earth science data from the USGCRP agencies available through cloud computing environments. Computational environments that can efficiently process big data volumes with high input and output demands are critical for reprocessing large data sets for multi-sensor observing systems. Such reprocessing is a key to the

seamless integration of observing system data sets with minimum time-dependent biases for comprehensive monitoring of the Earth's changing environment.

Enhanced Data Discoverability, Integration, and Interoperability. The USGCRP is building on advances in information management and sharing, including the Global Change Information System (GCIS) to increase scientific data discoverability, integration, and interoperability. GCIS is a USGCRP developed open-source web-based resource that provides structured links between global change information resources. Following the initial release of GCIS in support of the NCA3 and the USGCRP web site GlobalChange.gov in May 2014, the structured provenance data in GCIS has been used by the global change community as a resource to understand how data and resources are connected. The GCIS is supporting the development of *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment* and is key foundational infrastructure for the Sustained NCA, including a climate change indicators pilot (Goal 3).

The USGCRP member-agency efforts are improving discoverability of global change data and the integration and interoperability of data management systems through the use of advanced technological and computational capabilities (e.g., EarthCube geoscience data management and access cyber-infrastructure). The USGCRP efforts to improve discoverability and usability of earth observations data held by its member agencies require coordinating assessments, data management, and planning across the agencies, and fostering international collaboration. The Program will continue to promote this coordination and build upon existing efforts. These include the draft Common Framework for Earth Observations Data (CFEOD) by the U.S. Group on Earth Observations (USGEO), and work being done under the Big Earth Data Initiative (BEDI) to enhance discoverability and interoperability of Federal Earth observations, data, and information products.

Extending GCIS. Extending GCIS beyond assessments into other areas of the Program will help tie various agency efforts together. In particular, the USGCRP member agencies are developing databases of stakeholder needs and details of their adaptation and mitigation projects, efforts, experiences, and best practices to support decision-making. GCIS will be further developed to allow users to access this information from a central site, linking multiple agencies and tracing the connections from observations, models, and research to decisions.

Navigating Challenges

There has been significant progress in data collection methodology documentation and agency metadata practices that support credible science, enhance reproducibility, and enable discoverability. However, further improvements are needed, such as standard, adequate citation of datasets in peer-reviewed publications. Efforts are underway in the science community to facilitate complete traceability and reproducibility of scientific articles. Owing to a lack of widespread consistency on best practices, datasets are often insufficiently cited and made available. Data management plans, may be incomplete and lack incentives for full implementation. The USGCRP agencies will continue to work with their internal and externally funded scientists to share best practices and motivate compliance with agency data policies.

Progress has been made toward standards (e.g., the Administration mandate on machine-readable data formats), but further work is needed to create a culture of data identification featuring persistent, resolvable identifiers and documentation, with machine-readable metadata. The USGCRP will continue to demonstrate the value of metadata development and documentation, encourage scientists to comply with existing policies, and work with universities, journal

publishers, and data archives to facilitate these efforts. To encourage traceability, the USGCRP agencies will continue to develop better practices of documentation and identifier creation for datasets.

Looking forward, the USGCRP must leverage high capacity and cloud computing to continue to serve global change observation and modeling data. Cloud computing can help address the computational needs of model downscaling and the ability to consider vast amounts of observational data (physical, biological, economic, and social) alongside model data (*see Section 1.4*). Trends in high capacity and cloud computing are increasingly leveraged by individual USGCRP agencies, but additional coordination is needed for more efficient integration of individual cloud initiatives and better identification of data user demand.

The aforementioned challenges are heightened by a reach beyond the traditional bounds of information sharing and management, created by the integrative, complex global change research that the USGCRP pursues. Increasingly, global-scale challenges call for integrating social and economic data into the Program's analyses and models. This integration requires careful consideration of privacy and data access issues inherent in social science and economic data, as well as the technical and science challenges surrounding the variety of data and metadata formats and requirements. Integration solutions must combine scientific and technical innovations, careful and nuanced understanding of the linkages between the data, and comprehensive and sound policies around data access, privacy, security, and management.

Goals 2, 3, 4: Making Science Actionable and Accessible

Goals 2, 3, and 4 of the 2012–2021 Strategic Plan describe a cohesive and complementary set of philosophies and activities focused on making USGCRP's science easily accessible and useful to a wide range of decision makers for their consideration in determining potential actions (here called "actionable science"). The Strategic Plan remains the guiding blueprint for USGCRP; this Update highlights selected areas where significant progress has been made, and discusses how the Program will build on progress and navigate challenges.

USGCRP Goals for Making Science Actionable and Accessible

Goal 2. Inform Decisions: Provide the scientific basis to inform and enable timely decisions on adaptation and mitigation.

Goal 3. Conduct Sustained Assessments: Build sustained assessment capacity that improves the Nation's ability to understand, anticipate and respond to global change impacts and vulnerabilities.

Goal 4. Communicate and Educate: Advance communications and education to broaden public understanding of global change and develop the scientific workforce of the future.

Progress in these three goals relies on the strength of the USGCRP's science, which provides the essential basis for translating science to reach decision makers and citizens. The Program's work in these three goal areas benefits from continuous connection with Goal 1 as the USGCRP seeks both to improve the utility of knowledge gained from fundamental research and to use lessons from these newer goals to inform research priorities. Advances in information management have also been critical to success in these three goals. For example, new web technologies allow open sharing of climate science information and tools, traceability of scientific data, and connections to related resources at scales, or with detail, that decision makers can use. Finally, engagement of stakeholders is

critical to accomplishments under these three goals. Engagement allows the Program to understand potential user needs, but also provides users with the transparency and validity they need to trust the USGCRP's climate science.

These goals act together to: help the USCGRP to continuously identify needs for science, capacity-building (e.g., science translation, training, and education) and communications; provide relevant, up-to-date information to decision makers; improve the Nation's ability to anticipate and respond to global changes; and evaluate success in providing truly useful information that meets users' needs. Achievements in these three goals often use many of the same processes and tools, and result in similar outcomes. For example, products of the sustained assessment, especially NCA3, have been used for communication about climate impacts, education about risk management, and have been adapted to inform a wide range of decision-making processes. For that reason, this Update treats these three goals as a set, similar to the way objectives under Goal 1 are discussed.

Several significant changes have affected the USGCRP's sphere of work since the release of the Strategic Plan. The development and May 2014 release of the NCA3 provided an unprecedented opportunity to communicate about climate science and impacts, as did the release of the IPCC Fifth Assessment reports, in which the USGCRP participated. They also created demand for ongoing assessment activities, capacity, and tools. The communication and engagement conducted around the reports engendered a Federal infrastructure for outreach that can be adapted and expanded for new products and emerging climate issues. Similarly, the announcement of the President's Climate Action Plan (PCAP) in June 2013 and related policies encouraging domestic and international response to climate change have prompted an increased emphasis on research and communication around climate response strategies, and created strong agency needs for climate information, training, and development of risk assessment capabilities. See, for example, Executive Orders 13653 and 13677; Recommendations of the State, Local, Tribal Task Force; new greenhouse gas (GHG) reduction targets and methane reduction strategies. Actions in response to these announcements also highlighted the importance of regional collaboration and increased the demand for assessment and decision support products at sub-national scales.

In general, there has been a marked increase in demand for climate science, including science translation, downscaled information, climate information in risk-based frameworks, training and guidance (e.g., resilience exercises), and monitoring and evaluation of response effectiveness. The increase in demand presents opportunities to expand messages and reach new audiences, while also presenting the challenge of defining the USGCRP's role in keeping up with a large and diverse set of new information needs. In addition, there are opportunities to deliver information on a variety of time and distance scales, in more coordinated ways; they also presents challenges with articulating the suitability of various climate information products for different decision needs. Recent extreme events have been one driver of the increased demand for translated science information using USGCRP recent science advances on the relationship between climate change and extreme events (Objective 1.1) to communicate with the public. Extreme events have also provided effective focal points for decision support activities such as the development of a sea level rise projection tool in the wake of Superstorm Sandy.

Goal 2: Inform Decisions

Goal 2. Inform Decisions: Provide the scientific basis to inform and enable timely decisions on adaptation and mitigation.

- ***Objective 2.1. Inform Adaptation Decisions:*** Improve the deployment and accessibility of science to inform adaptation decisions.
- ***Objective 2.2. Inform Mitigation Decisions:*** Improve the deployment and accessibility of science to inform decisions on mitigation and the mitigation-adaptation interface.
- ***Objective 2.3. Enhance Global Change Information:*** Develop the tools and scientific basis to enable an integrated system of global change information, informed by sustained, relevant, and timely data to support decision-making.

In the face of a changing climate, the USGCRP is linking decision makers with resources and experts in areas such as ecosystem adaptation, sustainable water resources and utilities, improved public health, and other societal goals. The USGCRP agencies are implementing the President's Climate Action Plan and the 2014 Federal Agency Climate Change Adaptation Plans while assessing economic, cultural, and natural resource vulnerabilities to climate change both domestically and internationally. Agencies are using resources such as the NCA3 (with data provided through the GCIS), the Climate Data Initiative, Climate Resilience Toolkit, the IPCC Fifth Assessment Report (AR5), and the USGCRP Federal Adaptation Resource Library. Because decisions about climate preparedness and adaptation are made at all spatial scales, from local to international, the USGCRP agencies are delivering decision support that is aligned with a range of scales. Such decision support is accomplished through sustained Federal coordination of international partnerships, Federal communities of practice, and regional climate science centers that serve a range of sectors at the community-level. Recent efforts include programs and activities that equip regions and states with climate information and tools specific to their needs. These resources illustrate observed climate trends and likely future conditions that will facilitate climate preparedness and resilience. In addition, local and community-scale information and tools are increasingly being provided by other governmental and private sector organizations that also use USGCRP information, such as the NCA3. Identifying where climate impacts may worsen or improve existing stressors in their regions helps communities integrate climate change into their risk management practices. Since the release of the 2012 Strategic Plan, there has been increasing demand for science translation, downscaled information for decision-making, decision support tools, training and guidance, and monitoring and evaluation of the effectiveness of strategies and research.

Maintaining Directions

The USGCRP will continue to engage with decision makers to understand their research and information needs *(see also Goals 3 and 4*), and to identify and deliver actionable science to users to help inform adaptation and mitigation decisions. This includes the continued collection, delivery, and translation of data and information resources at various spatial and temporal scales. It also includes working with other governmental and private sector entities to help support various types of decision makers in both the public and private sectors (e.g., resource managers, engineers, healthcare professionals, insurance agents, state and local officials, etc.) on the selection and application of science for adaptation and mitigation responses. The USGCRP agencies can provide guidance on how to assess the certainty and reliability of available data, as well as how to interpret and use climate science and information. They also can advance innovative data sharing and information exchange approaches (e.g., co-production of research and

knowledge, citizen science, participatory scenario planning, etc.) to facilitate the continued development of user-driven science.

