Review of the U.S. Global Change Research Program's Update to the Strategic Plan Document

DETAILS

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Acknowledgments

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their participation in their review of this report:

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Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions nor did they see the final draft of the report before its release. The review of this report was overseen by **Marvin A. Geller,** Emeritus, Stony Brook University, Sarasota, Florida, and **David M. Karl,** University of Hawaii at Manoa. They were responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

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Summary

The report reviews the draft Update to the U.S. Global Change Research Program's (USGCRP) 2012 Strategic Plan. The Strategic plan sets out a long-term vision for the research program to guide the Program's thirteen federal departments and agencies in meeting the mandate of the Global Change Research Act (GCRA) of 1990. The Update (USP) provides a more detailed view of priorities and strategies for the next three years, and is part of a family of documents that also includes the annual report *Our Changing Planet,* which describes annual priorities included as part of the President's budget request. The Committee was tasked with formally reviewing the USP (see the Statement of Task in Appendix A), drawing on its prior review of the draft Strategic Plan in 2012 and its ongoing attention to the progress of the Program in the intervening years (see the Committee's charge in Appendix B).

Overall, the Committee believes the Program is moving forward well and has accomplished many things. The Committee commends the USGCRP for putting together a draft USP that identifies a number of critical research questions and describes a set of strategies and programs to address an expanding set of national information needs. The Committee notes that the demand for science-based information on global change is likely to increase as the effects of global change are experienced in more sectors and systems across the United States, and as a growing number and diversity of decision makers confront the need to consider global change in investments, community planning, and other routine decisions. The draft USP identifies many increasingly pressing scientific needs and proposes to address them.

However, the Committee believes that the draft Update does not yet outline priorities and a strategy that will identify and meet information needs that are particularly urgent and for which the scientific opportunities are greatest. This is essential, given that it is not possible for the Program to respond to all of the demands it is likely to face in the coming three to five years. In particular, the Committee has identified five broad, inter-related areas where it feels the USP needs to be strengthened to meet this goal. These, and associated recommendations, are briefly described in the remainder of this summary.

1. Boundary spanning and interacting with stakeholders: The Strategic Plan and USP describe commitments to advance science that is use-inspired as well as fundamental (Goal 1) and to provide information that can be used to inform decisions, conduct assessments, and support education and training (Goals 2-4).[1] This requires sustaining two-way communication about what constitutes useful and scientifically valid knowledge across the boundary that separates users of scientific information from those who produce it. Sustaining interactions with stakeholders at the boundary of use and science is a challenge, particularly for an entity such as the USGCRP, which is itself a collection of agencies and departments responding to their own stakeholders and mandates. Learning

[1] Appendix E lists the Goals and Objectives from the Strategic Plan.

from ongoing interactions with stakeholders to update the Strategic Plan thus requires a concerted effort.

> *Recommendation 1*: **The USP should build upon insights derived from the interaction between researchers and users, to articulate a coherent program of research investments that will advance understanding and inform decision-making, as well as facilitate assessments salient to audiences beyond the federal government.**

Nurturing this boundary role, particularly through the sustained assessment process, has the benefits of facilitating science translation at scales at which actions are taken and encouraging an expanding set of partners to assume an increasingly active role in applying USGCRP-produced data, models, decision-support tools, and other products.

> *Recommendation 8*:[2] **The Committee recommends that the USP discussion of Goal 3 (sustained assessments) more clearly articulate the Program's efforts to sustain relationships with user communities, provide a wider range of products or services, and develop the scientific foundations for assessment.**

2. Articulation of Research Accomplishments: From its earliest days, USGCRP has undertaken use-inspired and discovery-driven research. Both are critical because of the complexity of the Earth system and the societal choices that drive climate change and provide the context for responses. The structure of the USP could be improved to underscore not just the activities, but also the high-level use- and discovery-driven accomplishments of the 2012-2015 period under each of the objectives.

> *Recommendation 2*: **The USP should articulate more clearly the USGCRP's recent research accomplishments, as well as the impacts of earlier discoveries, in addition to describing its activities. Balancing discussion of accomplishments across research areas including interdisciplinary and social science research would be useful in establishing the value of the Strategic Plan's arguments in support of each of these lines of research.**

3. Learning from Engagement and Selecting Priorities: The Program has made great strides through the National Climate Assessment (NCA) and other activities in strengthening interactions with stakeholder groups, including both the research and user communities. This is a valuable opportunity for organizational learning about societal needs that can then help to inform prioritization (along with evaluation of other criteria, such as scientific opportunity).

[2] Recommendation 8 appears as the last recommendation of the main body of the report in the discussion of Goal 3 of the draft USP (Section 4.3), but is presented out of order in the Summary here.

Recommendation 3: The USP should describe and incorporate a higher level of interaction with the research community in the process for planning and updating the Strategic Plan.

Recommendation 4: The USP should include an analysis of what is being revealed about user needs through the activities used to interact with stakeholders; this includes the recently-completed Third National Climate Assessment (NCA3), related activities such as NCANet, and interactions of the Program with user and producer communities through the Interagency Working Groups or professional societies. This analysis of societal needs should inform prioritization of specific scientific initiatives, which is the essence of use-inspired science as specified in the USP's current emphasis on "joint production of actionable science."

4. **Articulation of Priorities and Rationales:** While the draft USP provides interesting and useful information on the intent of the various goals of the Strategic Plan, the Committee found it difficult to understand how the Program is refining its objectives and approach for the coming three years. The Committee suggests that a small set of priority areas should be identified and systematically discussed in a consistent fashion throughout the document. Use of a common template that includes descriptions of the societal needs and science questions, recent progress specific to the priority, near-term targets/products, resources required, and collaborations needed for progress (with federal and other domestic institutions, as well as international programs and entities) would help readers understand the benefits and resources required for each priority.

Recommendation 5: The USP should present a clear set of priorities that respond to both societal needs and scientific opportunity for discovery.

Recommendation 6: The descriptions of priorities in the USP should reflect both the near-term payoffs of new initiatives and the value accruing from long-term research efforts already in progress.

5. **Human Behaviors and Global Change:** The draft USP includes a laudable commitment to fuller integration of social science research into both its fundamental science (understanding interactions of Earth and human systems) and decision-facing components (information for decisions, assessments, and education/training). The adoption of integrated social-natural science approaches in Goal 1 and the effective use of social science knowledge in Goals 2-4 have been recurring challenges for the Program for some time, and the USP continues to lack specifics about how social science research will be integrated into the four goals. Several elements of progress are described (e.g., formation of a Social Science Coordinating Committee [SSCC]), but the USP should build on ongoing progress in the research community regarding specific approaches to the integration of social science to achieve priority research and decision support/assessment/education objectives.

***Recommendation 7*: The USGCRP would benefit from and should undertake a detailed review of advances in the integration of social science into research pertinent to anthropogenic forcing, vulnerability, and capacities for response to global change (e.g., adaptation, mitigation).**

Additional major comments: Chapter 3 of this review offers comments on a wide range of issues raised by the draft USP including its discussions of observations, modeling, and information management. The Committee also comments on the role of the Program in a possible initiative on climate intervention and in research needs in light of the 2015 agreement of the Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) in Paris.[3]

Chapter 4 comments on the Strategic Plan's Goals 2 (Inform Decisions), 3 (Conduct Sustained Assessments), and 4 (Communicate & Educate). The Committee agrees with the draft USP's grouping of Goals 2, 3, and 4, and suggests that the common theme in these goals is the boundary-spanning responsibility that the USGCRP is already undertaking. Social science research on boundary spanning, boundary organizations, and the networks they facilitate or organize, as well as mechanisms that promote adaptive learning to improve interactions between the research community and the wide range of user communities is also discussed. In addition in Chapter 4, the Committee also comments on the sustained assessment process, indicators, regional climate centers, and international research collaborations.

[3] The Committee notes that USP was released before the UNFCCC agreement in Paris.

Chapter 1: Introduction and Overview

The Update to the Strategic Plan (USP) is a supplement to the Ten-Year Strategic Plan of the U.S. Global Change Research Program (USGCRP) completed in 2012 (USGCRP, 2012). The Strategic Plan sets out a research program guiding thirteen federal agencies in accord with the Global Change Research Act (GCRA) of 1990. This Committee reviewed the Strategic Plan in 2012, and we have followed the progress of the Program in the intervening years.

The Committee was asked to review the draft USP document, examining both its content and clarity. The Committee's statement of task for this report is included in Appendix A, its overall charge to advise the USGCRP is in Appendix B, and the Committee membership is included in Appendix C. This report addresses whether USGCRP's efforts to achieve its goals and objectives, as documented in the USP, are adequate and responsive to the Nation's needs, whether the priorities for continued or increased emphasis are appropriate, and if the written document communicates effectively, all within a context of the Committee's broader knowledge of the history and trajectory of the Program.

Overall, the Committee believes the Program is moving forward well and has made important contributions to the Nation. The USGCRP deserves credit for identifying many increasingly pressing scientific needs and for proposing to address them.[1] Historically, the USGCRP has concentrated on the physical sciences of climate dynamics. The Earth system is complex, and the draft USP rightly recognizes the need for better understanding of its driving forces as they operate over many different time scales and geographic spans. Understanding of the changing Earth system has increased dramatically in the quarter century since the GCRA was enacted, and discoveries are still improving our understanding in significant ways—for example, in illuminating the connection between severe weather events and climate change. The USGCRP has contributed significantly both to advancing knowledge in these areas and conveying that knowledge to the research community, decision makers, and the public through its National Climate Assessments. The USGCRP also has correctly identified that the complexity of the Earth system lies in part in the interactions between ecosystems, society, and the physical system, and has begun to make some progress in integrating models that account for ecological processes and social dynamics, although this work is less mature than physical models. The Program should be commended for its efforts and successes and for its plans regarding a continuation of those efforts going forward, as articulated in the draft USP.

Nonetheless, the Committee sees in the draft USP evidence of increasing tension between the need for additional work in the areas traditionally the focus of the USGCRP

[1] The draft USP appears to have been written so that parts of it could be read by particular audiences without reading the whole. This is a sensible expository strategy but it needs to be explained, and guidance provided, so that an unwary reader need not wade through the repetitions found in the draft USP. That repetitiveness highlights the bureaucratic writing style of the draft; the document would benefit if this characteristic were minimized in the final version.

and a broadening range of scientific questions needed to advance the Nation's understanding of and ability to address and respond to global change. For example, experiences with climate-related events, many of them anticipated by the climate science, have precipitated a rise in demand for climate science and the communication of that science, as the report acknowledges. They also have brought additional scientific questions to the fore that have not previously been central to the USGCRP's research portfolio and that also deserve attention. These include questions about the costs and benefits of various mitigation and adaptation options and how best to achieve their objectives; about the feasibility, costs, and benefits of options for climate intervention; about multiple stresses climate change puts on ecological and socioeconomic systems and how they may respond in surprising ways owing to complex feedbacks, tipping points, and nonlinearities; about ways to better inform decision making in the face of climate change and uncertainties about its specific future consequences; and about the processes of decision support and what makes some decision support tools and approaches more effective. Many of these are the broad purview of the social sciences, but beyond calling for "effective engagement of social scientists" (draft USP, p 13, line 17), there are few specific details on how the Program intends to address these new questions.

A number of these needs have been identified in the draft USP, and its authors deserve credit for this. However, the Committee observes that, although some of these needs have been identified not only in the draft USP but also in previous strategic planning documents, the draft USP provides little direction or information regarding how the Program intends to address these needs over the coming years beyond the creation of a Social Science Coordinating Committee. Nor does the draft USP describe how these needs have changed since the Strategic Plan was adopted in 2012. In that document, the two competing priorities—the Program's traditional research and emerging scientific needs—were described:

> "To serve society in meeting present and future challenges, this research program will be built on two principles. The first is to improve fundamental scientific understanding of the integrated natural and human components of the Earth system. The second principle is to focus on the essential science needs for reducing ecological and societal vulnerability to global change by increasing resilience and helping the Nation manage risk through well-informed responses."