Building on Progress

The USGCRP will continue to advance the Strategic Plan, including in the areas below.

Decision-Scale Knowledge. The USGCRP directly, or through collaborations, will support research, collaboration, data sharing, and knowledge exchange on temporal and spatial scales of decision-making ranging from years to decades, from a national to a local community-level. Examples of such efforts include the collaboration with the Federal Emergency Management Agency (FEMA) on Climate Change Preparedness and Resilience Exercises for the Houston-Galveston Region, using information from NCA3, and a FEMA-led effort involving USGCRP agencies and staff to develop the Sea Level Rise Tool for Sandy Recovery. It will use effective practices, lessons learned, and approaches captured from evaluation of adaptation and mitigation actions, including the co-benefits and synergies between them (Objective 1.2), to inform more durable actions at multiple scales. Doing so will enable flexible and responsive management approaches, and will facilitate identification of potential areas of improved collaboration between the public and private sector. It will be important for the USGCRP to define boundaries between what the private sector and the Federal Government can and should, respectively, provide. No single entity can address this issue independently; collaboration can encourage a "whole community" approach to tackling the challenges and opportunities that continue to emerge in the face of a changing climate. As part of this effort, the USGCRP will use its adaptation resources and capabilities to support climate education.

Integration of Social and Behavioral Sciences. USGCRP and its member agencies participate in a number of efforts to develop resources and tools for adaptation to climate change and its impacts. Increasingly, these efforts are incorporating social science perspectives (e.g. the Social Vulnerability Index) and combining climate science and demographics in ways that allow the user to customize data sets and visualizations to their topic and location of interest (see for example, the Climate Explorer or Climate Resilience Toolkit). USGCRP will continue to support and prioritize such efforts, and to explore emerging opportunities to better integrate social sciences into its decision support portfolios

Supporting Agency Adaptation Planning. The USGCRP will provide expanded support for agencies to meet climate policies through the utilization of actionable science, including analysis of collective agency science needs for their adaptation planning. This will include supporting agencies as they work to fulfill requirements related to adaptation and resilience outlined in recent Executive Orders 13953 (*Preparing the United States for the Impacts of Climate Change*) and 13693 (*Planning for Federal Sustainability in the Next Decade)*. The Program and its member agencies will identify common research and information needs specified in Federal Agency Climate Change Adaptation Plans, and continue to expand efforts to fulfill those needs. Notable work around this includes the Climate Explorer (as part of the Climate Resilience Toolkit) and the Regional Climate Change Preparedness and Resilience Exercises for Texas (Houston-Galveston) and Colorado.

Science Translation. In order to build on progress already made through its Inform Decisions portfolio, the USGCRP will identify components, characteristics, and metrics of successful science translation, and implement effective practices for enhancing and mainstreaming translational capacity. To extend translational capabilities, the USGCRP will provide guidance on

scales and certainty in interpreting climate projections for effective framing and decision-making for specific audiences (such as the Regional Climate Scenario Summaries).

Navigating Challenges

There are challenges in the Inform Decisions portfolio that the USGCRP will need to navigate over the next few years. Central among these is the importance of analyzing climate change risks and opportunities at the interface of climate and non-climate stressors (e.g., economic changes, land use concerns, national security, sector-specific decisions, etc.). To address climate change as a "threat multiplier," for example, the Program will need to view Earth and human system as a whole rather than by individual sectors or entities. This holistic approach helps to illustrate how climate change can amplify existing threats, stressors, or hazards (e.g., instability from large scale human migration, public health, hazardous chemical spills, or ocean acidification), enabling the identification of co-benefits and conflicts between various strategies to enhance sustainability and resilience over time.

Building from its interdisciplinary research efforts, the USGCRP will improve engagement between science producers and decision makers. Users are making decisions at various scales of management and planning, so it is important for the development of research to be framed, in part, by user needs. Through joint identification of research needs in targeted areas and joint development of knowledge (often called co-production), the Program can engage with users early in the production process, helping to define the scope of USGCRP products, as well as encourage the development of actionable science that is most relevant to decision makers and can be applied to address climate-related management challenges.

Lastly, the USGCRP will support its member agencies in coordinating between Federal and regional levels. Research and engagement efforts at regional, state, and local levels to understand decision contexts, analyze risk, and collaborate with decision makers on adaptation options have grown in scope in recent years to meet rapidly rising demands by decision makers at these scales, with much work done at the regional climate centers and programs operated by the USGCRP agencies. The USGCRP will work to find a balanced approach between ensuring that the regional organizations are well informed of priorities and activities, and engaging them as appropriate, while recognizing that regions and states have the need to self-organize and develop networks and information exchanges that work for their particular needs and constituencies.

Goal 3: Conduct Sustained Assessments

Goal 3. Conduct Sustained Assessments: Build sustained assessment capacity that improves the Nation's ability to understand, anticipate, and respond to global change impacts and vulnerabilities.

- ***Objective 3.1. Scientific Integration:*** Integrate emerging scientific understanding of the integrated Earth system into assessments and identify critical gaps and limitations in scientific understanding.
- ***Objective 3.2. Ongoing Capacity:*** Strengthen and evolve ongoing capacity to conduct assessments with accessible, transparent, and consistent processes and broad participation of stakeholders across regions and sectors.
- ***Objective 3.3. Inform Responses:*** Inform responses to global change with accurate, authoritative, and timely information that is accessible to multiple audiences in multiple formats.
- ***Objective 3.4. Evaluate Progress:*** Ensure ongoing evaluation of assessment processes and products, and incorporate the findings into an adaptive response for systemic improvement.

The urgent need for timely information is paired with the growing recognition of how a changing climate affects a multiplicity of decisions. The sustained assessment process is intended to provide decision-makers with more timely, concise, and useful information distilled from scientific research. This process includes ongoing, extensive engagement with public and private partners, and targeted, scientifically rigorous reports that address concerns in a timely fashion. As required by the GCRA, the process also supports quadrennial reports, such as the NCA3 and the upcoming fourth NCA, as well as international collaborations.

Maintaining Directions

The Program has made dramatic progress in conducting assessments over the recent past and continues to strengthen implementation of the sustained assessment process, based on principles in the Strategic Plan. The USGCRP will maintain the strongest elements of the successful approach built around methods developed for the NCA3 and IPCC. This process has already supported several ongoing assessment activities and will benefit the USGCRP's involvement in a range of national and international climate assessments, such as on biodiversity and ecosystems and ozone. The USGCRP will continue to participate in international assessments, including planning for the IPCC Sixth Assessment Report.

Building on Progress

The USGCRP will continue to advance the Strategic Plan, including in areas highlighted below.

Sustained Assessment. The success of the NCA3 and its procedures provides a strong platform on which to build a sustained assessment process that shifts focus from the single end-product, such as a comprehensive assessment report, to delivering multiple products to meet the decision-making needs of diverse groups of readership. These products, which include but are not limited to quadrennial NCAs, will be produced sequentially to draw on one another as appropriate. Furthermore, these products will sustain momentum generated by the NCA3 while also responding to the demand for more information and knowledge about climate impacts and adaptation options, recognizing the demands on the participating agencies in producing these products for the Nation. The USGCRP is developing a dynamic and adaptive framework for

sustained assessment that will provide projections and scenarios that can be used for assessing climate risk and impacts in the context of multiple stressors, moving beyond those currently available. Such a framework will also help identify research needs for incorporation in USGCRP science prioritization and planning.

Sustained Assessment Reports. Where urgent needs exist to assess the country's state of knowledge (e.g., changing patterns of weather extremes, including drought) or where there is an emerging topic of interest with a sufficient body of science, the USGCRP will promote synthesis of new information and insights as they emerge, without waiting for the next quadrennial report. These efforts will strengthen and evolve through the USGCRP's current capacity to conduct such interim assessments. Furthermore, the consistency of the transparent development and engagement processes developed as part of the NCA3 leverage protocols and innovations developed over the past few years. A strong example of this is the use of traceable accounts, or links that distill science findings to the underlying publications and datasets they come from, within the GCIS. These efforts increase transparency, communicate confidence levels, and provide enhanced discoverability of the most relevant information for a given need.

Tools for Sharing Assessment Findings. Since the release of the 2012–2021 Strategic Plan, the USGCRP has built a cadre of powerful tools that greatly increase assessment capacity, provide efficient and effective support for assessment processes and products, and make assessment products more accessible and useful to decision makers and citizens. The on-going development of such tools is a key aspect of this Goal, and the NCA3's innovative website's visibility, traceability, and content are models for communicating effectively across the Federal Government and beyond. The USGCRP's Global Change Information System (GCIS) improves information content, transparency, and traceability across USGCRP reports, including the upcoming report on climate change and human health. The USGCRP's Review and Comment System, used now for multiple national and international assessments, streamlines widespread distribution, review, and comment collection for global change reports and assessments. Website analytics provide insight into stakeholder interest and constitute one avenue for program evaluation. The USGCRP will continue to build these tools and make them available across the Federal Government to improve the Nation's ability to inform responses to climate change and build capacity for scientific assessments and information sharing.

Stakeholder Engagement. Another key aspect of building assessment capacity and informing responses is connecting with stakeholders at all scales of government and organizations, as well as with individuals. The USGCRP has fostered an innovative platform—NCAnet—for collaboration that identifies new resources and capacity to enable complementary climate assessment efforts outside the Federal Government. This self-assembled network is immensely valuable for the broad dissemination of USGCRP products by harnessing the power of existing networks of which some NCAnet participants are partners, such as non-governmental organizations and faith groups. The USGCRP will continue to support this approach to co-produce information through sustained interaction via various affinity groups that form amongst the participants. The most recent groups focus on economic valuation of climate change impacts and the use of climate scenarios to understand how future conditions might plausibly evolve under a range of policy decisions. More robust and regular engagement between scientists and stakeholders through sustained assessment strengthens the ability of the United States to respond to the challenges of climate and global change.

Scenario Development and Use. The USGCRP has identified the need for a systematic approach to scenarios, encompassing climate, land use and land cover change, population and demographics, and other key climate-related drivers of global change impacts, to support the

sustained assessment enterprise and its emphasis on decision support. Consistent, informative sets of scenarios that address key areas of need, such as regionally specific information and impacts-relevant metrics such as changing characteristics of extreme events, can both support risk assessment and decision-making and identify scientific gaps in need of future research, leveraging the full capabilities of the USGCRP modeling enterprise (*see Models for Decision-Making, p. 19*). Key tasks include identifying products (e.g., downscaled projections, contextual framing) and their features (e.g., spatial and temporal scales, variables of interest, uncertainty), as well as strategic and implementation guidance for use within research, assessment, and decision communities, including mechanisms for access and opportunities for users to engage in product development and use.