The increasing tension between the Program's traditional research priorities (e.g., the physical science of climate change) and emerging scientific needs requires more explicit attention in the strategic planning process.

Thus, although the Committee commends the USGCRP for putting together a draft USP that identifies a number of critical research questions and the call for efforts to address an expanding set of needs, the Committee also believes that the draft Update does not yet fulfill its purpose. More is needed to provide the Program with a strategic document that can guide its evolution, ensuring it is as responsive as possible to the expanding and evolving needs of the Nation. In particular, the Committee has identified

five broad, inter-related areas where it feels the USP needs to be strengthened to meet this goal:

1. Greater recognition of the role of the USGCRP as a "boundary" organization connecting the science community and a spectrum of audiences, and the implications of this role for the development and design of its workplan;
2. A clearer articulation of USGCRP's recent research accomplishments with a balance between discovery-based research (driven by questions identified by the scientific community) and use-inspired research (driven by questions identified by stakeholder and user groups);
3. More robust and transparent engagement of the science and user communities in the process of reviewing progress and selecting program priorities and an analysis of what is being revealed about user needs through previous engagement activities;
4. A clearer statement of current priorities within given areas of research and the rationales for those priorities that reflects both the near-term payoffs of new initiatives and the value accruing from long-term research efforts already in progress; and
5. A review of research to enhance our understanding of human behaviors and institutions that contribute to global change, as well as those that determine or affect responses to that change (including both mitigation and adaptation responses).

These five themes recur throughout this report, and they are described and discussed in more detail below in Chapter 2. In addition, the Committee has more specific comments on the individual components of the draft USP, as reflected in the individual goals and objectives, which are provided in Chapters 3 and 4 of this report. Chapter 5 provides some concluding comments. Editorial and other more detailed Committee comments are included in Appendix D.

Throughout, the Committee takes care not to supplant the judgment of the USGCRP's leaders with its own view of priorities, but rather to indicate where priorities are not clearly articulated and grounded in an understanding of evolving needs and opportunities and with the directions set forth in the 2012 Strategic Plan.

Chapter 2: Setting Priorities for Global Change Research

The 2012 10-year Strategic Plan sets forth ambitious objectives for the USGCRP to meet the Nation's and global community's need for science-based information to manage the risks of global environmental change (Appendix E lists the Goals and Objectives from the Strategic Plan). The challenge of delivering usable information to society is acknowledged as a major additional direction for the USGCRP, something requiring both a commitment to communication and interaction with potential users, but also to research into the process of decision support itself. The 2012 plan laid out a decadal agenda for research in both the natural and social sciences that will provide both fundamental scientific information and knowledge about how to support its proper application by society.

The Committee believes that the draft USP should provide a sense of what has been learned over the first three years of implementation. This includes insights related to specific scientific information needs, as well as how to meet the USGCRP's commitment to inform society. Based on these insights and "lessons learned," the USP should also describe an updated understanding of needs and challenges. This understanding should provide the foundation for refined priorities for the middle three years of implementation of the 10-year plan.

This chapter sets forth some of the Committee's reactions and recommendations on how to improve the USP to tell the high-level story of progress in the Program's evolution, starting with the recognition of the importance of better understanding and conducting interactions at the boundary of science and application. The Committee strongly endorses the Program's commitment to moving in this direction but also notes the importance of balancing use-inspired and discovery-driven science. We are concerned that there have not been more interactions with the research community and more advantage taken of the insights from users through the National Climate Assessment. Below we recommend improvements to the process of interacting with user and research communities in steering the Program to achieve its objectives. While we acknowledge the importance of climate change as a key component of global change and applaud the draft USP's focus on a subset of the issues described in the 10-year plan, we continue to believe that interactions between climate and other stressors will be central to understanding how climate change impacts evolve and how society can manage the risks and opportunities. Finally, we describe our concerns related to the continued vagueness in descriptions of research to better understand human contributions and responses to global change and recommend a more focused, problem-driven strategy that mirrors the approach of the wider research community.

2.1 RECOGNITION OF THE ROLE OF USGCRP AS A FACILITATOR OF BOUNDARY SPANNING

Goals 2-4 identify an essential role for the Program: to assure that the boundaries are observed and spanned between the science community (itself guided by Goal 1) and a spectrum of audiences: decision makers (Goal 2), non-federal users (Goal 3), and the education and training community (Goal 4). It is sensible to treat Goals 2-4 in an integrated fashion. The boundary-spanning role is different in an important way from the research planning and coordination role required in Goal 1. While Goal 1 requires the Program to attempt to coordinate the research activities of the 13 agencies in terms of setting broad research directions and budgets in a way that advances scientific understanding of global change, the articulation of Goals 2-4 in 2012 marked a qualitative shift in how the USGCRP interpreted the mandate of the GCRA. Under the 2012 Strategic Plan, "advancing understanding" is to be carried out so as to inform decisions, to support an ongoing process of assessing climate change, and as a component of education and training. In all these arenas, the Program was not just the facilitator of conversations within the scientific community; it was also responsible for navigating the boundary between scientific knowledge and its users both in and beyond the federal government. In effect, the Program took on the responsibilities of a boundary organization.

As the term suggests, a boundary organization faces in two directions, toward both the research and the user communities: it is accountable for assuring that sound scientific knowledge is produced and that this knowledge is useful within its proper application (Cash et al., 2003; Guston, 2001). "[T]he boundary organization provides an institutionalized space in which long-term relationships can develop and evolve, two-way communication is fostered, tools for management (such as models) are developed and utilized, and the boundary of the issue itself is negotiated. As such, the boundary organization is dynamic and changing, responding to the changing interests of actors on either side of the boundary." (Cash, 2001, p. 450) In practice, the task of the boundary organization is to assure that researchers and users develop a partnership that produces knowledge that is *credible, salient,* and *legitimate* for use in decision making, assessment, and education. Credible knowledge is technically adequate in its handling of evidence. Salient knowledge is relevant to the decision or other use to which it is applied. And legitimate knowledge is fair, unbiased, and respectful of all stakeholders (Clark et al., 2011).

It is important to keep in mind that these three dimensions of useful and valid knowledge are implemented differently in the science and user communities. For instance, knowledge that is adequate for decision making may or may not have been validated by the peer review that is used within the scientific community. It is central to the mission of the boundary organization that it respect both users' and researchers' ways of judging the value of knowledge, illuminating conflicts and resolving them where possible (Clark et al., 2006).

Boundary organizations have come to prominence as a critical instrument of use-inspired research (Stokes, 1997) because of the need in this approach for researchers to work with prospective users from the beginning of a research project to co-produce

knowledge. The two-way translation of what constitutes useful and scientifically valid knowledge is essential and frequently requires a boundary organization. This is a role played historically by extension agents and field research stations in agriculture, for example (Cash, 2001). This boundary organization framework could be usefully employed in describing the USGCRP's activities; however, in many instances the discussion in the draft USP is of a one-way transfer of knowledge to end-users, rather than the two-way process envisioned in the 2012 strategic plan.

Goal 2, Informing Decisions, articulates the USGCRP role in use-inspired research, also called actionable or translational research. Decision support depends on credibility, salience, and legitimacy, all of which in turn require developing and providing information in the context of ongoing relationships between users and scientists. Intermediaries skilled in science communications can play an instrumental role in these relationships. Goal 3 sets out the Program's role in assessments, including the National Climate Assessment, which report on the state of knowledge in a wide range of scientific subjects germane to a changing climate. An assessment is a boundary object, jointly produced by representatives of the research and user communities (Clark et al., 2011; Guston, 2001), a product fashioned collaboratively by representatives of the science community and communities of users. Again, maintaining ongoing relationships with user communities is a core challenge for the science programs of agencies that comprise the USGCRP as they transition the assessment process to something more than production of periodic reports (NCA Sustained Assessment Special Report). Education and training, described in Goal 4, similarly require interactions between the research and learning communities to assure that the knowledge transmitted is credible, salient to students, and forms part of a legitimate course of study. (Note that the Committee discusses the plans for the sustained assessment in more detail in Chapter 4, including a recommendation for how USGCRP could update the USP document.)

In sum, Goals 2, 3, and 4 all require boundary-spanning functions, and the USGCRP accordingly has a role in seeing that these functions are implemented by the relevant federal entities, or by the Program serving as a boundary organization itself. This can happen, in part, through knowledge networks (Frank et al., 2012) such as NCAnet.

The draft USP, however, needs to highlight co-production more strongly (for example on p. 32 ln 13-14) because, among other things, that would put USGCRP into a stronger role as boundary spanner between users and science communities. The formal study of boundary organizations is in a relatively early stage, and it appears that the USGCRP is still digesting the organizational implications of its boundary mission. Engagement with users strengthens understanding over time, as the questions being pursued under Goal 1 are informed by the co-production process. Without co-production society's priorities are expressed through budgets only. With substantive communication between the science community and users, budget decisions should be based to a greater degree on a scientifically informed judgment of priorities. This, among other elements of the co-production of actionable research, is missed in the current draft (see for example p. 31 ln 40ff).

Boundary spanning is instrumental to a goal that is substantive as well as procedural: to coordinate from the disparate missions of 13 federal agencies a research

program that can advance the goals of the Strategic Plan. In the remainder of this report the Committee offers analyses and recommendations intended to assist the Program in forging a coherent set of priorities in light of resource constraints and a variety of tensions that need to be managed in order to advance understanding and to enable use of scientific knowledge in facing the practical problems posed by global change.

Recommendation 1: The USP should build upon insights derived from the interaction between researchers and users, to articulate a coherent program of research investments that will advance understanding and inform decision-making, as well as facilitate assessments salient to audiences beyond the federal government.

2.2 ARTICULATION OF RESEARCH ACCOMPLISHMENTS

From its earliest days, USGCRP has undertaken research that is use-inspired and discovery-driven. The Program combines and integrates these outcomes in its support of fundamental research motivated by societal considerations (Stokes, 1997). Goal 1 of the plan is to advance science of the integrated natural and human components of the Earth system. Advancing the knowledge of the Earth system is an important foundation for decision support and much of that knowledge is generated through discovery-driven approaches.

Even with increasing emphasis on use-inspired science in the Strategic Plan, discovery-driven science remains critical because the Earth system is complex, with biophysical and biogeochemical interactions in and between the land, atmosphere, and ocean defining the behavior of the system. Global change is a science of surprise, where emergent features are seen in the system that may not be seen in the individual components of the system. In other words, the integrated whole is greater than the sum of the individual components, the history of the system matters, and cause and effect relationships are often quite complex. By necessity the understanding of the integrated components of the Earth system requires ongoing research and observations—research that is driven by the curiosity of how our planet functions. Coupling this natural system with the human component adds another dimension of complexity with its own surprises (see draft USP p. 14, lines 10-12). Discovery-driven research is the foundation for advancing our understanding of the Earth system and it helps inform use-inspired research.

There have been many examples over the history of the Program of discoveries that have advanced our understanding and enabled new capabilities for decision support. These include the discovery of atmospheric rivers and their role in better understanding of precipitation; the discovery of the integrated ocean circulation, ice, and atmosphere dynamics in the Arctic, leading to better process understanding of ice-melt so critical to quantifying sea level rise; the new discoveries of biological functioning that can aid in ecosystem restoration and management in a changing physical environment. The USP should articulate some of the USGCRP's recent advances in fundamental science, as well

as the recent impacts of earlier discoveries.[1] This is also an opportunity to begin to highlight what might be important for the next strategic plan. The structure of the USP could be improved to underscore separately not just the activities, but also the high-level accomplishments of the 2012-2015 period under each of the objectives of Goal 1.

In recent years, social science research has led to important new insights relevant to understanding and providing information to manage global change. Individual decision making is now understood as sometimes being based on rational optimization but often on the use of cognitive shortcuts and heuristics, and often involves not just individual utility maximization but also altruism and conformity to norms (Dietz, 2015; Kahneman, 2011; Schultz et al., 2007). The behavior of organizations and policy systems as well as of individuals is strongly influenced by network ties, and networks can provide a useful mechanism for transmitting information about mitigation of and adaptation to climate change (Frank et al., 2012; Henry, 2009; Henry and Vollan, 2014). The forces that drive human stress on the environment have been substantially examined, with sophisticated literatures examining the forces that influence both land use change and greenhouse gas emissions (Blanco et al., 2014; Levy and Morel, 2012). That literature in turn has identified influences that can constitute leverage points for change. The understanding of commons management has become very sophisticated and can contribute to the design of institutions at every level from the local to the global (Dietz et al., 2003; Ostrom, 2007). In parallel, processes for linking scientific analysis to public deliberation have been extensively studied, improving the ability to diagnose particular contexts and to apply design principles in developing processes for environmental assessment and decision making (NRC, 2008).

This Committee reiterates the importance of discovery-based research and the importance of an Earth-system approach. The value of this research to society is only going to grow as we continue to be surprised by our changing planet. Rigorous comparison of the value of discovery-driven versus use-inspired research remains a challenge. The evaluation of use-inspired research should be partly practical: whether useful knowledge leads to better solutions to problems. This is harder to assess than one might think because the utility of knowledge often does not emerge until long after research is completed, and it can then be embodied in ways that are hard to trace back to the original research. Another criterion for evaluation involves realizing the potential for rapid or fundamental advance when there is a confluence of new data, methods, and other research capacity. Without good methods to estimate the likely returns to either discovery-driven or use-inspired research, the question of how to balance the Nation's investment in these two avenues of global change science remains. Even though asking users is an imperfect measure, the Program could consider ways for federal agencies that are users of global change research to participate in evaluation of the Program's fundamental science (Goal 1) as well as research in pursuit of Goals 2-4. This Committee is planning studies of metrics for the Program that are intended to advance our

[1]Some examples of advances that could be highlighted and places in the draft USP document that would benefit from examples are included in Appendix D.

understanding of ways to estimate the value of use-inspired and discovery-driven research.

Recommendation 2: The USP should articulate more clearly the USGCRP's recent research accomplishments, as well as the impacts of earlier discoveries, in addition to describing its activities. Balancing discussion of accomplishments across research areas including interdisciplinary and social science research would be useful in establishing the value of the Strategic Plan's arguments in support of each of these lines of research.

2.3 BETTER PROCESS FOR DEVELOPING PRIORITIES AND LEARNING FROM STAKEHOLDER ENGAGEMENT

Process for Developing Priorities

The USP provides an important opportunity for the Program to understand better the needs and views of both the research and user communities. Unlike the deliberations that lead up to *Our Changing Planet* each year, the writing of the draft USP is a process that can be opened up to the wider public. Indeed, the public comment process to which this report contributes is one method of engagement with users and the scientific community. Moreover, Chapter 1 of the draft USP includes the statement that a key aspect of the program "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" (p. 8). Other sections of the draft USP include similar statements.

It is thus surprising to the Committee that interaction with participating research communities to develop the draft USP has not been transparent, and moreover that interactions through mechanisms such as the NCA do not appear to have been systematically mined in setting priorities and developing a strategy. The main locus of USGCRP interaction with stakeholders in the 2012-2015 period has been preparation and release of the NCA3. This report effectively described the state of science as it pertains to understanding impacts and planning and implementing adaptation and mitigation responses. Feedback from the needs identified in the NCA to the near-term priorities described in the draft USP is not described in specific terms and reflected in clear priorities.

In making this observation about engagement, the Committee draws upon the perspective that in strategic planning, especially for public agencies, process is as important as the final plan itself (Bryson, 1995). The USP planning and drafting process appeared to involve limited interaction with users and scientists. Some Town Hall meetings at professional associations are mentioned, but a more focused set of engagements that provided an opportunity to interact with USGCRP leaders and members of the Interagency Working Groups responsible for the different areas of the program does not seem to have been attempted. Such opportunities were included in the preparation of previous Strategic Plans and would provide an opportunity for program managers, users,

and the research community to provide comments on initial ideas for the Update. This could also include reflections on how USGCRP science is being used, what approaches are more or less effective in framing science for decisions, identification of specific information needs and opportunities for co-production of knowledge, and similar issues. An open process of engagement is needed to ensure that priorities reflect user needs and that the research community shapes these priorities to reflect its understanding of scientific potential for progress and opportunity for discovery. The regional centers described later in Box 4.1 would also be useful venues for interaction between the producers and users of scientific knowledge.

The Committee urges the USGCRP to improve approaches for ensuring both user and science community input into its strategic planning process. If program needs and schedule allow, the USGCRP could convene an open workshop to discuss specific priorities and plans described in the Update and consider this community input in refining the USP. If this is not possible, we strongly recommend that the Program incorporate specific plans for such workshops on a periodic basis to help guide the evolution and implementation of the USGCRP. In addition, we suggest that the USGCRP transparently incorporate input from the NCA sustained assessment process in discussing decision making needs. One approach to this could be to periodically engage NCANet members and NCA advisory processes in distilling lessons and needs identified in the assessment process.

Recommendation 3: The USP should describe and incorporate a higher level of interaction with the research community in the process for planning and updating the Strategic Plan.

What Has Been Learned from Users and Researchers?

Societal needs play an increasingly important role in helping USGCRP program managers to set priorities for research. Ideally, these needs should inform the priorities for investments in observations, process research, and modeling needed to advance understanding and thus improve information for applications. The needs cited in the Introduction to the 2012 Plan (pp. 1-2) and subsequently throughout the document are extremely broad and appropriately cover the range of topics described in the Program's enabling legislation. In a real sense, looking at the situation in 2015 and for the coming three to five years, the need for information is likely to increase, as global environmental change is experienced in more and more sectors and systems across regions of the United States and as an increasing number and diversity of decision makers confront the need to consider global change in investments, community planning, and other routine decisions. The necessity of having the USP reflect on what is being learned about societal needs is driven by the fact that it is not possible for the Program to respond to all of these demands simultaneously. It is thus essential to formulate a strategy that can identify and meet information needs that are particularly urgent, and for which the scientific opportunities are greatest.

The draft USP fails to go beyond previous descriptions of need and scientific opportunity. The USP should present in a self-reflective way what the Program has learned about the needs of users over the last three years, and how these evolving needs are shaping implementation and prioritization of the long-term objectives described in the 2012 Strategic Plan. Integrated into this sense of evolving need should be a clearer statement of specific program accomplishments, both scientifically and in terms of provision of information for decision support. Such a cross-cutting discussion and synthesis of needs and highlights affords an opportunity for the Program to communicate its accomplishments and to place the evolving priorities into context (see also "Setting Priorities while Sustaining Long-Term Commitments" below).

Recommendation 4: The USP should include an analysis of what is being revealed about user needs through the activities used to interact with stakeholders; this includes the recently-completed Third National Climate Assessment (NCA3), related activities such as NCANet, and interactions of the Program with user and producer communities through the Interagency Working Groups or professional societies. This analysis of societal needs should inform prioritization of specific scientific initiatives, which is the essence of use-inspired science as specified in the USP's current emphasis on "joint production of actionable science."

2.4 BETTER ARTICULATION OF PRIORITIES

The USP can be significantly strengthened to clarify the Program's priorities and convey to the Nation what the benefits are of continued investment. The USGCRP's judgments about priorities are no doubt driven by its understanding of shifting needs and circumstances since the Strategic Plan was completed in 2012. It is therefore important that the USP describe what is being learned as the Strategic Plan is implemented and circumstances change.

How Do the Identified Objectives Fit Together?

Another weakness of the draft USP lies in the articulation of priorities. This needs to be improved so that Program objectives over the next three to five years can be understood. A reader of the draft finds three sets of goals; these appear to overlap, but there is no clear relationship articulated among them:

- In its strategic overview, the draft USP "spotlights" three areas: (a) extremes, thresholds, and tipping points; (b) predictions; and (c) science to inform policy making and management. (p. 10).
- Chapter 3, Objective 1.1 (Earth system understanding) highlights: (a) tipping points and thresholds; (b) using long data records to understand Earth's climate variability;

(c) the global warming hiatus; (d) rapid Arctic change; (e) carbon cycle and ecological modeling; (f) research for identifying gaps in the climate observing system; (g) cloud regime transitions and aerosol chemistry; (h) water cycle research (pp. 13-17).

- Chapter 3, Objective 1.2 (science for adaptation and mitigation) highlights: (a) models for decision making; (b) resilience and vulnerability research; (c) translational research to inform adaptation and mitigation; (d) carbon cycle research; (e) methane cycling (pp. 19-21).

Additional science-related objectives are articulated for observations, modeling, and information management. The draft is silent how these goals have evolved from those stated in the 2012 plan. What considerations influenced their selection now? How does the USGCRP see the goals evolving? Will any priorities adopted earlier be phased out? Are there issues that are not current priorities but are under consideration for emphasis in future updates?

The broader question is how readers should interpret these highlighted topics. One possibility is those "spotlighted" on p. 10 should appear as recurring themes throughout the USP. However, they are not featured as a set in the draft after this first mention. The "climate extremes and tipping points" topic is raised as a focused topic (see specific comments in Chapter 3, including a recommendation regarding the presentation of these topics in the USP), the topic of "predictions" is not named as such (although improving "projections" does arises a number of times), and the issue of "science to inform policy making" is so broad that it is difficult to see as an organized priority. A second interpretation is that all of these topics constitute Program priorities. But as a set of priorities, they do not give a sense of strategic direction that responds to either need or opportunity for discovery. The topics in Objective 1.1 conflate two groups of issues: Some that are integrative and respond to recent attention in the NCA or the media (e.g., the hiatus and rapid Arctic change); others follow a more traditional science-driven formulation (e.g., carbon cycle and ecological modeling, water cycle). Objective 1.2 highlights topics that are apparently judged to be particularly important for informing adaptation and mitigation, but these do not fit together as a strategy of investment. In particular, an integrated framing of questions that draw together the natural and social sciences is lacking, even though mitigation and adaptation present challenges that require an integrated body of knowledge.

For all three groups, it remains unclear what the specific information needs are for these topics and how the information will be used. In what sense do these topics represent opportunities for advancing knowledge? As stated, these topics do not form a strategy.

The draft USP says that "Since release of the Strategic Plan, the USGCRP has matured its priority-setting approach" (p. 13). There should accordingly be an increasingly explicit relationship between evolving societal needs or discovery opportunities to both Objectives 1.1 and 1.2. For example, the USP should link USGCRP priorities for research on the water or carbon cycles to specific adaptation or mitigation decision support needs, or to products from the Sustained Assessment process, or to near-term opportunities to advance fundamental understanding of interactions of atmospheric chemistry and the

water cycle.[2] Another area where coordination needs to be improved is between the topics identified in Objective 1.2 and the objectives included in Goals 2 (Inform Decisions) and 3 (Conduct Sustained Assessments). The specific topics listed in Goal 2 include Decision-Scale Knowledge, Integration of Social and Behavioral Sciences, Supporting Agency Adaptation Planning, and Science Translation. How are these related to the topics listed in Objective 1.2?[3] The failure to provide a logical set of priorities across the Program's objectives is a major deficiency of the draft USP.