Indicators Pilot System. The USGCRP recently launched a pilot indicators system, as called for in the Strategic Plan. Indicators are variables, typically constructed from long time-series observations that can be used to measure the status or trend of a system, point out vulnerabilities, and inform decision-making at local, state, and national levels. The pilot, available now to all, provides an initial set of indicators in a common format that is intended for use by non-specialists. It will also provide key data sets that will be used to support the Fourth National Climate Assessment (NCA4), and will be expanded over time. It aims to go beyond documenting climate change to encompass climate impacts, vulnerabilities, and responses. It will leverage and build on existing indicator efforts by integrating data from Federal agencies, non-governmental organizations, academia, and the private sector. The indicators pilot and its future developments are intended to support planning and decision-making, with a broader range of indicators extending to climate vulnerabilities and preparedness.

Integrating Social Sciences. The USGCRP's Social Sciences Coordinating Committee (SSCC) is providing specific recommendations to the Program on ways to better incorporate social sciences in the next NCA. The group analyzed the previous NCA to find good examples of inclusion of social sciences, as well as areas where social sciences could have improved the report from the perspective of science, research, communication, or usefulness to readers. The group's ideas for the next report include everything from new topics and the way to structure chapters, to best practices for representing social science inputs, such as economic valuation of climate change impacts. In spring 2016, the SSCC also plans to convene a workshop involving several social science professional associations, together with USGCRP staff and affiliated Federal researchers and program managers. Drawing on current research perspectives from several social science disciplines, the objective is to identify specific, implementable actions that the USGCRP or its member agencies could take to enhance the effectiveness of Federal climate change activities.

Navigating Challenges

Despite strong progress towards implementing the objectives of this goal, challenges remain. Overall, the high expectations created by the success of the NCA3 process require the USGCRP to balance resources and effectively leverage Federal capacity, while building on grassroots enthusiasm. Recent Executive Orders directed agencies to integrate climate into their operations and decisions based on the results of the quadrennial NCA reports. However, embedding climate risk assessment and adaptation responses into Federal agency planning have greatly increased the need for the USGCRP to foster coordination and cooperation around climate issues. To deliver appropriate support, the USGCRP will need to better define key aspects of the sustained assessment process and products that can meet agency needs while managing expectations. Utilizing the new Federal Advisory Committee for Sustained Assessment, leveraging engagement

activities such as NCAnet, and active outreach to key stakeholders, are required to address this challenge.

The USGCRP needs to continue to share its assessment capabilities and technical expertise with domestic and international partners to foster global capacity under the Strategic Plan (Goal 4). Regional assessments, such as those in collaboration with the Arctic Council, support for other national assessments such as in India, thematic assessments such as for ozone, and the next IPCC assessment, are important endeavors, and will require careful consideration and marshaling of USGCRP resources.

Ensuring ongoing evaluation of assessment processes and products, and incorporating the findings into an adaptive response for systemic improvement requires defining and measuring metrics of success. This remains a research issue that the USGCRP is working with the National Academies of Sciences, Engineering and Medicine's Committee to Advise USGCRP to address. Incorporating risk-based framing into assessments more comprehensively over time will require providing guidance on the consistent use of recent research and approaches. USGCRP will build on agency efforts to apply risk framing and climate information in a consistent framework, and will embed those efforts into sustained assessment activities and reports.

Goal 4: Communicate and Educate

Goal 4. Communicate and Educate: Advance communications and education to broaden public understanding of global change and develop the scientific workforce of the future.

- ***Objective 4.1. Strengthen Communication and Education Research:*** Strengthen the effectiveness of global change communication and education research to enhance practices.
- ***Objective 4.2. Reach Diverse Audiences:*** Enhance existing and employ emerging tools and resources to inform and educate effectively, providing for information flow in multiple directions.
- ***Objective 4.3. Increase Engagement:*** Establish effective and sustained engagement to enable a responsive and wholly integrated Program.
- ***Objective 4.4. Cultivate Scientific Workforce:*** Cultivate a capable, diverse scientific workforce that is knowledgeable about global change.

Goal 4 seeks to foster greater public understanding of science through information dissemination and to gain greater awareness of the public's science and information needs through engagement and dialogue. Communication, education, and engagement are essential tools for achieving the objectives outlined in the three other goals of the 2012–2021 Strategic Plan. Like many of the activities conducted in support of the Strategic Plan, agencies' communication, education, and engagement efforts are often coordinated through interagency working groups and other collaborations under the flag of the USGCRP, but with much of the implementation carried out by the agencies. In some cases, especially when communication, education, and engagement efforts are focused on primarily interagency product like the National Climate Assessment, the USGCRP takes a lead role in developing and implementing products and activities that are disseminated through the Program and individual agencies.

Maintaining Directions

The USGCRP has made significant progress on communicating and educating about interagency global change research priorities, scientific assessments, and activities. Areas where the Program

will maintain its direction include coordinating education research investments and making research results more accessible via the Education Interagency Working Group; supporting forums for dialog, including USGCRP-focused communities of practice like NCAnet; and participating in Federal and non-Federal communities of practice that focus on communication, education, and engagement. Another important direction is engaging stakeholders in the scientific assessment process through calls for public comment on draft materials (e.g. draft NCA3, draft report on climate change and human health), in-person and virtual public forums, and requests for information relevant to emerging activities such as the sustained assessment process. Yet another important area via the USGCRP member agencies is providing Federal grants and other resources that build climate literacy by supporting networks of scientists, educators, and other professionals involved in strengthening climate literacy within disciplines and among the general public. Specific efforts include assisting in the White House OSTP's Climate Education and Literacy Initiative (CELI), supporting the implementation of the climate-related National Academies Framework for Science Education and the resulting state education standards, and creating and participating in forums that deliver USGCRP research findings to educators. USGCRP member agencies continue to fund training for young scientists to improve abilities to evaluate, understand, interpret, and apply climate science.

Building on Progress

Through the USGCRP, Federal agencies collaborate on and coordinate a comprehensive strategy for climate and global change education, engagement, and communication that enhances the work of individual agencies. The Program will continue to leverage work done across its working groups, communities of practice, Federal-university networks, etc. to enhance dialogue and more effectively reach decision makers and key stakeholders. The USGCRP will build on this progress in a number of ways, including those highlighted below.

Understanding Audiences and Creating Messages that Resonate. Data from digital media (e.g., web traffic, social media tracking) and print orders can be used to explore which products and sections of products are seen and potentially used most often. By expanding the USGCRP research to more fully incorporate social and behavioral sciences, including through the Social Sciences Coordinating Committee, the Program can better understand behavioral responses to information provided to stakeholders about climate change and associated risks and opportunities. These results can be used to establish a knowledge base that relates to readers' past experiences, knowledge, and social context. This knowledge base can inform human responses to climate and global change through offering coordinated education, communication, and decision support programs, as well as other partnerships and collaborations. Such communications may include providing the science that specific sectors find most compelling, such as health considerations as a rationale for responding to climate change.

Building and Maintaining Communities of Practice, Partnerships, and Collaborations. NCAnet has proven to be an effective means to engage with a variety of organizations, especially through the use of affinity groups that address particular topics of interest. Supporting additional affinity groups and encouraging existing and new NCAnet participants to engage with these groups can drive the development of activities and materials that use NCA3 and other USGCRP products. Moving beyond NCA, the USGCRP can also build or participate in communities of practice that focus on other areas of activity. Developing public-private collaborations and partnerships with educators, private industry, and researchers can increase the awareness and use of NCA findings and that of other USGCRP products, as well as the Climate Resilience Toolkit (initiated as part of the President's Climate Action Plan). Finally, leveraging the results of climate change education investments through stronger connections to, and closer collaboration with,

other Federal funders and the private philanthropic community can help operationalize projects that proved successful in the pilot phase.

Building Capacity to Use Scientific Information and Tools. Through efforts like NCAnet and the interagency community working on the Climate Data Initiative and the Climate Resilience Toolkit (*see Climate Data and Tools (CDAT) box on p. 29*), the USGCRP can continue to facilitate discussions about how to engage with stakeholders and how to assess their needs for climate information and tools. The Program will continue to build scientific capacity by increasing awareness of these tools and integrating them into education and communication efforts targeting multiple audiences, and by fostering increased ability for people to understand and interpret climate science findings for their particular needs. For example, the USGCRP may facilitate discussions on efforts to enhance and complement Federal trainings for place-based educators with these tools. The Program has already demonstrated the ways in which new communication technologies can be deployed in developing, disseminating, refining, and using climate tools. Further learning from these will enrich future efforts.

Coordinating and Extending Citizen Science Opportunities. An emerging opportunity is integrating data and information from new sources, including from citizen science and crowdsourcing, with Federal sources. The USGCRP is exploring these opportunities through participation in communities of practice such as the Federal Community of Practice on Crowdsourcing and Citizen Science and associated workshops on climate change indicators, health, and Earth observations. USGCRP's focus includes the use of citizen science as both a form of education and outreach, and as an approach that can support research and observing activities.

Training the Federal Workforce. In response to Executive Orders and requests from a number of Federal agencies, the USGCRP is collaborating with agencies across the Federal Government to develop and provide training resources on climate change for a variety of fields.

Navigating Challenges

There are a number of areas related to communicating and educating where the USGCRP is facing challenges, some recognized in the Strategic Plan. Particular areas where the Program may consider focusing efforts include areas where progress has already been made, but challenges remain, as identified below.

Coordinating, translating, synthesizing, and disseminating relevant communication research across the USGCRP can still be a challenge. Although the Strategic Plan noted the importance of this area, The Program does not have an active communication research-focused or broader communications interagency group, reflecting workload realities. Such a group could conduct a research needs assessment, identify and catalog relevant Federal and non-Federal communication research (using the Tri-Agency Climate Education (TrACE) catalog as a model), and translate and disseminate relevant research findings.

The USGCRP agencies have limited understanding of the motivations, needs, and learning styles of diverse stakeholders relevant to climate change risks. A better understanding of these audiences, building on social science insights, is essential to providing information in ways that different audiences can use; this is key to building an informed citizenry and developing tools and resources related to communication, education, and engagement activities. Developing such an audience map is another area where coordination among agencies would benefit from a communication research interagency working group.

Foundational climate change knowledge and understanding of related effects on sectors, such as health, economy, agriculture, and disaster risk, is required for the workforce in an increasing number of economic sectors. As a result, efforts to build a diverse, scientifically-literate future workforce will require engaging under-represented groups to build the necessary knowledge and skills prior to college. Efforts to deepen science and climate literacy across higher education, including in community colleges and technical training programs, and in a wide array of disciplines, will require new translation for USGCRP research results to ensure appropriate use, as well as training in evaluating, understanding, interpreting and applying climate science. Many professional fields, such as architecture and planning, engineering, and law, include professional development and training requirements that could provide opportunities to build climate literacy through incorporating USGCRP research.

For the past decade, the USGCRP agencies and non-Federal organizations have supported extensive efforts to implement climate change education, build public awareness of the impacts of climate change, and engage communities on this issue. These efforts are increasing the public's ability for social engagement around critical climate change issues, even in the midst of political and social barriers. Many such programs have achieved positive on-the-ground results around the country. However, challenges still exist in coordinating initiatives across various audiences, leveraging resources, and scaling best practices.

Chapter IV: International Cooperation

Global change is, at its core, an issue that requires an international, coordinated response. The U.S. Congress recognized the importance of international cooperation and collaboration and codified it in the Global Change Research Act of 1990 (GCRA). Through international cooperation, the USGCRP and its member agencies are leveraging existing and emerging scientific knowledge to accomplish programmatic goals and strategic priorities.

The Global Change Research Act mandates the USGCRP to do the following:

- Promote international, intergovernmental cooperation on global change research;
- Involve scientists and policymakers from developing nations in such cooperative global change research programs;
- Promote international efforts to provide technical and other assistance to developing nations which will facilitate improvements in their domestic standard of living while minimizing damage to the global or regional environment

The Changing Landscape

The landscape of international cooperation on global change research is undergoing transformational change, to which the USGCRP is in an excellent position to contribute and respond. There has been considerable progress in cultivating cross-disciplinary research collaborations towards a common goal of a sustainable and resilient world. This approach is most visible in the recent establishment of Future Earth, a major international research platform that builds on more than two decades of successful international science collaborations such as the International Programme of Biodiversity Science (DIVERSITAS), the International Geosphere-Biosphere Programme (IGBP), the International Human Dimensions Programme (IHDP), and, the World Climate Research Programme (WCRP) —all four being international research organizations that USGCRP has supported and engaged in. The United States is serving as one of the five Future Earth global hubs, which provides the USGCRP and the broader research community with a unique opportunity to help shape and benefit from research advancements emerging from this integrated initiative.

Several significant national and international research assessments have been completed since the USGCRP 2012–2021 Strategic Plan was released, including the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment (AR5) report, the forthcoming United Nations World Ocean Assessment, and the 2014 World Meteorological Organization/United Nations Environment Programme Scientific Assessment of Ozone Depletion. These assessments review and synthesize the most current state of scientific knowledge on global change issues. The USGCRP experience in engaging with international research assessments has demonstrated that cutting edge science comes from a global. For international assessments to have credibility, and to ensure the best available expertise is utilized, they need involvement of, and leadership from, all countries.

Maintaining Directions

As the USGCRP actively fosters inter- and trans-disciplinary, action-oriented science during this 2012–2021 period, international cooperation is critical to entraining expertise and leveraging limited resources from around the world. The USGCRP's involvement in international global

change activities cuts across the breadth of the activities and advances all four goals of the Strategic Plan.

Advancing Science. Since its inception, the USGCRP has invested and been involved in international global change research through WCRP, IGBP, IHDP, and DIVERSITAS programs, and the Earth System Science Partnership (ESSP). Member agencies continue to be actively involved in international scientific research efforts by establishing U.S. branches, providing representation to the appropriate steering committees and secretariats, or facilitating involvement in strategic planning. The USGCRP actively engages with international partners to ensure that cooperation on modeling continues to advance understanding of the climate system and providing information at scales relevant to decision-making. This is achieved through engagement with research initiatives such as WCRP, the Coupled Model Intercomparison Project (CMIP), and the Coordinated Regional Climate Downscaling Experiment (CORDEX), as well as data support accessibility services such as Earth System Grid Federation (ESGF). The United States continues to engage with various international observation networks, including but not limited to Committee on Earth Observation Satellites (CEOS), Group on Earth Observations (GEO), Global Climate Observations Systems (GCOS), Intergovernmental Oceanographic Commission (IOC), and the World Meteorological Organization (WMO). Such efforts provide the United States with the ability to coordinate resources with other countries and foster strategic planning for the establishment of Earth observations—both remote and non-satellite.

Inform Decisions. The USGCRP will continue to work with partners to develop and enhance the capacity of researchers and decision makers in less-developed countries, promote global change research cooperation, and focus on efforts to improve early warning systems (including those for heat, famine, drought, and infectious disease surveillance) to help prepare for and prevent climate-related outbreaks and health emergencies. The USGCRP-supported SysTem for Analysis, Research, and Training (START) works in Africa and Asia to foster informed decision-making on global change. The Global Framework for Climate Services (GFCS) is a valuable partner of the USGCRP, as it provides an international mechanism to enhance the use of climate research across all time scales in decision-making at global, regional, and national levels. The USGCRP will continue promoting and fostering regional cooperation in global change research through partnerships with key regional institutions, such as the Inter-American Institute for Global Change Research (IAI) and the Asia-Pacific Network for Global Change Research (APN).

Conducting Sustained Assessments. The USGCRP will continue to build on its extensive experience in contributing to global, regional, and thematic scientific assessments**.** The USGCRP has hosted a technical support unit for the last several IPCC assessment cycles, mobilizing the national research community to author and provide commentary for the IPCC and other assessments (e.g., World Ocean Assessment, Climate Action Reports). Research and researchers supported by USGCRP have also contributed to the annual Global Carbon Budget released by the Global Carbon Project over the last ten years, of which the USGCRP's U.S. Carbon Cycle Science Program is a major part. The USGCRP has been involved in thematic assessments, such as the Ozone Assessment, the Intergovernmental Platform on Biodiversity and Ecosystem Services, and the World Ocean Assessment. These efforts provide important information about the state of global environmental, social, and economic aspects. The USGCRP will continue to work with partners to identify themes, scope them, develop assessment processes, and mobilize the U.S. scientific community to draft and comment on these assessments. The USGCRP contributions to such regional and global scientific undertakings help inform the direction of the U.S. research community.

Communicate and Educate. An increasing number of fields, including healthcare, agriculture, emergency preparedness and response, and city and regional planning, require knowledge about climate change science and impacts. At the international scale, the USGCRP serves a critical role in communicating national actions on climate change by coordinating the United States input into the United Nations Framework Convention on Climate Change (UNFCCC) National Communication.

Building on Progress

Increasing Global Access and Exchange of Data. The global community is increasingly pursuing open data sharing policies to advance international scientific cooperation and innovation. This is evident through national-level initiatives as well as international efforts such as the G7 Open Data Charter, the Organisation of Economic Co-operation and Development (OECD) Open Government Data Project, the Global Earth Observing System of Systems Data Sharing Principles, the World Bank's Open Data Initiative, and the E-infrastructure project sponsored by the Belmont Forum. The United States and the USGCRP have always enacted and promoted open data sharing policies (e.g., WMO Resolution 40). This gradual shift in policy in other countries will benefit each U.S. research effort through expanded access to observation and monitoring data that improve models and predictions. As progress is being made around the exchange of physical and biological data, there is increasing attention being focused on the incorporation of socio-economic data in research efforts for global sustainability. This is an emerging area that the USGCRP will need to continue exploring through multilateral and bilateral partnerships.

International Field Campaigns. The USGCRP agencies and the scientists they fund participate in a number of international field campaigns to study climate-related issues. Multi-national cooperation allows for various combinations of satellite, land based, and airborne and marine platform observation to be combined for greater insight and to validate remote sensing observations (e.g. GOAmazon and validation of the Global Precipitation Measurement satellite). There is also increasing cooperation in providing international access to the field stations of multiple countries, particularly in remote areas with difficult access. The USGCRP agencies will continue to help develop and utilize these opportunities for strengthening scientific results and leveraging international investments.

Advancing Activities in Specific Research Areas. There are numerous research areas in which U.S. scientists and the USGCRP agencies cooperate internationally to leverage resources and achieve common science objectives. Informal cooperation among scientists of different countries occurs in virtually every area of USGCRP science. More formal relationships exist in areas such as climate variability and change (CLIVAR), global energy and water cycles (GEWEX), and numerous areas of carbon cycle studies (e.g., the Global Carbon Project and the North American Carbon Project (NACP)). The USGCRP will continue to build on long-standing facilitation and coordination efforts with global partnerships in key research areas.

Role of USGCRP for Future IPCC Directions. Having played a significant role in the successful IPCC Fifth Assessment Report cycle, the USGCRP—in close collaboration with the State Department, technical agencies and the U.S. non-Federal climate science community—will ensure that the United States continues to play a leadership role in the IPCC as it embarks upon its Sixth Assessment Report cycle (AR6). In 2016, IPCC will focus on initial scoping of the AR6 products, including the first Special Report of the cycle. The USGCRP will continue to play a leading role for the United States in terms of soliciting authors.

Leveraging and Building on Successful Domestic Efforts. As a leader in global change research, the USGCRP has had a variety of successes that other governments and organizations are interested in duplicating for their national or organizational context. The National Climate Assessment (NCA), particularly the NCA3, captured national and global attention for its scientific rigor and topical comprehensiveness. Sharing the results and lessons learned, and providing technical assistance, where feasible, are opportunities the USGCRP will welcome. For example, the USGCRP is also starting to share its best practices and approaches to information technology with other countries, such as India, to support other national assessments. There is also emerging interest to expand sustained assessment efforts to include focused assessments in key regional trans-boundary areas such as the Arctic, which will support the U.S. Chairmanship of the Arctic Council, among other Arctic-related priorities for the United States and USGCRP.

Navigating Challenges

International opportunities for the USGCRP to significantly leverage domestic investments in global change research and scientific collaboration include participation in joint research calls for proposals, such as the Belmont Forum's Collaborative Research Actions. Beyond technical advancements in understanding the biophysical world, there is growing interest in cross-disciplinary collaboration among various stakeholders and disciplines on global change research that have not traditionally been engaged. For example, integrating and advancing social science research within the environmental context—a key goal of Future Earth—is a challenging but essential component of societally relevant global change research. While these new collaborators bring unique and valuable perspectives, as well as potential resources, an enhanced approach to research and funding mechanisms may be needed. One example of a growing need in the integration of social science and environment is a better understanding of the climate risks to cultural heritage. The Belmont Forum has been able to quickly adapt to accommodate growing interest and participation by partners. The USGCRP has been at the forefront in supporting recent success around the areas of identifying mechanisms for cooperation in multilateral research funding. This initial progress brings with it higher expectations and unique challenges in meeting those expectations.