The Committee notes that the USGCRP as an entity does not have its own budgetary authority but rather relies on leveraging the resources allocated to the participating agencies and departments through Congressional appropriations. The Congressional authorization and appropriations process can sometimes result in very specific instructions or mandates and can affect the ability of agencies to align their programs with the priorities of the interagency effort as developed through USGCRP working groups and other coordination mechanisms, such as bi-lateral interagency agreements. The chapter on USGCRP's "Implementation Strategy" describes the structure of the interagency process, and this Committee's recent report (*Enhancing Participation in the U.S. Global Research Program* [National Academies of Sciences Engineering and Medicine, 2016]) provided options for increasing collaboration and engagement of mission-oriented agencies and offices. As drafted, the USP does not provide any basis for understanding the alignment of interagency Program objectives with the priorities of individual agencies. The Committee realizes that the detailed cross-walk between agency and USGCRP priorities occurs in *Our Changing Planet*, which is intended to assist Congress in evaluating program integration. The Committee feels, however, that valuable information would be added to the USP if it identified which agencies or departments (and preferably which programs within these agencies) were engaged in some of the specific priority activities described.

A final critical issue related to discussion of priorities throughout the document is that it is not possible to estimate, even roughly, how much funding would be needed to support each major set of goals. The Committee understands that portrayal of budgetary information is primarily the province of the *Our Changing Planet* report series, and moreover, that multi-year budget commitments are not feasible in many cases. But this and future Updates to the Strategic Plans would benefit by giving at least some sense of scientific and programmatic needs, level of effort, and relative priority; this information is necessary to evaluate whether the objectives are achievable in a near-term time frame and which objectives would be deferred if sufficient funding were not available.

[2] One interpretation is that the Objective 1.1 goals represent discovery-driven science while those for Objective 1.2 are motivated by specific adaptation and mitigation uses. But this does not seem correct when several of the topics seem to be identical, and it is not explained how questions or expected deliverables differ across the different sets of objectives.

[3] One could argue that Goal 2 is more focused on development of methods for decision support, but several of these topics (e.g., integration of social sciences, supporting agency adaptation planning) do not fit that categorization.

Recommendation 5: The USP should present a clear set of priorities that respond to both societal needs and scientific opportunity for discovery.

Describing Near-Term Priorities Within the Context of Sustained Long-Term Commitments

The social, biogeochemical, and biophysical drivers of global change unfold over a variety of time scales. The carbon dioxide emitted from fossil fuels alters the composition of both atmosphere and ocean. The energy balance of Earth would continue to shift for centuries, even if human-caused emissions were to cease completely. Those emissions are unlikely to cease in the near term, however, given the understandable desire of many to increase their access to inexpensive energy. Earth is a coupled human-natural system, manifesting complex behavior that needs to be studied over substantial spans of time and space (see Box 2.1).

A long-term program of scientific research, aimed at both discovery and problem-solving, has yielded large benefits over the past generation, and the USGCRP has played a central role in that learning. The positive reception of the NCA provides one benchmark of the returns to the Nation of the Program's investments in knowledge. Sustaining that stream of investments will essential in the future. The Earth system continues to change, so that observations are critical. The processes at work in global change—from demographic transitions to the cycling of carbon through the Earth system—are increasingly well understood but continue to surprise us, in part because of the many non-linearities in their component systems and their complex interactions. And the models devised to describe these processes and to organize the observations of the Earth system have become indispensable in order that we may see what it is that we know.

Given that the funding requirements for research described in the Strategic Plan exceed available resources, the capacity to respond to new developments, both in the science and in the demand for knowledge, requires careful balancing of near-term and long-term objectives. Although the Committee does not find the efforts in the draft USP to spotlight research topics satisfactory, many of the highlighted areas are ones in which either the demand for knowledge or the opportunity for rapid advance of scientific understanding are apparent. In the Committee's view, the USP needs to identify a focused set of priority information needs from among the larger set described in the 2012 Strategic Plan. These should be prioritized on the basis of near-term payoff and their ability to advance long-term research efforts already in progress. Ideally, the priorities articulated should then drive an integrated set of observational, process research, modeling, and decision support initiatives that will lead to products to meet these needs. The Committee understands that these would not be the only areas the USGCRP will work on in this next phase of implementation of the Strategic Plan. Work on many other topics with longer term benefits introduced in the 2012 Plan would also continue.

Recommendation 6: The descriptions of priorities in the USP should reflect both the near-term payoffs of new initiatives and the value accruing from long-term research efforts already in progress.

BOX 2.1 Integration of the Earth System

The knowledge of the workings of the biophysical components of our Earth system is unbalanced. In particular the interaction of *both* of the major fluid bodies—the ocean and the atmosphere—is critical to understanding the changes in circulation, and the transfer of heat, water, and carbon. While climate change is often talked about in terms of the response of the surface of the planet, it neglects the deep reservoir of heat that is taken up by the ocean. Recent evidence of major heating in the deeper ocean illustrates just how important the ocean has been in moderating the climate change we have seen to date (Meehl et al., 2011; Nieves et al., 2015). New understanding of salinity changes can help inform seasonal changes in precipitation patterns (Johnson et al., 2012). And the bio-physical interactions in the marine environment are beginning to indicate how non-linear interactions are compounding the impact on life in the ocean. In short, the atmosphere may be the messenger of the climate system, but the ocean is its memory. That change in memory has long-lasting consequences. The ocean is under-sampled (its physics, chemistry, and biological functioning) compared to the atmosphere; it is a frontier in many respects as discoveries are made in every scientific expedition into the ocean. However, the ocean sciences community has had to make difficult decisions given the limitations in funding for observational infrastructure and science (NRC, 2015a). This is discovery-driven research with important consequences for life in the ocean and on the land—for food, resources, weather and precipitation patterns, transportation, etc. It is important that discovery-driven research within the USGCRP keep in mind that it is the integration of the Earth system—with special attention to the ocean—that will enable the use-inspired research and informed decisions.

2.5 NEED TO PLAN INTEGRATION OF SOCIAL SCIENCE TO ADDRESS SPECIFIC ASPECTS OF HUMAN-INDUCED FORCING, VULNERABILITY, AND CAPACITY FOR RESPONSE

The draft USP includes a laudable commitment to fuller integration of social science research into both its fundamental science (i.e., understanding all components of the Earth system) and translation/communication (i.e., decision support, decision making, science-policy research) components. It states that the integrated USGCRP program "conducts cutting-edge fundamental and use-inspired science and *relevant* social science" (emphasis ours), without defining what is meant by "relevant." Moreover, the draft USP notes in several places a lingering challenge to understanding human drivers and responses to global environmental change (e.g., p. 11, lines 34-38; p. 14, lines 10-12; p. 19, lines 13-16) and difficulty in effectively engaging social scientists (e.g., p. 12, line 17; p. 17, lines 39-40).

The Committee endorses this direction and the steps underway to implement that intent. The Program has made some progress in terms of integrated assessment modeling, impact and vulnerability modeling, and in the development of a social vulnerability index in its Climate Resilience Toolkit. It is too early to evaluate the impact these actions will have, but the Committee applauds this direction. However, we note that the adoption of integrated social-natural science approaches in Goal 1 and the effective use of social science knowledge in Goals 2-4 have been recurring challenges for the Program for some

time. More than a decade ago, one of the high level goals of the Climate Change Science Program (CCSP) specifically identified social science as necessary to "Understand the sensitivity and adaptability of different natural and managed ecosystems and human systems to climate and related global changes" (CCSP Goal 4), and one of the CCSP's core approaches included a research thrust and interagency working group on "Human Contributions and Responses" (CCSP, 2003). The 2012 Strategic Plan gives even more emphasis to incorporating social sciences.

The draft USP continues to lack specifics about how social science research will be integrated into the four goals, and there have been some clear advances. For example, The Social Science Coordinating Committee (SSCC) was a good first step, but little information is provided on any outcomes of its deliberations or how its work differs from previous efforts such as the Human Contributions and Responses Working Group. Another positive development of which the Committee is aware is that some of the Agency research competitions held with funds that are considered part of the USGCRP budget cross-cut require an "end to end" framing of research that *integrates* (not just adds on to) social science framing and research objectives. It might be helpful in assessing progress on integration of social sciences to analyze and refer to results from this approach across the agencies in addition to including other indicators of trends in social science integration, for example, trends in funding levels, number of social scientists funded or participating in program activities, and so on.

More generally, the Committee notes that much progress is being made in the broader social science community in integrating natural and social science research to improve understanding of how coupled human-environment systems are co-evolving. There is a significant body of research in the fundamental social sciences in the academic and policy communities that directly relates to global environmental change (e.g., NRC, 1992, 1997, 2010a, 2013); two illustrative examples are provided in Boxes 2.2 and 2.3. These lines of social science research range well beyond research on decision support and work done in support of decisions (which the Committee discusses later in Chapter 4).

While the Committee has not had adequate time to discuss and evaluate factors that contribute to successful integration, we note two characteristics that seem important: specificity and joint framing. With respect to specificity, much integrated natural-social science research is planned in a way that identifies the particular insight or information that is required from the social sciences and how it will be integrated into other research. Examples abound in areas such as land use/land cover change, water resources, a wide range of "impacts" research, and studies of environmental consequences of different institutional arrangements or policies. The Committee understands that the USP cannot be as specific as required in an individual research study, but we believe that where the research described under Objectives 1.1 and 1.2 addresses aspects of interactions between human and natural systems, the USP could discuss conceptually the role of social science in contributing to answering the questions raised. Because of the more general sense of progress in the community, the Committee was surprised that draft USP continues to lacks specifics about the integration of the social sciences: For what specific purposes is social science needed, and how will social sciences be involved?

With respect to framing, the Committee notes that simply calling for greater integration of social science within a climate change agenda set largely by the natural sciences fails to recognize and build upon the theoretical and methodological approaches of the social sciences and limits the contributions that the natural and social sciences can bring together (NRC, 1992, 2010b). This challenge is partly recognized in the Navigating Challenges section of Objective 1.2 (draft USP p. 21). However, the activities listed still come across as natural science driven (what information the natural sciences can supply and what social science inputs are needed for a natural science decision support agenda?). This is particularly important for research in areas germane to vulnerability, mitigation, and other climate-related subjects that could help inform all of the Objectives throughout Goal 1 of the Strategic Plan.

A logical next step to better informing the USGCRP and its strategic planning would be a broad review of the relevant social science research. For example, one area of research that might deserve particular attention is developing understanding of vulnerabilities to the multiple stressors involved in global change (see Boxes 2.2, 2.3, and 2.4). A review would be part of the process of harnessing the existing knowledge base in the social sciences (see the conceptual framework laid out by Weaver et al. [2014]) and could be prepared by a science advisory group (similar to how the Carbon Cycle Working Group elicits input from the research community on its specific plans) or through an independent external group.

Recommendation 7: The USGCRP would benefit from and should undertake a detailed review of advances in the integration of social science into research pertinent to anthropogenic forcing, vulnerability, and capacities for response to global change (e.g., adaptation, mitigation).

BOX 2.2 Fundamental Social Science Research Related to Global Change—Response to Heat Waves

Social science research is needed for more than identifying particularly vulnerable locations and systems, but also to understand how multiple, interacting stressors could alter resilience, and to more effectively communicate with individuals and communities the risks of a changing environment and the range of options for managing risks. While federal and state adaptation activities are critical, individuals and communities also will need to prepare for and adjust to changing environmental conditions. Collaborations of climate and social scientists can identify options to better motivate change.