The GCRA mandates the provision of technical assistance to developing nations and engagement with developing nations in cooperative global research programs—within the context of "facilitating improvements in the domestic standard of living while minimizing damage to the global or regional environment." The USGCRP will continue supporting broad initiatives that help fill this gap at regional and national levels, albeit considering which avenues it can most effectively provide technical assistance to developing nations given resource constraints. The USGCRP recognizes the benefits of research in the development context and the importance of sustained collaborations.

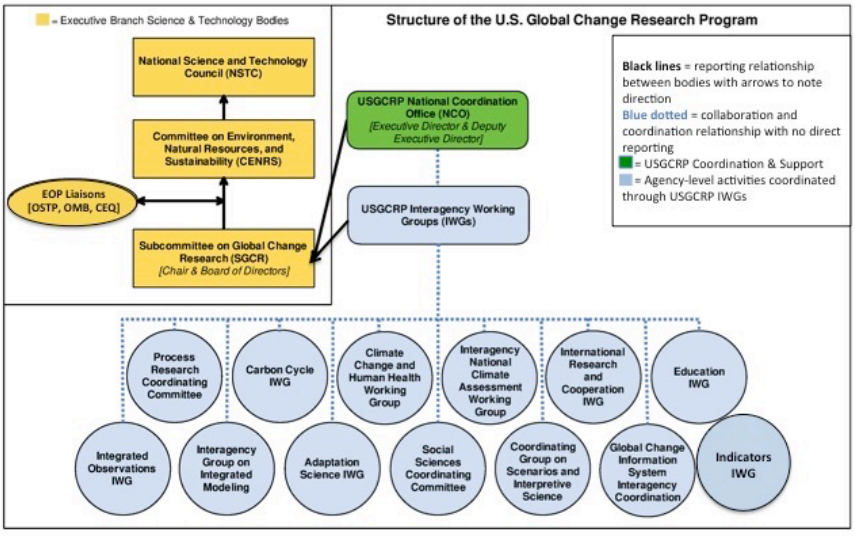
The changing landscape of international cooperation is providing the USGCRP with opportunities to both benefit from and contribute to global change research advancements across the world. Building upon the progress made since 1989, both domestically and internationally, the USGCRP is in an excellent position to take advantage of these opportunities, advance its position as a leader in global change research, and continue to execute the vision of international cooperation laid out in the GCRA.

Chapter V: Implementation Strategy

Since release of the Strategic Plan in 2012, the USGCRP has adopted new, and refined prior, approaches to its implementation, with a focus on both advancing fundamental science and fostering its utilization for decision-making. This chapter speaks to USGCRP governance and program coordination, program planning and implementation, and the role of collaborative relationships in accomplishing USGCRP goals. It also discusses the USGCRP's sustained assessment process, initiated under the Strategic Plan, and its role as an important avenue for the Program in translating its science for decision makers, and incorporating decision maker needs into the USGCRP's science planning and prioritization.

USGCRP Governance and Program Coordination

The USGCRP is a confederation of the global change science arms of its 13 member departments and agencies *(see Chapter II)*. Research and related activities carried out by the agencies in support of USGCRP are guided and overseen by the National Science and Technology Council's (NSTC) Subcommittee on Global Change Research (SGCR), which is chartered under the Committee on Environment, Natural Resources, and Sustainability (CENRS). The SGCR membership is comprised of a Principal from each member agency, with liaisons to the Executive Office of the President's Offices of Science and Technology Policy (OSTP) and Management and Budget (OMB), and the Council on Environmental Quality (*see "Structure of the U.S. Global Change Research Program" below*). The SGCR Chair is nominated from one of the USGCRP member agencies. USGCRP Executive and Deputy Executive Directors, Federal employees on detail to the NSTC and OSTP, are responsible for overseeing integration and planning activities of the USGCRP and the implementation of interagency efforts. In addition, they direct the activities of the National Coordination Office, which facilitates program integration and provides day-to-day coordination and support for the interagency activities of USGCRP. OSTP and the OMB work closely with the SGCR to establish research priorities and funding plans to ensure that the USGCRP's work aligns with national priorities, reflects agency planning, and meets the requirements of the Global Change Research Act of 1990 (GCRA).



Caption: Overview of lines of reporting and collaboration for the Subcommittee on Global Change Research (SGCR), within the NSTC structure, and in guidance and oversight of USGCRP interagency activities. The Process Research Coordinating Committee integrates and guides the work of the Clouds-Chemistry-Aerosol Processes, Nitrogen Cycle, and Biodiversity & Ecosystems clusters.

The Interagency Working Groups (IWGs) are major vehicles for coordinating and implementing research and related activities across the agencies. All contribute to USGCRP strategic program

planning, share information and maintain cooperation across the agencies, and report on their activities to the SGCR and the agencies. As appropriate to their particular area and the stage of their projects, the IWGs develop reports, products, and tools for national use; develop or capitalize on interagency research solicitations; host webinars and workshops; and publish scientific papers. Upon request, some interact with the Executive Office of the President in activities, such as national prioritization efforts, climate preparedness exercises, and data portal development. A subset of IWG activities may be seen in *Our Changing Planet*.

The figure "*Structure of the U.S. Global Change Research Program*" above shows how the family of USGCRP IWGs, some of which have been developed since 2012, bring together cross-agency expertise in areas of need identified in the Strategic Plan. Most IWGs have participation that extends beyond the USGCRP member agencies, thus enhancing wider cooperation within the Government. Many participate in Communities of Practice in their area. Communication and cooperation among IWGs and the SGCR occur through a variety of mechanisms: IWG joint projects and planning; participation in developing the USGCRP annual interagency priorities; IWG co-chair workshops and an annual all-IWG meetings; and regular programmatic reporting. The SGCR establishes interagency task teams as needed to scope potential new areas of USGCRP activity or to accomplish near term planning or tasks.

Program Planning and Implementation

Strategic Framework

Structured around the GCRA, the 2012–2021 Strategic Plan is the cornerstone of the USGCRP's strategic planning, and its goals and objectives remain the guiding document for USGCRP priorities and activities. Triennial updates like this one draw from the Strategic Plan and provide a sharpened focus that helps guide the Program in the nearer term. Annual strategic planning (for interagency priorities planned two years in advance) and ongoing sustained assessment activities are other key elements of an integrated strategic framework for the USGCRP. The guidelines for implementing the Strategic Plan are detailed therein and briefly noted in "*USGCRP Implementation Guidelines*."

The USGCRP Interagency Priorities, shared annually with OSTP and OMB, spotlight specific areas within USGCRP that: 1) are responsive to the GCRA, Strategic Plan, and Administration priorities; 2) evolve over several years as progress is made; 3) depend on progress in USGCRP's long-term investments; 4) are best accomplished by a collective, comprehensive multi-agency effort; and 5) may depend on unique capabilities of individual agencies in key areas. The priorities typically capitalize on, or help drive, advances in USGCRP core science capabilities in observations, modeling, understanding, and reaching decision makers. Each priority addresses

USGCRP Implementation Guidelines

- Advance a strong scientific foundation
- Phase in new activities thoughtfully
- Build/maintain a diverse portfolio that allows:
  - Consistent & freely available observations
  - Scientific exploration and science development for societal use
  - Leveraging agency strengths and coordination
  - Transparent access to data and tools
  - Increasing interdisciplinary research, especially between natural and social sciences
  - Improving science translation and utilization
- Build collaborations that leverage USGCRP's science and increase its impact
- Enhance international partnerships
- Evaluate key aspects of performance
- Use adaptive management principles to improve performance

emerging basic research areas, the harvesting of maturing science to inform decisions, and providing information to stakeholders. These priorities help provide focus for IWG activities and collaboration. A team of SGCR and IWG members guide evolution of the priorities over successive years.

For Fiscal Years 2015 and 2016, the USGCRP is spotlighting the topics below. See Chapter II and III for more background and the USGCRP's annual report to Congress, *Our Changing Planet*, for highlights of progress in these areas.

- Extremes, thresholds, and tipping points, with foci on: 1) Arctic climate change, its regional impacts and its connections to global climate; 2) understanding the water cycle under a changing climate, including both wet and dry extreme conditions, and their impacts.
- Forecasts, including for regional climate projections at intra-seasonal to decadal time horizons and spatial resolutions of 50 km to as fine as 10 km.
- Science to inform policy-making and management, with an emphasis on enhanced joint production of actionable science between science-producer and science-user/decision-maker communities.

The USGCRP's sustained assessment effort is a powerful tool for both strategic planning and tracking program performance. Internationally, the USGCRP is participating in the planning for the sixth IPCC Assessment Report and the special topics it will address. The Program's Climate Change and Human Health Assessment report brings a strong focus on modeling and understanding health impacts in the context of a changing climate and identifies related research needs. The USGCRP is currently scoping special assessment activities on extremes, climate science and the carbon cycle, which would synthesize recent advances in research and understanding of impacts in these areas. These and other assessment reports would document scientific progress from the USGCRP and other organizations, and identify research and capability needs.

The sustained assessment includes activities that support broader USGCRP goals, including a pilot indicators system and the development of scenarios of likely future climate change and impacts in key sectors *(see Chapter III, Goal 3).* It also includes processes that promote continuous and transparent participation of scientists and stakeholders across regions and sectors, enabling new information and insights to be synthesized as they emerge, providing learning opportunities for the Program as a whole in strengthening stakeholder interactions. Key elements of this NCA engagement include periodic Requests for Information from the public, a Federal Advisory Committee, interaction with the National Academies Committee to Advise USGCRP, and NCAnet *(see Chapter III, Goal 3).*

Program Performance

Tracking Program performance is central to demonstrating the USGCRP's accomplishments and value, and also to guiding its future development. As a multi-agency confederation, however, it can be difficult to distinguish between the work that agencies would do independently and that done because of the USGCRP collective. In this challenging area of performance measures for interagency efforts, the Program is focusing its attention in two areas that have strong and explicit central coordination: the National Climate Assessments and the interagency priority areas just discussed. The National Academies' Committee to Advise USGCRP ("the Committee") is initiating an effort to provide advice to the USGCRP on performance measures. The first stage involves reviewing the USGCRP areas of effort and accomplishment, with an eye to distinguishing those that most depend on collective efforts, such as the NCA and USGCRP interagency priorities.

The USGCRP is planning for an external evaluation of the impact of the NCA3 report that was released in May 2014. The framework for the evaluation will draw from a 2014 Frameworks for Evaluating the National Climate Assessment community workshop that recommended quantitative and qualitative approaches to evaluating the impact of NCA3 products (including public events by its author team) and processes for stakeholder engagement, coordination, and co-production. The workshop recommendations are feeding into planning for the fourth NCA, and the evaluation results will inform the USGCRP's longer-term assessment planning. The Program also views the NCA3 evaluation as a learning tool for USGCRP in developing and using performance measures to guide future development.

The National Academies Committee to Advise USGCRP plays an important role in external evaluation and guidance for USGCRP. Formal mechanisms included their reviews of the 2012–2021 Strategic Plan, the NCA3, and the draft report *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment*, all of which helped improve those publications and also inform USGCRP's direction. The National Academies Committee will also be hosting a workshop to evaluate approaches for integrating a risk-based framework into parts of the fourth NCA, and more broadly in subsequent years. In addition to the formal reviews and workshops, the Committee meets with the SGCR two to three times a year. Recent and upcoming topics of those meetings include the Program's progress towards implementing its Strategic Plan, approaches towards this Update of the Strategic Plan, and the role of broader engagement in helping the USGCRP meet the Nation's needs in preparing for the impacts of climate change. The National Academies recent report "*Enhancing Participation in the U.S. Global Change Research Program*", provides thoughtful examples of general strategies and specific actions that the USGCRP can take to deepen the its connections within the public and private sectors.

Collaborative Relationships

Interagency Collaboration

The USGCRP member agencies participate in programmatic areas related to their mission and strengths. Coordination across these areas, guided by USGCRP's Strategic Plan creates a comprehensive framework implemented by the working groups and the agencies. Each agency depends on the work of others, and all depend on the observing and modeling capability developed by a few agencies. In fact, some essential agency observing programs exist outside the formal the USGCRP budget reporting structure. Looking ahead, the SGCR is working to more systematically engage the non-research and development parts of their respective departments or agencies, to bring that broader perspective into USGCRP planning. Engagement in this manner that is time effective and has low bureaucratic overhead remains a challenge.

Collaboration among the USGCRP agencies, and with non-member Federal agencies, is critical to implementing the Strategic Plan and helping the Nation respond to climate change and its impacts. *Our Changing Planet* annually showcases some of the outcomes from interagency cooperation, including those involving non-member agencies. Cooperation between the Federal Emergency Management Agency (FEMA) and the USGCRP agencies, for example, produced a sea level rise tool for recovery after Superstorm Sandy. In identifying science needs for adaptation, the USGCRP mines input from all Federal agencies that file Climate Change Adaptation Plans, not just USGCRP members. Using NCA3 regional climate scenarios as a basis, the Program is cooperating with FEMA on climate preparedness exercises in multiple parts of the country. Representatives from non-member agencies participate regularly in many of USGCRP IWGs, bringing a more response-oriented perspective to the Program.

The USGCRP is developing closer cooperation with other Subcommittees under the NSTC CENRS as a way of strengthening its connections with other Federal interagency groups (and their members) working in related areas. For example, the USGCRP's Arctic priority is developed and tracked in cooperation with the IARPC, building on the National Arctic Strategy, and in consultation with the U.S. Arctic Executive Steering Committee. The USGCRP is also working with the National Ocean Council and its subgroup, the Subcommittee on Ocean Science and Technology, in areas related to: the Arctic, the ocean's role in climate; ocean acidification; and the development of future sea level rise scenarios for the U.S. coastline, and the incorporation of sea level rise into Federal agency coastal flood hazard mapping tools. As another example, the National Plan for Civil Earth Observations, developed by OSTP through an interagency effort led by the U.S. Group on Earth Observations (USGEO), places a high priority on sustaining observations for Earth systems research, directly supporting the USGCRP's strategic goals. Further strengthening these relationships, where they can result in more cohesive Government preparation for climate change, is a USGCRP goal. In particular, the Program brings the longer-time perspective of future climate change to the work of other Subcommittees.

External Relationships

As stated in the Strategic Plan, the USGCRP is committed to better connecting its science and science products with science users. The Program aims to understand stakeholder needs, facilitate stakeholder uptake of USGCRP science and products, and foster co-development of science assessments and other products as appropriate, with the goal of establishing bi-directional dialogue between science producers and users that feeds into programmatic planning. That said, the ever-growing call for climate and global change information, across all sectors and at scales from local to global, puts considerable pressure on Program resources.

In addressing that need, the USGCRP is grounded in its strengths as an interagency research program, recognizing that it lacks the capacity to interact with all potential users. Rather, USGCRP information is often used by other government and non-governmental organizations to provide customized knowledge at the local and community levels (e.g. the Climate Data and Tools through the U.S. Climate Data Initiative, FEMA Climate Resilience Exercises at the regional and community scales). In terms of providing science information, all USGCRP data are freely available to all users, and the Global Change Information System (GCIS) is increasing the discoverability of Federal climate data linked to science translation products like the NCA. The USGCRP's new pilot indicators effort shows trends over time in key aspects of climate-related change, in formats intended for decision makers. The USGCRP will continue to build on this initial effort by adding new indicators to the suite and through evaluation of their utility for decision makers. USGCRP agency participation in Administration efforts like the Climate Data Initiative and Climate Resilience Toolkit is contributing to tools and data in targeted topics of particular societal interest, including climate change and human health, water, coastal flooding and resilience, and the Arctic.

The USGCRP's interaction with stakeholders, and understanding of their needs, comes largely through two avenues: via the agencies and through the National Climate Assessment. Member agencies feed their stakeholder interests and needs into the USGCRP strategic planning process, including this Update and the development of annual interagency priorities, which include an element of actionable science and informing stakeholders. The NCA3, from the start, incorporated stakeholder engagement into the development of the report and its related products, and is expanding on this effort as part of the sustained assessment process. NCAnet, a self-selecting and self-organizing group of collaborators, brings together more than 150 professional societies, non-governmental organizations, and other private and public sector organizations to

societies, non-governmental organizations, and other private and public sector organizations to discuss key regional and sectoral topics of interest to the members. They provide awareness of non-Federal science that is available, and of information needs outside the Government, all of which feed into sustained assessment and planning for the fourth NCA. They also enhance uptake of USGCRP products. Stakeholder engagement through the agencies and via the sustained assessment are important to the USGCRP's engagement at the regional level, and with a number of agency regional groups participating in the NCA.

The USGCRP recognizes that relationships beyond the public sector are becoming increasingly important, as many areas of business are moving to include global change information in their financial and business planning. The Program is moving judiciously in this area, learning from the private-public partnerships developed to support the Climate Data Initiative. Goals for any such collaborations would include: co-production of knowledge that is made universally and freely available; uptake of USGCRP knowledge by the private sector into translational science or tools that serve specific constituencies; and understanding science needs.

Appendix I. Table of Common Acronyms

AR5 – Fifth Assessment Report (of the IPCC)
AR6 – Sixth Assessment Report (of the IPCC)
CDAT – Climate Data and Tools
CDI – Climate Data Initiative
CENRS-Committee on Environment, Natural Resources and Sustainability
CEOS – Committee on Earth Observation Satellites
CMIP – Coupled Model Intercomparison Project
CRT – Climate Resilience Toolkit
EO – Executive Order
EOP – Executive Office of the President
ESM – Earth System Model(ing)
GCIS – Global Change Information System
GCM – General Circulation Model
GHG - Greenhouse gas(es)
GCRA—Global Change Research Act of 1990
IAM – Integrated Assessment Model(ing)
IAV – Impact, Adaptation, and Vulnerability (Models)
IARPC – Interagency Arctic Research Policy Committee
IPCC – Intergovernmental Panel on Climate Change
IWG – Interagency Working Group
MATCH – Metadata Access Tool for Climate and Health
MIP – Model Intercomparison Project
NCA – National Climate Assessment
NCA3 – Third National Climate Assessment
NCA4 – Fourth National Climate Assessment
NCO—National Coordination Office of the USGCRP
NRC – National Research Council (*now known as the National Academies of Sciences, Engineering, and Medicine*)
NSTC—National Science and Technology Council
OSTP – Office of Science and Technology Policy
PCAP – President's Climate Action Plan
SGCR—Subcommittee on Global Change Research,
SOST – Subcommittee on Ocean Science and Technology
US CLIVAR or **CLIVAR** – U.S. Climate Variability and Predictability Program
USGCRP – U.S. Global Change Research Program
USGEO – U.S. Group on Earth Observations

Note: Terms and definitions taken from the official glossary for the NCA3.

Appendix II. Glossary

Adaptation

Adjustment in natural or human systems to a new or changing environment that exploits beneficial opportunities or moderates negative effects.

Adaptive management

A structured process of flexible decision-making that incorporates learning from outcomes and new scientific information. The process facilitates decision-making by resource managers to manage and respond to climate change impacts.

Aerosol (Atmospheric)

Aerosols are fine solid or liquid particles, caused by people or occurring naturally, that are suspended in the atmosphere. Aerosols can cause cooling by scattering incoming radiation or by affecting cloud cover. Aerosols can also cause warming by absorbing radiation. *Related terms: aerosols*

Biodiversity

The variety of life, including the number of plant and animal species, life forms, genetic types, habitats, and biomes (which are characteristic groupings of plant and animal species found in a particular climate).

Biogeochemical cycles

Fluxes, or flows, of chemical elements among different parts of the Earth: from living to non-living, from atmosphere to land to sea, from soils to plants.

Carbon capture and storage

The process of capturing carbon dioxide and injecting it into geologic formations underground for long-term storage.

Carbon cycle

Circulation of carbon atoms through the Earth systems as a result of photosynthetic conversion of carbon dioxide into complex organic compounds by plants, which are consumed by other organisms, and return of the carbon to the atmosphere as carbon dioxide as a result of respiration, decay of organisms, and combustion of fossil fuels.

Carbon sequestration

Storage of carbon through natural or technological processes in biomass or in deep geological formations.

Climate change

Changes in average weather conditions that persist over multiple decades or longer. Climate change encompasses both increases and decreases in temperature, as well as shifts in precipitation, changing risk of certain types of severe weather events, and changes to other features of the climate system.

Climate intervention

Intentional modifications of the Earth system, usually technological, as a means to reduce future climate change.

Climate variability

Natural changes in climate that fall within the observed range of extremes for a particular region, as measured by temperature, precipitation, and frequency of events. Drivers of climate variability include the El Niño Southern Oscillation and other phenomena.

Drought

A period of abnormally dry weather marked by little or no rain that lasts long enough to cause water shortage for people and natural systems.

Ecosystem

All the living things in a particular area as well as components of the physical environment with which they interact, such as air, soil, water, and sunlight.

Ecosystem services

The benefits produced by ecosystems on which people depend, including, for example, fisheries, drinking water, fertile soils for growing crops, climate regulation, and aesthetic and cultural value.

El Niño-Southern Oscillation

A natural variability in ocean water surface pressure that causes periodic changes in ocean surface temperatures in the tropical Pacific ocean. El Niño Southern Oscillation (ENSO) has two phases: the warm oceanic phase, El Niño, accompanies high air surface pressure in the western Pacific, while the cold phase, La Niña, accompanies low air surface pressure in the western Pacific. Each phase generally lasts for 6 to 18 months. ENSO events occur irregularly, roughly every 3 to 7 years. The extremes of this climate pattern's oscillations cause extreme weather (such as floods and droughts) in many regions of the world.
Related term: El Niño

Emissions scenarios

Quantitative illustrations of how the release of different amounts of climate altering gases and particles into the atmosphere from human and natural sources will produce different future climate conditions. Scenarios are developed using a wide range of assumptions about population growth, economic and technological development, and other factors. *Related terms: emissions scenario, emission scenario*

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.