For example, all deaths during a heatwave are preventable and yet heat is a leading cause of weather-related mortality in the United States.[a] Knowing that the frequency, intensity, and duration of heatwaves are projected to increase is insufficient. Research has shown that older adults are the most vulnerable to high ambient temperatures, with very high awareness when a heatwave is declared, and with a significant proportion (approximately 75%) knowing at least one activity that a highly vulnerable person, such as himself or herself, should undertake to reduce risk (Sheridan, 2007). However, less than 50% actually do anything differently during a heatwave.

Other stressors affecting future heat-related mortality include aging populations, the increasing prevalence of obesity and diabetes, and increasing use of drugs that affect susceptibility to high ambient temperatures. Economic and other constraints may prevent individuals from taking actions, such as turning on air conditioning or traveling to a cooling center. Better understanding is needed of how these multiple factors interact in order to develop more effective approaches to communicate risks and motivate appropriate behavioral changes. Without this understanding, more precise forecasts and projections of heatwaves will not increase resilience.

[a] http://www.nws.noaa.gov/om/hazstats.shtml

BOX 2.3 Fundamental Social Science Research Related to Global Change—Safety Nets

Effective social safety nets have been used to assist people both to climb out of and to not fall into poverty, as well as to lower crime risks and to promote stable livelihoods (See review in Hallegatte et al., 2016, Chap. 5). They can be formal or informal and public and/or private (e.g., via families). Design, practice, and research into such safety nets have been very much the domain of the social science community. But many existing safety nets are subject to disruption by changing climates, such as through more frequent disruptions to livelihoods from extreme climate events or increased pressures on health care systems through changing disease patterns. Therefore, a better understanding of the nature of these safety nets and their sensitivity to climate impacts is likely to increase the range of options to be considered in tackling adaptation and reducing the impact of mitigation measures. These issues are discussed in the World Bank's recent report *Shock Waves* (Hallegatte et al., 2016). Building the knowledge base to understand the interaction of safety nets and a changing climate might be addressed, for example, via an interagency working group of the USGCRP.

BOX 2.4 Importance of Multiple Stresses in Global Change

Climate change is occurring against a backdrop of spatially dense and intense use of resources from Earth's environmental systems, as well as historically novel human institutions and conditions. In rich nations people live longer, healthier, more productive lives than our ancestors dreamed of; the probability of going hungry has declined drastically; the frequency with which people encounter strangers from cultures different from their own has increased greatly; and more and more wild species are going extinct. In other locations (even in wealthy nations), others live in poverty, exposed to environmental hazards, and in numbers that are unprecedented (NRC, 2003). A changing climate is part of a suite of transformational changes of human origin. Like human-induced greenhouse warming, these other changes are accelerating and involve major transformations of the Earth system—surface and groundwater systems, pollution and eutrophication arising from human-dominated nutrient cycles, global land-to-ocean sediment transport, and the proliferation of engineered chemicals with unknown, long-term impacts. As climate-related stresses increase, their impacts interact more strongly with these other stresses on humans and ecosystems. This has implications for both global change science and the Program's investment in the social sciences.

The explicit framing of the draft USP is to focus on "climate-related global change" (draft USP, p. 4 ln 32-37). This focus is consistent with that of the 2012 Strategic Plan. But the implicit assumption of this framing is that climate change is the primary driver of impacts, despite abundant evidence from the research literature, NCA3, IPCC, and other reports that impacts arise from the interaction of the hazards associated with a changing climate with the sensitivity of the exposed human and natural systems, and with the ability of human systems to prepare for, respond to, cope with, and recover from hazards. Multiple hazards and stresses interact to produce impacts, and the capacity of natural and human systems to adapt to climate change must be viewed through the lens of synergies and interactions.

Chapter 3: Science Focus and Scope

As the draft USP is an update to the ten-year 2012 plan, a reasonable expectation is that it will include updates on accomplishments, sharpened questions, greater specificity about deliverables and time lines, and more clarity on resources required for producing these deliverables. While the draft Update provides interesting and useful information on the intent of the various goals, the Committee found it difficult to understand what the Program uses as metrics of progress and hence how it documents tangible progress, as well as how the Program is refining its specific objectives and approach to each of the challenges it addresses.

In this chapter we begin with recommendations for clarifying the discussion of the objectives and specific topics that the draft USP describes as priorities. In the sections that follow, the Committee offers comments on some of the major issues brought up in Chapter III of the draft USP, following the structure of the draft. This is not intended to be a comprehensive review of the draft; the Committee did not have the time to include all of the expertise needed to do that. In addition, for the reasons presented earlier in this report, we believe the Program leadership should reconsider which priority topics it is in fact pursuing in the Update to the Strategic Plan.

3.1 TEMPLATE FOR CONSISTENT PRESENTATION OF TARGETED RESEARCH CHALLENGES AND TOPICS

The draft USP uses a reasonable framework to stage its discussion of each high-level objective. This includes sections on “Maintaining Directions,” “Building on Progress,” and “Navigating Challenges.” While this framework is logical, it is not effective in practice because it is not implemented consistently and it does not supply enough detail with respect to accomplishments and refinements to the plan. It therefore inadequately informs discussion at the level of the specific goals or priorities presented below each of the main objectives. For example, the “Building on Progress” sections are not standardized and do not indicate what progress is being made in addressing the issues raised. We offer several suggestions. The Committee believes that the sections on “Maintaining Directions” should restate the 2012 Plan’s objectives and describe how the objectives are evolving in response to changing needs and scientific opportunities. Perhaps a better title such as “Strategic Directions and Learning from Experience” would reflect both continuity and change in objectives. The Committee feels that sections titled “Building on Progress” should showcase examples of how the Program is making progress by documenting specific accomplishments. It is in these sections that specific topics such as tipping points/thresholds, climate variability, attribution, etc. are introduced in the draft. The text in these sections provides useful information about the intent and general area of research, but discussion of progress is often not specific enough to enable the reader to understand why scientific progress or changes in circumstances have led the Program to

shift research emphasis in response to the progress made since 2012. In addition, the discussion of next steps and future objectives is very general and lacks specific deliverables, timetables, or resource requirements (e.g., technical inputs). The "Navigating Challenges" sections provide interesting discussion of general issues that cut across the specific topics listed but do not provide a satisfactory evaluation of challenges to progress. More specifics are provided below.

Even for the high-level numbered objectives, it is not possible to get a useful sense of progress or new goals. It is important to identify significant accomplishments since the Strategic Plan was completed in 2012, describing the context of these achievements so that non-specialist readers can appreciate what has been done. For instance, on p. 23 multi-agency field campaigns are discussed, but there is no description of a particular campaign to illustrate what such a project can contribute and how it should be analyzed within a context of continuous observations and monitoring. The Committee is not asking that each example in Chapter III be fully developed; rather, the USP could use specific illustrations to bring out the meaning of "maintaining directions," "building on progress," and "navigating challenges."

In discussing how the Program will invest in the next several years, few specific metrics are offered. Where appropriate, metrics may be available for funding that lies within a single member agency of the USGCRP, and including these in the text would strengthen the USP document considerably. In many important cases, however, it is the interagency synergy brought by the Program that should be the focus of progress going forward. In the areas spotlighted on p. 49, it may be possible to identify metrics already. This might take the form of specific tasks that are planned to be accomplished within the next few years. The Committee is looking forward to working with the Program on the question of metrics in a separate study, which is now being organized. Here, we note that the NRC's report *Thinking Strategically* (NRC, 2005) contains practical advice on principles and challenges associated with developing and using metrics to chart progress in global change research.

As discussed in Section 2.4, for each research priority (including carbon cycle, water cycle, predictions, rapid Arctic change, etc.), the Committee recommends that the USP:

- describe the societal needs and/or scientific research questions addressed;
- provide a brief, high-level overview of the current state of knowledge, including major advancements produced by the Program that are related to each topic;
- outline benefits from the proposed research including specific products (e.g., data sets, model studies, publications, assessments/reports, maps, decision support tools) to be achieved in the near and long term;
- identify needed technical assets (data sets, analytical tools, field campaigns, models); and
- offer a listing of key collaborations with other national and international programs that will help to support its research agenda.

In Chapter 2 the Committee has discussed the identification of these priority areas in the draft USP. We propose that a small set of research challenges or topics should be identified and discussed, using the template above to enable readers to understand the societal needs/science questions, advancements, benefits/ deliverables, and the inputs/collaborations that are needed. These could evolve from USP to USP depending on emerging societal need and scientific opportunity and would call out priorities from among the ongoing research of the Program. The Committee realizes this will require significant effort and that therefore the USP may need to highlight a smaller number of priority topics for attention during the next phase of the Program. The Committee understands this to mean that other areas of ongoing research will continue as well, but not with the same level of attention to developing an integrated program linking societal needs/science questions, outputs, and required resources. Establishing this framework now will facilitate improved setting of objectives and tracking of progress in the future.

The comments below follow the structure of the draft for Goal 1. This is not a comprehensive review of the draft USP discussion but instead provides high-level comments in the areas that the committee felt were most important. More detailed (but more narrowly focused) line-by-line comments are included in Appendix D.

3.2 EARTH SYSTEM UNDERSTANDING (OBJECTIVE 1.1)

The draft USP highlights topics that seem to deserve greater investment in the next several years. In this section, the Committee examines the specific topics discussed in the draft USP; in subsequent sections the Committee comments more holistically on how each Objective is discussed in the draft USP.

Tipping points and thresholds: This section of the draft USP discusses new data sets related to climate thresholds that are available over "unprecedented temporal and spatial scales … utilized with more sophisticated modeling and theoretical understanding … providing improved insight into prediction and uncertainty analyses" (p. 14). No specifics are provided with respect to these accomplishments. Tipping points may be "surprises" in the Earth system response, but determining tipping points requires more than process research and experimentation. The potential for complex feedbacks is mentioned as a source of uncertainty for climate scenarios, but no specific research questions, deliverables, or research needs are discussed. Without some specificity, it is not possible to understand the work to be done under this heading. Two potentially illustrative examples are the idea of Arctic amplification of global climate warming and the teleconnections leading to long-lived weather patterns associated with the polar vortex (Francis and Vavrus, 2012, 2015). More problematic is that the text refers only to physical climate tipping points. Some of these are obviously important, e.g., understanding when grounded ice sheets have reached a point at which their collapse cannot be halted. But there is no mention of the problem of understanding threshold and tipping point responses in the wide variety of impact sectors of concern, and indeed in adaptation response strategies themselves. The polar vortex example again would provide an excellent vehicle

for such articulation of societal impacts. Additionally, there is now very limited understanding of the limits of adaptive capacity. The need to develop alternative adaptations is itself a type of threshold response.

Using Long Data Records to Understand Earth's Climate Variability: The focus of this area appears to be reanalysis and synthesis of instrumental and paleoclimate data to understand past climate variability. This has been an objective of the Program for over 20 years. The text nicely describes the character of the data sets and how they can be used to constrain variability in key features of the global climate, as well as challenges associated with developing related data free of biases. Reference is made to the importance of these data for attribution (the next topic). But it is surprising that recent specific accomplishments are not described, nor are any specific outputs or deliverables mentioned. What have we learned in this area of research that enables us to better understand how current climate is extending beyond past variability? What are the implications for our understanding of the evolution of some of the key climate features mentioned? How have those accomplishments informed next steps in the research portfolio?

In this context, examples could be identified that capitalize the Nation's investments in such long-term data sets, which are then used to empower new research. One prime example is the USGS archival stream gage time series with 850,000 station-years of data and real-time stream gage networks (~10,000 stations), as well as computational platforms for creating a broad suite of value-added research products (e.g., climate trend analysis, attribution studies of hydrologic response to land cover change) or user products (e.g., drought or flood alerts) (Castronova et al., 2013; Tarboton et al., 2011).