Extreme events

A weather event that is rare at a particular place and time of year, including, for example, heat waves, cold waves, heavy rains, periods of drought and flooding, and severe storms. *Related term: extreme weather*

Extreme precipitation (events)

An episode of abnormally high rain or snow. The definition of "extreme" is a statistical concept that varies depending on location, season, and length of the historical record.

Feedback

The process through which a system is controlled, changed, or modulated in response to its own output. Positive feedback results in amplification of the system output; negative feedback reduces the output of a system.

Food security

When all people at all times have both physical and economic access to sufficient food to meet their dietary needs for a productive and healthy life.

Forcing

Factors that affect the Earth's climate. For example, natural factors such as volcanoes and human factors such as the emission of heat-trapping gases and particles through fossil fuel combustion.

Global change

Changes in the global environment that may alter the capacity of the Earth to sustain life. Global change encompasses climate change, but it also includes other critical drivers of environmental change that may interact with climate change, such as land use change, the alteration of the water cycle, changes in biogeochemical cycles, and biodiversity loss. [See also *climate change*]

General Climate Models (GCM)

Mathematical models that simulate the physics, chemistry, and biology that influence the climate system.

Global warming

The observed increase in average temperature near the Earth's surface and in the lowest layer of the atmosphere. In common usage, "global warming" often refers to the warming that has occurred as a result of increased emissions of greenhouse gases from human activities. Global warming is a type of climate change; it can also lead to other changes in climate conditions, such as changes in precipitation patterns.

Greenhouse gases

Gases that absorb heat in the atmosphere near the Earth's surface, preventing it from escaping into space. If the atmospheric concentrations of these gases rise, the average temperature of the lower atmosphere will gradually increase, a phenomenon known as the greenhouse effect. Greenhouse gases include, for example, carbon dioxide, water vapor, and methane.

Heat wave

A period of abnormally hot weather lasting days to weeks.

Indicator

An observation or calculation that allows scientists, analysts, decision makers, and others to track environmental trends, understand key factors that influence the environment, and identify effects on ecosystems and society.

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 to reduce the amount and speed of future climate change by reducing emissions of heat-trapping gases or removing carbon dioxide from the atmosphere. *Related term: mitigate*

Ocean acidification

The process by which ocean waters have become more acidic due to the absorption of human-produced carbon dioxide, which interacts with ocean water to form carbonic acid and lower the ocean's pH. Acidity reduces the capacity of key plankton species and shelled animals to form and maintain shells.

Ozone

A colorless gas consisting of three atoms of oxygen, readily reacting with many other substances. Ozone in the upper atmosphere protects the Earth from harmful levels of ultraviolet radiation from the Sun. In the lower atmosphere ozone is an air pollutant with harmful effects on human health.

Paleoclimate

The climate that existed during the period before modern record-keeping. Paleoclimate can be measured with "natural thermometers" such as ice cores or tree rings.

Permafrost

Ground that remains at or below freezing for at least two consecutive years.

Preparedness

Actions taken to build, apply, and sustain the capabilities necessary to prevent, protect against, and ameliorate negative effects.

Resilience

A capability 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

Risks are 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 assessment

Studies that estimate the likelihood of specific sets of events occurring and their potential positive or negative consequences.

Risk management

Planning to manage the effects of climate change to increase positive impacts and decrease negative impacts.

Risk-based framing

Planning based on the pros and cons of a given set of possibilities; includes assessment of a risk in terms of the likelihood of its occurrence and the magnitude of the impact associated with the risk.

Scenario(s)

Sets of assumptions used to help understand potential future conditions such as population growth, land use, and sea level rise. Scenarios are neither predictions nor forecasts. Scenarios are commonly used for planning purposes.

Sink

A natural or technological process that removes carbon from the atmosphere and stores it.
Related term: Carbon sink

Stakeholder

An individual or group that is directly or indirectly affected by or interested in the outcomes of decisions.

Stressor

Something that has an effect on people and on natural, managed, and socioeconomic systems. Multiple stressors can have compounded effects, such as when economic or market stress combines with drought to negatively impact farmers.

Tipping point

The point at which a change in the climate triggers a significant environmental event, which may be permanent, such as widespread bleaching of corals or the melting of very large ice sheets.
Related terms: threshold

Traditional knowledge

Knowledge, practices and beliefs that have been handed down through generations.

Uncertainty

An expression of the degree to which future climate is unknown. Uncertainty about the future climate arises from the complexity of the climate system and the ability of models to represent it, as well as the inability to predict the decisions that society will make. There is also uncertainty about how climate change, in combination with other stressors, will affect people and natural systems.

Validate

To establish or verify accuracy. For example, using measurements of temperature or precipitation to determine the accuracy of climate model results.

Value

Belief or ideal held by individuals or society about what is important or desirable.

Value (economic)

The benefit, usually expressed in monetary terms, gained from use or enjoyment from a good or service.

Vulnerability

The degree to which physical, biological, and socio-economic systems are susceptible to and unable to cope with adverse impacts of climate change.

Vulnerability assessment

An analysis of the degree to which a system is susceptible to or unable to cope with the adverse effects of climate change.

Related term: Vulnerability analysis

Appendix III. USGCRP Member Agencies

This section summarizes the principal focus areas related to global change research for each USGCRP member agency.

Department of Agriculture

The U.S. Department of Agriculture's (USDA) global change research program empower land managers, policy makers, and Federal agencies with science-based knowledge to manage the risks and opportunities posed by climate change; reduce greenhouse gas (GHG) emissions; and enhance carbon sequestration. USDA's global change research program includes contributions from the Agricultural Research Service (ARS), the National Institute of Food and Agriculture (NIFA), the Forest Service (USDA-FS), the Natural Resources Conservation Service (NRCS), the National Agricultural Statistics Service (NASS), and the Economic Research Service (ERS). These USDA entities ensure sustained food security for the Nation and the world. They maintain and enhance the health of U.S. forests and natural resources while identifying risks to agricultural production, ranging from temperature and precipitation changes to the changing biology of pests, invasive species, and diseases.

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

Department of Commerce

The National Atmospheric and Oceanic Administration (NOAA) and the National Institute of Standards and Technology (NIST) comprise the Department of Commerce's (DOC) participation in the USGCRP.

NOAA's strategic climate goal is "an informed society anticipating and responding to climate and its impacts". NOAA's overall objective is to provide decision makers with predictive understanding of the climate and to communicate climate information so that people can make more informed decisions in their lives, businesses, and communities. These outcomes are pursued by implementing a global observing system, conducting research to understand climate processes, developing improved modeling capabilities, and developing and deploying climate educational programs and information services. NOAA aims to achieve its climate goal through the following strategic objectives:

- Improved scientific understanding of the changing climate system and its impacts.
- Assessments of current and future states of the climate system that identify potential impacts and inform science, service, and stewardship decisions.

- Mitigation and adaptation efforts supported by sustained, reliable, and timely climate services.
- A climate-literate public that understands its vulnerabilities to a changing climate and makes informed decisions.

NIST works with other Federal agencies to develop or extend internationally accepted traceable measurement standards, methodologies, and technologies that enhance measurement capabilities for science-based greenhouse gas emission inventories and measurements critical to advancing climate science research. NIST provides measurements and standards that support accurate, 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. In FY 2009, NIST was included as a discrete element of USGCRP's budget crosscut to provide specific measurements and standards of direct relevance to the program.

Department of Defense

The Department of Defense (DOD) – while not supporting a formal mission dedicated to global change research – is developing policies and plans to manage and respond to effects of climate change on DOD missions, assets, and the operational environment. Various research agencies within DOD sponsor and undertake basic research activities that concurrently satisfy both national security requirements as well as the strategic goals of USGCRP. These include the Office of Naval Research (ONR), the Air Force Office of Scientific Research (AFOSR), the Army Research Office (ARO), and the Defense Advanced Research Projects Agency (DARPA). When applicable, the research activities of these agencies are coordinated with other Federally sponsored research via USGCRP and other entities.

Because the performance of DOD systems and platforms are influenced by environmental conditions, understanding the variability of the Earth's environment and the potential for change is of great interest to the Department. DOD is responsible for the environmental stewardship of hundreds of installations throughout the U.S. and must continue incorporating geostrategic and operational energy considerations into force planning, requirements development, and acquisition processes. DOD relies on the Strategic Environmental Research and Development Program (SERDP), a joint effort among DOD, DOE, and EPA, to develop climate change assessment tools and to identify the environmental variables that must be forecast with sufficient lead-time to facilitate appropriate adaptive responses. Each service agency within DOD incorporates the potential impact of global change into their long-range strategic pans. For example, the Navy's Task Force Climate Change (TFCC) assists in the development of science-based recommendations, plans, and actions to adapt to climate change. The USACE Engineer Research and Development Center (ERDC) Cold Regions Research and Engineering Laboratory (CRREL) also actively investigates the impacts of climate trends for DOD and other agencies. The CRREL research program responses to the needs to the military, but much of the research also benefits the civilian sector and is funded by non-military customers such as NSF, NOAA, NASA, DOE, and state governments.

Department of Energy

The Department of Energy's (DOE) Office of Science supports fundamental research to understand the energy-environment-climate connection and its implications for energy production, use, sustainability, and security – with particular emphasis on the potential impact of increased anthropogenic emissions. The ultimate goal is to advance a robust predictive understanding of Earth's climate and environmental systems and to inform the development of sustainable solutions to the Nation's energy and environmental challenges.

Two DOE research areas focus on areas of uncertainty in Earth system models: Atmospheric System Research (ARM) (science of aerosols, clouds, and radiative transfer) and Terrestrial Ecosystem Science (role of terrestrial ecosystems and carbon cycle observations). DOE also collaborates with NSF to develop the widely-used Community Earth System Model, supports methods to obtain regional climate information, integrates analysis of climate change impacts, and analyzes and distributes large climate datasets through the Program of Climate Model Diagnosis and Intercomparison and the Earth System grid. The Department also supports the ARM Climate Research Facility, a scientific user facility that provides the research community with unmatched measurements permitting the most detailed high-resolution, three-dimensional documentation of evolving cloud, aerosol, and precipitation characteristics in climate-sensitive sites around the world.