Attribution: The topic is well defined, but always presents a challenge to discuss. One issue with the discussion of this topic in the draft USP is that there is no sense of what the Program has learned about how to attribute natural or human influences on events such as the recent floods and heat waves mentioned. What specific products could be expected to result from this research, and what sorts of decisions might they be used to inform? When might these products be available, assuming availability of needed observations, modeling, or budgets? A brief discussion of the overall approaches (e.g., inductive versus deductive approaches), if not specific numerical techniques used to isolate human from natural variability and forcing, seems prudent for the USP to offer.

The Global Warming "Hiatus": This is "another timely, priority question" (p. 15) that has already spurred numerous USGCRP supported studies, mostly under the scientifically more precise label of inter-annual climate variability. The Committee agrees that research has not yet resolved the issue (e.g., Rajaratnam et al., 2015) and thus could constitute an excellent example of how the agencies could achieve focus and coherency of purpose on a major Earth system question. However, the write-up should summarize key relevant studies and discuss how the similarities and differences of their results have changed the nature of the questions or approaches used. The discussion could also include more on

the interplay of decadal oscillation, deep ocean warming, and wind patterns. Next steps in this area are relatively clearly articulated, but it seems to the Committee that it would be possible to identify some specific deliverables and ideas about what can be accomplished in the next 3-5 years given required resources. The Committee notes that another example to consider is research on the polar vortex—where a targeted challenge might be articulated, with results that could be anticipated within the remainder of the current Strategic Plan.

Rapid Arctic Change: This topic focuses on impacts of climate change in the Arctic, as well as the effects of Arctic change on the broader Earth system, including various extreme weather events. A number of specific topics are listed for emphasis related to permafrost, sea and land ice, interactions with nutrient cycles, etc. This discussion misses the importance of ocean-ice dynamics in glacier melt—a critical process that has not been incorporated into system models. Further, the text does not discuss any specific insights that have emerged from recent research, nor are any specific objectives stated. Usefully, the section mentions cooperation with a number of national and international programs and the opportunity presented by the U.S. chairmanship of the Arctic Council. Being more specific about the nature of these collaborations would bring out the ways in which they enable the USGCRP to leverage its own resources to advance the science.

Carbon Cycle and Ecological Modeling: This section contains an interesting discussion of integrated research to better understand the implications of human and natural factors on the carbon cycle, including such factors as emissions from energy used in water resources management. The carbon cycle portion of the write-up would be even stronger if it presented a few specific findings, for example, what has been learned about the relative contribution of urban areas to the regional carbon cycle, and how these advances are being made: Do they primarily stem from observations, inventory methods looking at energy and materials flows in/out of cities, or other approaches? Members of the Committee are aware that an update to the State of the Carbon Cycle Report is being developed. This would be an excellent opportunity to discuss the relationship between information needs and the science being conducted by the Program.

The ecological modeling discussion also needs additional specificity. How have recent advances improved understanding of rates of biodiversity loss or changes in genetic diversity? There is also a lack of discussion of ocean acidification and of bio-physical marine environments, especially the ocean rainforest-coral reef systems. Improved assessments of regional to local impacts are suggested as a result of development of improved sensors and testable ecological forecasts. What scientific or practical questions or problems will these improved assessments support?

Water Cycle Research: The discussion in the draft USP of water systems must necessarily provide by a broad overview, yet the report here is too synoptic and misses important points. The report highlights the issue of “wet and dry extremes,” with specific mention of drought, but curiously not of flooding. Mention should be made of the readiness of the USGCRP research agenda to translate research findings into the domain of water

infrastructure and water resource management through improvements in climate extremes and linked hydrologic system understanding, which to date is regarded as severely limited (NRC, 2011). The text discusses exclusively the issue of how climate change accentuates water cycle extremes, with no mention of other important human factors that dictate the nature of hydrologic extremes, for example, land use change or water management. In addition, there is no treatment of the issue of water pollution, which itself creates water scarcity from the standpoint of its usability. The USP should also discuss the observational underpinnings of water cycle studies, for example, the conjunctive use of satellite and in situ measurement (Famiglietti et al., 2015; Fekete et al., 2015).

Navigating challenges: This section raises two challenges, the first related to incorporating human dimensions research, and the second related to the surge in demand for high resolution climate data. The discussion of social sciences seems oddly placed, as the rest of Objective 1.1 is couched in natural science terms. A discussion of the role of social science in Objective 1.1 can of course grow out of the need to understand the links tying biophysical system behavior to human drivers or impacts, or to the need for social science in the development of decision support systems.

The demand for high-resolution data is important, and in other sections (e.g., Objective 1.2, "Models for Decision Making"), it is treated as a research topic in its own right. Certainly responding to requests for this information is a challenge, but at some place in the document, there needs to be a strategy for addressing it. For example, work at the regional climate centers suggests that for many requests for high-resolution data, the underlying decision would be better supported with other types of information. In order to understand potential changes in frequency of different types of extreme events, it may be more helpful to study the frequency of synoptic weather patterns associated with the extremes. A coherent response would involve research to better understand and catalogue needs and appropriate approaches for meeting them, as well as increasing provision of downscaling per se. Needs could be better addressed not only as modeling, but by tailoring climate information for use in impacts, adaptation, and mitigation research and decision making. Downscaling and modeling are only one part of the science needed for decision support. Because this issue is also relevant to Objective 1.2 and Goals 2-3, the USP might usefully consolidate the discussions that occur in these different sections into strategy to advance the science and meet user needs in one section, and then cross reference this discussion as needed.

3.3 SCIENCE FOR ADAPTATION AND MITIGATION (OBJECTIVE 1.2)

The draft USP begins its exposition of Objective 1.2 with a statement that its research should, in principle, cover a "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" (p. 18). The recent climate agreement in Paris has advanced the global consensus regarding climate change, with substantial implications for Objective 1.2.

Impacts and vulnerability have been a minor focus of the USGCRP to date. With the COP-21 accord, the commitment by individual countries to specific targets for mitigation of greenhouse gas emissions opens lines of research needed to help the United States and other countries meet their commitments. The five-year pledge and review cycle presents an opportunity for adaptive management, but it is unclear exactly what the base of scientific knowledge would need to be to support that process. In revising its draft and finalizing the USP, the USGCRP should be responsive to this need by increasing and broadening its plans for mitigation and adaptation-related research and decision support. In particular, there is a need to move from a mindset of "respond/adapt" to a more integrated "prevent/respond" mindset that recognizes the interactions among mitigation, adaptation, and impacts.

To date, the USGCRP, through Objective 1.2 of the draft USP that is focused on "Science for Adaptation and Mitigation," has devoted some effort to "advanc[ing] understanding of the vulnerability and resilience of integrated human-natural systems" (p. 12). The USGCRP has primarily focused on the evaluation of the impacts of climate change, and not on use-inspired research to inform mitigation decisions. While the existing portfolio of research is critical, it does not address the salient questions related to climate resilient pathways that combine both adaptation and mitigation actions. It may be time for the Program to broaden its science base to address climate-resilient pathways (including both adaptation and mitigation)—that is, how the Nation can best meet its mitigation targets while adapting to a changing climate. There is ongoing work to assess the best strategies for transferring the products of basic research into use-inspired applications (e.g., Allen et al., 2013; Bidwell et al., 2013; Rosenzweig et al., 2014).

An approach suited to the international setting now requires not only research on the benefits of mitigation, but also research (including social science) related to how mitigation targets can be achieved and at what cost (including comparisons with the costs of doing nothing). The Committee recognizes that the development of engineering technologies or approaches to reducing or capturing carbon emissions is conducted by various federal agencies and is outside the scope of the USGCRP. However, engineers often design the built environment and associated risk management systems, and there is an opportunity to more fully engage with the physical and engineering sciences communities as part of use-inspired research. For example, the USGCRP can use the results of the work by the agencies who do work on the development of engineering technologies to examine the set of mitigation options that are technologically feasible and to conduct research related to possible adoption of various alternatives. This could include research on costs of adoption, policy instruments to promote adoption (for example, carbon taxes, cap-and-trade, more stringent energy efficiency standards), barriers to adoption (including economic, social, and political barriers), and the relevant risks and tradeoffs involved. The current draft USP lacks any explicit plans for conducting or facilitating these types of research.

In addition, mitigation-related research and decision support requires better understanding of the drivers of future emissions, including economic and demographic forces (and the associated impacts on land use change). Developing effective strategies for limiting the magnitude of climate change and adapting to it requires an understanding of

likely trajectories of greenhouse gas emissions, and those trajectories are in turn dependent on the scale, content, and techniques of production used to support consumption, which are in turn influenced by individual and organizational decisions and by institutions. Understanding the complex dynamics that shape these trajectories gives a better sense of possible future emissions. Such understanding also can identify potential leverage points for mitigation.

A substantial and sophisticated literature has emerged to assess the relative importance of various driving forces at the level of nations. In parallel, a literature has developed around household decision making about energy, including the adoption of new technologies. This existing body of work provides a starting place for a more sophisticated assessment of the trajectory of emissions and albedo change, and can help identify non-linearities and potential surprises. Simple models, such as the Kaya identity (a CO_2-oriented statement of the IPAT identity that posits environmental (I)mpact is a function of (A)ffluence, (P)opulation, and (T)echnology), that assume direct proportionality between changes in drivers and stress on the environment cannot capture these dynamics. Thus research on drivers at levels ranging from the household to the nation is useful in evaluating the impact of existing trends, such as urbanization or shifts in consumption patterns. They can also underpin policies intended to reduce anthropogenic forcings. For example, recent research suggests that increases in renewable energy portfolios only partially displace conventional sources. A solid understanding of the degree of displacement is essential to understanding the impacts of policies to promote renewables. At the household level, a great deal has been learned about what factors influence energy decision making and how to design policies and programs that will be effective in shifting consumer energy demand. In the context of mitigation, cross-sectoral opportunities should more completely be identified, for example, how the costs of energy-for-water (e.g., pumping for a variety of applications) could be offset by water-for-energy (e.g., hydroelectricity production).

Greater understanding of adaptation is also needed. For example, the interplay of climate and development choices will be key determinants of the magnitude and pattern of future vulnerabilities and the resilience of communities to prepare for and manage risks. Therefore, it is critical for research to explore the range of future vulnerabilities, as described, for example, in the Shared Socioeconomic Pathways (O'Neill et al., 2014). In most cases, uncertainties in climate science are small compared with uncertainties about how future societies will evolve, what technologies will be available, what regulations will be promulgated, and other factors. Better understanding of the range of possible vulnerabilities can inform not just adaptation decisions, but the broader range of decisions that will be taken by communities and states; many of these decisions may be made with little attention to the implications of a non-stationary climate, but they will affect how vulnerability will evolve over coming decades.

In addition, the information needed for adaptation will vary across sectors and across regions. The USGCRP is moving to be more effective at providing that information, and several agencies have developed regional centers to help make global change research more useful (see Box 4.1). However, because of the diversity of demands for information that is context specific and decision relevant, it is inevitable that adaptation

will require social learning about networks (Frank et al., 2012; Henry and Vollan, 2014). Thus an important topic for further research is the way in which information relevant to adaptation flows on networks, how networks re-form as a result, and how trust in information is accrued or lost.

Finally, research related to mitigation and adaptation needs to recognize and account for the interactions among mitigation, adaptation, and impacts and the associated tradeoffs among these three. Accordingly, it could be useful to reframe the USGCRP's work on mitigation and adaptation using the Paris commitments or the Representative Concentration Pathways (RCPs), which represent alternative future scenarios regarding greenhouse gas emissions and resulting atmospheric concentrations (Moss et al., 2010). For example, for various targets or RCPs, the USGCRP could ask, "What will likely be the level of mitigation needed, how can that level be accomplished (including the specific policies or regulations that could be used), what does the target imply for adaptation (over temporal and spatial scales, and across sectors), and what are likely to be the residual impacts?" The amount of adaptation needed and the residual impacts with which the Nation will need to cope differ across different emissions scenarios. The results of this work could then be used, for example, to provide guidance to public agencies on setting mitigation and adaptation targets (including the five-year cycle of INDC commitments under the Paris agreement) and designing and evaluating the impacts of policies and programs. Clearly, this necessitates research from not only the biophysical sciences but also the social sciences, including behavioral and economic.

In its current form, the discussion of the draft USP related to Objective 1.2 lacks the broader, integrated approach discussed above, as well as details on specific research plans, and information about how priorities within this Objective were set, what they mean in concrete terms over the remainder of the Strategic Plan, and how they relate to the priorities under Objective 1.1.

The priorities that are included under Objective 1.2 are: (1) Models for Decision Making, (2) Resilience and Vulnerability Research, (3) Translational Research to Inform Adaptation and Mitigation Decisions, (4) Urban Opportunities for Adaptation and Mitigation, (5) Carbon Cycle Research, and (6) Methane Research. These priorities are within Objective 1 (Advance Science). As described in Section 3.1, for each priority issue the USP should cover several specific points (see list on p. 26 of this report. Instead, the draft USP provides general and often rather vague discussions of issues that fall under these priority areas. As an example, the draft USP ignores the whole biofuels question, which includes important water, climate, and landscape linkage issues that will feed directly into the Nation's climate mitigation strategies; biofuels are mentioned not a single time across the whole report. More generally, the draft USP conveys little about the specific research that will actually be done and what it might accomplish.

In addition, it is not clear how or why these priority areas were chosen and how they relate to priority areas under other objectives. For example, although carbon cycling is an important research area, it is not clear why basic science on carbon in coastal ecosystems is a priority area under Science for Mitigation and Adaptation. Objective 1.1 also includes a priority area on the carbon cycle. Are these priority areas linked or overlapping, or are they distinct? Likewise, a key part of the methane cycling priority area

is focused on measurements and observations for use in biogeochemical models, as well as processes governing natural methane emissions. Although there is reference to the "Strategy to Reduce Methane Emissions" in the President's Climate Action Plan, it does not appear that the USGCRP's research agenda includes research on strategies to reduce anthropogenic emissions of methane.

Furthermore, the logical distinction between the two priority areas "Models for Decision Making" and "Translational Research to Inform Adaptation and Mitigation Decisions" is unclear. The "downscaling" under the modeling priority area is presumably what is needed to support the decision making at the regional or more local levels alluded to under translational research. Similarly, the "translational scenarios" in the latter presumably reflect the "potential future conditions" in the former. More clarity is needed on these two objectives, how they relate to each other, and how they contribute to a research agenda designed to improve options for mitigation and adaptation.

In addition, because Objective 1.2 falls under "Goal 1: Advance Science", the focus of both of these areas should be on the USGCRP's research related to the process of decision making or the support of decision making, rather than the *use* or *translation* of research (which is the focus of Goal 2: Inform Decisions). The specific research that would be conducted under these two priority areas needs more clarification. Although the Update refers to expanding "efforts to assess what levels of broad scale mitigation are necessary to avoid a range of adverse outcomes" (p. 19), as noted above, framing decision support needs primarily in terms of damages to be avoided does not address the fundamental need for information about how to avoid those damages or how best to adapt to reduce residual impacts.

Likewise, assessing vulnerabilities (under the "Resilience and Vulnerability Research" priority area) is an important step for better understanding and managing the risks of a changing climate, but more than that is needed to inform decision making. As noted in the NAS report on *Climate and Social Stresses: Implications for Security Analysis* (NRC, 2013), a critical gap in effective adaptation planning is the limited long-term data on factors affecting vulnerability. Investments are needed in long-term data collection to improve understanding of how vulnerability changes over time, and the reasons for those changes. Another need is benchmarking of current capacities to prepare for and manage climate variability and change; evaluations of the future effectiveness of adaptation decisions will need a baseline against which to compare.

Overall, it is problematic that the draft USP discusses almost exclusively what information physical climate science can provide—not what science is needed more broadly to support adaptation or mitigation decision making (see examples on p. 22 ln 7, p. 33 ln 17, p. 38 ln 6, and several other instances listed in Appendix D). Although there is text on adaptation, and descriptions of the importance of adaptation to ensuring the resilience of the Nation, these are not integrated with the discussions of climate science. Nearly every instance of "science, data, information, and knowledge" refers to physical climate science. This perspective informs much of the text, giving the overall impression that facilitating adaptation is primarily a matter of providing more and better information on projected changes in weather patterns to decision makers (also see Boxes 2.2 and 2.3). Note there is only one mention of adaptive management in the document (page 48); this

key issue is not discussed in the text on adaptation. It would be valuable to ensure the text focuses not just on what is needed in service to the Nation in a broader scientific context.

There is another line of research that would supplement the existing portfolio of work on adaptation and mitigation. In the draft USP the Program invites comments on the topic of climate intervention. The Committee's response is in Box 3.1.

BOX 3.1 Climate Intervention

In 2015 a committee of the National Academies of Science, Engineering, and Medicine raised an important issue regarding global change research: the potential national and global significance of studies to illuminate climate intervention—that is, deliberate human attempts to modify the Earth system so as to respond to unintentional climate change, a field also known as "geoengineering" (NRC, 2015c, b). The Academies' committee drew a distinction between two different approaches to climate intervention: carbon dioxide removal (CDR) and changes in the planetary albedo. Proposals to intervene in the Earth system, so as to deliberately exert human influence, have been discussed for decades (NRC, 2015a, b) but there has been no national-scale research effort to understand geoengineering as a systemic intervention. There have been studies relying on climate models, which are summarized in NRC (2015c, b), but these do not provide a sufficient understanding of interventions that might be undertaken. The report of that committee specified the USGCRP as a sensible point of leadership and coordination for federal research in this arena; this Committee agrees.

Questions relating to climate intervention include the technology and the environmental and climate impacts associated with different approaches, research areas that would fall within the mandates of individual federal agencies. However, climate intervention also raises a much broader set of issues, including issues related to relative risk assessment, risk perception, and international and global governance. In those respects, particularly, the USGCRP is well-positioned to take the lead as an integrating and coordinating interagency body for climate intervention related research, if such a research program is initiated.

The knowledge that seems most likely to be valuable to society in the coming decade concerns the system-level impacts of intervention approaches so that the public and decision makers can gain a scientifically informed sense of possible surprises ahead, as well as the potential benefits and costs of such approaches. Further, the governance challenges of climate intervention (particularly albedo modification) suggest that research on its social and institutional dynamics will be important to the national interest. In all these respects, the USGCRP provides a venue to assure that the needed studies are undertaken, with support from the federal government as well as other sources both public and private, so that the limited resources available will yield useful and timely results. In addition, USGCRP should play a leadership role in making sure that the U.S. government determines a path forward for governance.

A sensible program of research on climate intervention must explore a diverse portfolio of approaches because of the large uncertainties about whether any particular approach would work, how it would be implemented, and the institutional processes needed if a deliberate intervention in the Earth system is to be a responsible act of stewardship. Such a research program could in time require resources at a level that would force difficult tradeoffs within the USGCRP and among its member agencies. That possibility is one the scientific community will want to monitor as the idea of climate intervention is considered.

3.4 INTEGRATED OBSERVATIONS (OBJECTIVE 1.3)

The discussion of Objective 1.3 in the draft USP takes up observations of the biophysical components of Earth system and not the human dimensions. Thus, the section needs to be renamed or should incorporate the social science observations that are in place or needed.

Geoscience research requires physical, chemical, and biological observations. When studying a changing environment observations must be sustained over long periods of time. Shorter observational periods are appropriate in some cases for specific process studies.

Given the importance and financial requirements of long-term observing, it is essential that progress be documented in terms of the scientific understanding gained as well as the decision-support information that is provided via various types of observing platforms, sensors, and networks. The draft USP is vague on what has been maintained, what observing systems have been re-tooled, and what new observing systems have been put in place. The section discusses many opportunities that might be transformative, but it is not clear how priorities will be established among these opportunities. There is also no discussion of data informatics and progress towards easy depositing and retrieval of data. Is there really a need from the user community for raw data? And how will citizen science observations be quality-controlled and incorporated into a data information system?

The section on "Leveraging International and National Partnerships" includes a long list of coordinating mechanisms, which are repeated in the international section. Nothing is stated about what is being coordinated with these groups or how coordination is occurring or is reflected in the Program's priorities.

3.5 INTEGRATED MODELING (OBJECTIVE 1.4)

The update of research on integrated modeling would be more informative if reorganized to follow more closely the description in the Strategic Plan. As now drafted the selection of topics seems random, and thus the text does not emphasize how the research serves the stated objective: to "Improve and develop advanced models that integrate across the physical, biological and human components of the Earth System . . ."

The discussions of progress in spatial and temporal resolution and integration with observations are devoted to the physical models. Outside the mention of AgMIP there is no coverage of efforts on integration with chemical and biological systems. What efforts as have been under way should be included. Also, much of the physical-model detail in these sections, important as they are, should be taken up under Objective 1.1. The summary of this work is more usefully organized under a general heading of "Model Complexity," emphasizing the results that are key to understanding the links to chemical, biological, and human phenomena. The achievements in downscaling and multiple scales of temporal resolution are mentioned only briefly. In the same vein, the discussion of MIPs would be better if it focused on how they (or which ones of them) contribute to a better understanding of the integration of components of the climate system.

In its coverage of Earth and human systems the text does not reflect the attention given to this objective in the Strategic Plan. In the Maintaining Directions introduction, the draft notes that the USGCRP "includes" model development in this area, rather than declaring it a main objective. Moreover, the Progress section does not reflect the depth of existing work, and the Challenges description omits consideration of difficult tradeoffs in integrated model development; it should also include a discussion of priorities.

The opening section on Progress on Human and Earth Systems declares that the USGCRP is only "beginning to enrich" models in this area, and the following text fails to credit over 20 years of effort in this area, with achievements worth mention under the current Plan. Much of this work has been under the Integrated Assessment Research Program of DOE/BER/CESD, but also in the research programs and outreach efforts of NSF, USDA/ERS, EPA, and other agencies. Instead, the text points to advances in carbon modeling, work with the CMIP ensemble, and collaboration on a health report. To be more informative of the current state of this work, the Update needs to summarize the research to date on the integration of emissions drivers and policy cost, as well as climate effects on energy, land use change, agriculture, health, and water systems, carried out with representations of the physical climate system ranging from simple temperature balance models to EMICs to AOGCMS.

A main focus of the section on Navigating Challenges is the integration of human systems, and the Update would be enriched by discussion of two additional challenges. First, there has been much discussion between the USGCRP and the NAS of the fact that the changing landscape of the U.S. climate research effort includes increasing demands for information by stakeholders dealing with complex choices regarding adaptation and mitigation. Should this development suggest a change in focus among integrated modeling efforts, or even among broader USGCRP priorities?

Second, properly representing uncertainty and the limits to current knowledge is a crucial aspect of descriptions of human and environmental vulnerability and efforts to inform choices of adaptation. The discussion would benefit if it addressed the concern, clearly stated in the Strategic Plan, that the increases in model complexity, praised above, make it more and more difficult to quantify uncertainty in model results. This dilemma raises a question about priorities in the strategy of integrated model development, and the Committee believes that current thinking on the question should be summarized in this section.