Finally, DOE also conducts applied climate-related research, which is centered in DOE's Office of Energy Policy and Systems Analysis and Office of Policy and International Affairs. These programs develop and utilize energy-economic models, including integrated assessment models, to evaluate policies and programs that enable cost-effective greenhouse gas reductions and accelerate the development and deployment of clean energy technologies. This includes supporting work to characterize climate change impacts for use in policy analysis, vulnerability, and adaptation assessment and agency rulemakings. DOE also conducts assessments of climate change on electric grid stability, water availability for energy production, and site selection for the next generation of renewable 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 altered air contaminants, 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 change and health, translating scientific advances into decision support tools for public health professionals, conducting ongoing monitoring and surveillance of climate-related health outcomes, and engaging the public health community in two-way communication about climate change.

Department of the Interior

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

USGS scientists work with other agencies to provide policymakers and resource managers with scientifically valid information and predictive understanding of global change and its effects with the ultimate goal of helping the Nation understand, adapt to, and mitigate global change.

Specifically, the USGS Climate and Land Use Change Research and Development Program

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

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

Department of State

Through the Department of State (DOS) annual funding, the U.S. is the world's leading financial contributor to the United Nationals Framework Convention on Climate Change (UNFCCC) and to the Intergovernmental Panel on Climate Change (IPCC) – the principal international organization for the assessment of scientific, technical, and socioeconomic information relevant to the understanding of climate change, its potential impacts, and options for adaptation and mitigation. Recent DOS contributions to these organizations provide substantial support for global climate observation and assessment activities in developing countries. DOS also works with other agencies in promoting international cooperation in a range of bilateral and multilateral climate change initiatives and partnerships.

Department of Transportation

The Department of Transportation (DOT) conducts research to examine potential climate change impacts on transportation, methods for increasing transportation efficiency, and methods for reducing emissions that contribute to climate change. DOT's Center for Climate Change and Environmental Forecasting coordinates transportation and climate change research, policies, and actions within DOT and promotes comprehensive approaches to reduce emissions, address climate change impacts, and develop adaptation strategies. DOT also contributes directly to USGCRP's National Climate Assessment through focused research, such as the Center's Gulf Coast Studies. The Gulf Coast Phase 2 study, completed in FY 2015, developed tools to assist transportation agencies in performing climate change and extremes weather vulnerability assessments and build resilience.

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

- The Federal Highway Administration (FHWA) and other DOT agencies are undertaking climate impact and adaptation studies (including vulnerability and risk assessments), working with science agencies to develop regional climate data and projections, conducting methodological research, supporting pilot programs, and providing assistance to transportation stakeholders, including state and local agencies. DOT has requested additional funding in FY 2016 for these purposes. The Federal Transit Administration (FTA) completed seven Climate Change Adaptation Pilot studies to advance the state of the practice in adapting transit assets and operations to the impacts of climate change.
- The FAA manages the Continuous Lower Energy, Emissions, and Noise (CLEEN)

program as a government-industry consortium to develop technologies for energy efficiency, noise and emissions reduction, and sustainable alternative jet fuel. FAA also participates in the Commercial Aviation Alternative Fuels Initiative (CAAFI), a public-private coalition to encourage the development of sustainable alternative jet fuel.

Environmental Protection Agency

The core purpose of the Environmental Protection Agency's (EPA) Global Change Research Program is to develop scientific information that supports stakeholders, policy makers, 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 on statutory requirements, and includes: (1) improving the scientific understanding of global change effects on air quality, water quality, ecosystems, and human health in the context of other stressors; (2) assessing and developing adaptation options to effectively 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 impacts and benefits of greenhouse gas emission reduction strategies to support sustainable mitigation solutions. This research is leveraged by EPA Program Offices and Regions to support mitigation and adaptation decisions and to promote communication with external stakeholders and the public.

EPA relies on USGCRP to develop high-quality scientific data and understanding about physical, chemical, and biological changes to the global environment and their relation to drivers of global change. EPA's Global Change Research Program connects these results to specific human and ecosystem health endpoints in ways that enable local, regional, and national decision makers to develop and implement strategies to protect human health and the environment. In turn, EPA's research provides USGCRP agencies with information about the connections between global change and local impacts and how local actions influence global changes.

Research activities include efforts to connect continental-scale temperature and precipitation changes to regional and local air quality and hydrology models to better understand the impacts of climate change on air quality and water quality, and to examine how watersheds will respond to large-scale climate and other global changes, to inform decisions about management of aquatic ecosystems and expand understanding of the impacts of global change. Satellite and other observational efforts conducted by USGCRP are crucial to supporting EPA's efforts to understand how land use change, climate change, and other global changes are affecting watersheds and ecosystems, and the services they provide.

National Aeronautics and Space Administration

NASA's global change activities have four integrated foci: satellite observations, research and analysis, application, and technology development. Satellites provide critical global atmosphere, ocean, land, sea ice, and ecosystem measurements. NASA's 21 on-orbit satellite missions (as of February 2015) measure numerous variables required to enhance understanding of Earth interactions. NASA launched five Earth-observing missions in a 12-month period from February 2014 to January 2015: the free flying satellites Global Precipitation Measurement (GPM), Orbiting Carbon Observatory-2 (OCO-2), and Soil Moisture Active Passive (SMAP), and two payloads to the International Space Station: RapidScat and Cloud-Aerosol Transport System (CATS). In CY 2016, NASA is planning on launching two payloads to the International Space Station (Lightning Imaging Sensor, Stratospheric Aerosol and Gas Experiment III) and the Cyclone Global Navigation Satellite System (CYGNSS) constellation of eight nanosatellites to study winds associated with tropical cyclones. In 2014, NASA selected two additional payloads

to go to the International Space Station as part of its Earth Venture—Instrument series of missions: (1) the Global Ecosystem Dynamics Investigation Lidar (GEDI), which will characterize the effects of changing climate and land use on ecosystem structure and dynamics to enable radically improved quantitation and understanding of the Earth's carbon cycle and biodiversity; and (2) ECOsystem Spaceborne Thermal Radiometer Experience on Space Station (ECOSTRESS), which will address critical questions on plant-water dynamics and future ecosystem changes with climate through an optimal combination of thermal infrared measurements.

The Administration's FY 2016 budget also outlines an approach for NASA to conduct a program in sustainable land imaging (in coordination with the U.S. Geological Survey) and to take on future long-term monitoring responsibility for environmental parameters not directly in support of weather forecasting, such as solar radiation, Earth radiation budget, ozone vertical profile, and sea surface height.

NASA's program advances observing technology and leads to new and enhanced space-based observation and information systems. The Earth science research program explores interactions among the major components of the Erath system – continents, oceans, atmosphere, ice, and life—to distinguish natural from human-induced causes of change and to understand and predict the consequences of change. NASA makes significant investments to assure the quality and integration of data through calibration and validation efforts that include satellite, surface, and airborne measurements, as well as data intercomparisons. NASA also carries out observationally driven modeling projects that include data assimilation, reanalysis, process representation, initialization, and verification. Significant new multi-year airborne campaigns initiated in 2015 address major global environmental issues: sources and sinks of atmospheric carbon in the continental United States, the role of the ocean in melting of ice sheets off the coast of Greenland, the effects of biomass burning in Africa on cloud structure off its western coast, the latitudinal variation of radiatively and chemically active trace constituents in the upper troposphere over the Atlantic and Pacific Oceans, and the seasonal variation of biological productivity in the North Atlantic Ocean and its implications for the atmosphere above. Applications projects extend the societal benefits of NASA's research, technology, and spaceflight programs to the broader U.S. public through the development and transition of user-defined tools for decision support. The Earth science technology program enables previously infeasible science investigations improves existing measurement capabilities, and reduces the cost, risk, and/or development times for Earth science instruments.

National Science Foundation

The National Science Foundation (NSF) addresses global change issues through investments that advance frontiers of knowledge, provide state-of-the-art instrumentation and facilities, develop new analytical methods, and enable cross-disciplinary collaborations while also cultivating a diverse, highly trained workforce and developing educational resources. In particular, NSF global change programs support the research and related activities to advance fundamental understanding of physical, chemical, biological, and human systems and the interactions among them. The programs encourage interdisciplinary approaches to studying Earth system processes and the consequences of change, including how humans respond to changing environment 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 decisions makers to identify and evaluation policies for mitigation, adaptation, and other responses to the challenges of a changing and variable

environment. Long-term, continuous, and consistent observational records are essential for testing hypotheses quantitatively and are, thus, a cornerstone of global change research. NSF supports a variety of research observing networks that complement, and are dependent on, the climate monitoring systems maintained by its sister agencies.

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

Smithsonian Institution

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

The Smithsonian Grand Challenge Consortium for Understanding and Sustaining a Biodiverse Planet brings together researchers from around the Institution to focus on joint programs ranging from estimating volcanic emissions to ocean acidification measurement. Smithsonian paleontological research documents and interprets the history of terrestrial and marine ecosystems from 400 million years ago to the present. Other scientists study the impacts of historical environmental change on the ecology and evolution of organisms, including humans. Archaeobiologists examine the impact of early humans resulting from their domestication of plants and animals, creating the initial human impacts on planetary ecosystems. Together, these projects make up the Smithsonian's "Living in the Anthropocene" initiative.

These activities are joined by related efforts in the areas of history and art, such as the Center for Folklife and Cultural History, the National Museum of the American Indian, and the Cooper Hewitt Museum of Design to examine human responses to global change, within communities, reflected in art and culture, food, and music. Finally, Smithsonian outreach and education expands our scientific and social understanding of processes of change and represents them in exhibited and programs, including at the history and art museums of the Smithsonian. USGCRP funding enables the Smithsonian to leverage private funds for additional research and education programs on these topics.

U.S. Agency for International Development

The U.S. Agency for International Development (USAID) supports programs that enable decision makers to apply high-quality climate information to decision making. USAID's climate change and development strategy calls for enabling countries to accelerate their transition to climate resilient, low emission sustainable economic development through direct programming and integrating climate change adaptation and mitigation objectives across the Agency's development portfolio. USAID is the lead contributor to bilateral assistance, with a focus on capacity building, civil society building, governance programming, and creating the legal and regulatory environments needed to address climate change. USAID leverages scientific and technical resources from across the U.S. Government (for example, NASA, NOAA, USDA, USGS) as it

applies its significant technical expertise to provide leadership in development and implementation of low-emissions development strategies, creating policy frameworks for market-based approaches to emission reduction and energy sector reform, promoting sustainable management of agriculture lands and forests, and mainstreaming adaptation into development activities in countries most at risk. USAID has long-standing relationships with host country governments that enable them to work together to develop shared priorities and implementation plans. USAID's engagement and expertise in agriculture, biodiversity, infrastructure, and other critical climate sensitive sectors provide an opportunity to implement innovative cross-sectoral climate change programs. Finally, USAID bilateral programs work in key political and governance areas where multilateral agencies cannot.