Finally, the USGCRP's first Climate Modeling Summit (draft USP box, p. 27) cites the first in a series of meetings being planned to focus on models for decision makers. Participants in such a meeting should be extended beyond the six U.S. CMIP-scale modeling centers to include researchers on environmental and human interactions with the climate, and it should address these two additional challenges, as recommended in previous reports (NRC, 2012).

3.6 INFORMATION MANAGEMENT (OBJECTIVE 1.5)

A useful, cumulative program of research requires effective archiving and efficient access to data. Indeed, in many areas of science, substantial progress in fundamental understanding has come from improved management of large volumes of data in ways that make it accessible to an expanded community of researchers. In some research communities, such as the social sciences, there is a history of community data archives that stretch back more than half a century, and both community norms and requirements of funding agencies insure that data is readily available for reanalysis. In other communities, the tradition of data archiving and research based on analysis of shared data is less well developed. The Committee commends the efforts of the USGCRP to move towards improved archiving of and easy access to data useful for global change research. We offer the following specific suggestions regarding this Objective.

First, data archiving and access mechanisms should be designed with the users of those data sources in mind. The update does not discuss who the USGCRP sees as users for its efforts over the next three years, nor how those users will be consulted and called upon to evaluate and refine current efforts. In a similar vein, the draft USP does not offer examples of the ways the data being made available over the next three years are likely to be used. Unless the data system is designed with users in mind and is based on ongoing feedback from them, there is a high risk of building a sophisticated structure that gets little use. It is possible that the uses over the next three years are understood and users are engaged in advising the design of the system, but this was not clear from the draft. To be sure, one advantage of easy access to high quality data is that unanticipated lines of research emerge. But the possibility of serendipity is not a substitute for planning for specific uses with specific users.

Second, it is not clear how the effort is learning from long standing successes (and failures) in large scale data archiving and access initiatives. Nor was it clear how the effort underway will be evaluated over the next few years, nor what would be seen as success. It is also not clear what the next set of priorities will be, nor even how they would be determined once the efforts described are successful. That is, it would be helpful to anticipate the planning that will be undertaken to support what will be proposed in the next triennial update.

Third, while the discussion of social science data was welcome, it is not clear what data is likely to be incorporated and why. Given the long history of community data archives in the social sciences, there may be opportunities to be grasped both in terms of mechanisms for making data available and in the data itself. The Committee notes in passing that while concerns with confidentiality are of course important, social science data from federal agencies and other researchers are nearly always provided in forms that have already been vetted to protect confidentiality. While there may be cases where new protocols are needed, many of these issues have been worked out.

Fourth, there are several ongoing data initiatives worth mentioning because of their implications for strategic evolution in this objective. For example, the NOAA-National Water Center has data provision responsibilities of a kind that will provide valuable learning. ("Scientists at the Center will collaboratively research, develop and deliver state-

of-the-science national hydrologic analyses, forecast information, data, decision-support services and guidance to support and inform essential emergency services and high-value water management decisions." [NOAA, 2015]). In addition the hydrological science consortium CUAHSI is building a hydrologic information system that uses and creates value-added products from agency data sets and may provide an interesting path for testing federal-private partnerships. The Committee also notes that, given the importance of adaptation to the USGCRP, it is surprising that there is no discussion of the need for data on vulnerability that can be used for both assessment and for planning.

Chapter 4: Review of Decision Support Objectives and Plans

The 2012 Strategic Plan increased attention to developing and providing usable information. This was an important act of leadership, providing a way for the USGCRP to recognize and address a growing set of national needs for knowledge about global environmental change. The Program has made major progress in a short period of time, especially including the innovations achieved in the NCA. The Committee believes that the USP should build on these advances so that a productive and vibrant research enterprise can continue to stimulate discovery and support applications as the Nation addresses the changing circumstances brought by a climate that is no longer stationary and a world that continues to be dynamic in many dimensions.

The Committee believes that the grouping of Goals 2-4 in the draft USP (Chapter 3, pp. 31-32) is a sign of the evolution of the Program's approach to decision support that recognizes the connections among informing decisions, assessments, and education/communication. As discussed in section 2.1 of this report, as a set, Goals 2-4 signal that "advancing understanding" is to be implemented in a fashion that informs decisions, supports assessments, and provides a foundation for education and training. While it is important that the Program clearly states its commitment to all three sets of objectives, and each area has unique opportunities and challenges, all of the areas share things in common as well, as described in the draft USP. From the Committee's perspective, these three goals require development of knowledge (including about the processes of effective decision support) and a variety of mechanisms that expand the USGCRP beyond its traditional role of facilitating conversations within the scientific community to include spanning the boundary between scientific research and its users, both in and beyond the federal government. They also require evaluation and adaptive learning, not only within each area, but also across them with regard to their common elements. What is being learned about engagement and communication in the assessment process that can also be applied in improving decision support and educational materials? How can the assessment process be used to synthesize knowledge being gained in the many decision support activities underway in different sectors and regions? What workforce or other needs are identified that can help prioritize development of educational materials useful in training climate-savvy professionals in engineering, architecture, public health, and other fields? To realize the full potential of grouping these objectives together, the Committee recommends that the USGCRP develop mechanisms that promote adaptive learning across them. This does not mean, however, that the Committee is suggesting that the emphasis on these three topics be reduced. They are all at relatively early stages of development or in important transition (e.g., to a sustained, distributed assessment process) that requires continued prioritization if objectives are to be met.

The remainder of this chapter starts with a brief discussion of the need for research on decision support, as well as providing decision support as described in Goal 2 (see section 2.6 above for discussion of a broader range of opportunities for integrating social science in the USGCRP). The chapter then provides reactions and recommendations related to each of Goals 2-4.

4.1 RESEARCH ON DECISION SUPPORT AND ASSESSMENT PROCESSES

Decision support systems and tools are being developed for users in many sectors and regions. Some of these, such as many of those assembled in the Climate Resilience Toolkit (https://toolkit.climate.gov/) provide climate information to those who need it to assess vulnerability or plan adaptation. Others portray potential impacts related to specified changes in climate (e.g., drought, flooding) and processes such as sea level rise. Still others seek to support stakeholders in evaluating consequences of impacts for operation of infrastructure, for the economy, and for communities. Decision support in its various forms, including assessments, is a complex process that depends on high-quality science that includes information on uncertainty and levels of confidence. It also depends on knowledge of a variety of psychological, social, institutional, and other dimensions of the human context in which the information is used. In the 10-year Strategic Plan and the draft USP, the USGCRP commits to developing the knowledge required for effective decision support. It describes the Program's commitment to integrating social science research needed for decision support. But it has yet to articulate a clear and focused agenda for social science research needed to understand what distinguishes effective decision support in different contexts.

The NCA's chapter on Decision Support (Moss et al., 2014) identifies elements of this agenda, described relative to the different phases of an idealized adaptive risk management process that includes (1) framing the decision and information needs, (2) discovering and coproducing information, (3) integrating values, science, and other contextual factors, (4) deciding and implementing, and (5) monitoring, learning, and reviewing decisions and decision support. Each stage of any adaptive management process includes different challenges that must be considered in effective decision support. The Committee believes that the USP should begin to move the USGCRP toward a more specific description of social science research that will support evaluation of decision support tools and systems. Articulating the research agenda would advance some of the generalities mentioned (effective practices, lessons learned, etc.). The agenda also should provide concrete approaches for integrating social, behavioral, and economic science to support effective decision-making processes and to understand how different tools/systems affect decision-making processes and outcomes. This includes research in psychology, sociology, economics, etc. that evaluates how different tools/systems affect decision-making processes and outcomes (Moss, 2015).

This is not only a social science agenda but also involves research in climate and other natural sciences to develop tailored information about climate and other global change phenomena for decision support. Downscaling of climate model simulations, for

example, is often described (including by decision makers) as the key to improving decision making. But in some cases, this is not the best approach for providing the information decision makers actually are seeking (see discussion in section 3.2 of this report). Research that mines large archives of climate model data to determine frequency of occurrence of different threshold events or the synoptic conditions that give rise to them may provide information more useful for some types of decisions. Additional research on information tailoring, as well as work with engineers, architects, and other professionals to understand the information required for their modeling, analysis, design, and other activities, is also needed as a component of this agenda.

4.2 INFORM DECISIONS (GOAL 2)

As evidenced by the impacts of recent extreme weather and climate events, there is a critical need for science to inform decisions on adaptation and mitigation. As suggested above, the Committee sees in the draft USP a growing realization that the USGCRP has an important role to play in boundary spanning. In this section, we explore ways in which the USP discussion of this goal could serve as an opportunity to clearly articulate a research agenda, not just about research needed to improve decision making, but also research to understand what makes some decision support tools and approaches more effective than others. For example, heatwave early warning systems save lives, but can fall short of their potential (see Box 2.2). In this case, research is needed on effective approaches to encourage appropriate social and behavioral change.

Another research direction needed to support decision-making processes is better understanding of which components of successful decision support tools and approaches are unique to a particular context and which components can be transferred from one location to another. For example, the significant personal commitment of Mayor Michael Bloomberg was an important driving force in developing and implementing adaptation programs and projects in New York City. Better understanding is needed of the human and financial resources, capacity building, and political will needed to replicate this elsewhere.

It could be helpful to highlight the fact that decisions create path dependencies that could increase or decrease future vulnerability, depending on the magnitude and pattern of climate change. Understanding these path dependencies is important if decisions are going to continue to be effective with additional climate change.

Research also is needed on how individuals and societies can better prepare for and manage residual impacts that will be too costly or too difficult to eliminate. And, as illustrated in the recent extensive flooding in the Midwest, increased understanding is needed of how to better manage consequences, including mental health, of climate-related impacts.

As noted in the discussion of Objective 1.2, research is needed to develop baselines of current capacities in decision making and implementation against which progress can be measured; this effort includes deciding what information should be captured and monitored. The text refers to using results of evaluations of decision-support

activities to inform future activities, but does not describe the social science research needed to guide these evaluations, or who is going to do so. Further, it would be helpful to clarify what activities are planned with respect to developing metrics and guidance on scales and uncertainties and who will undertake these activities.

The substance of the Maintaining Direction sub-section is good, but the role of the member agencies is not clear, obscuring the real contribution of USGCRP. Interactions with users occur primarily through the agencies' existing networks of constituents. USGCRP can play a key role in synthesizing questions being asked, in a form that can guide work on Goal 1 across the government. USGCRP also can promote clearer, more coherent discussions of risk and vulnerability, so that stakeholders working with different agencies receive consistent and helpful perspectives and guidance on scientific knowledge and uncertainties. Including a brief discussion of the roles of the agencies would benefit this section.

The Navigating Challenges sub-section is very general; it talks about viewing Earth and human systems "holistically" without saying how, promises to improve engagement without specifics, and states that USGCRP will build on joint identification of research needs to target research and knowledge production without indicating what priorities are emerging. The "threat multiplier" example in this sub-section is useful. It is worth noting, in addition, that an important contribution of USGCRP lies in understanding and communicating opportunities in which a specific agency-focused research enterprise provides benefits beyond the scope of the agency's perceived mandate. Studies of wetland function in the coastal zone, for example, have contributed to understanding the way that natural functions of coastal ecosystems bring economic benefits and protection to human communities. The broader lesson is that global change research does not have to be comprehensive or integrated to bring significant social benefit.

The final sentence makes an extremely important point about needing to develop information and products to enable stakeholders to self-organize and apply the information for their particular needs. There also is a need to describe underlying research on boundary processes and science of decision support (or include these matters in Goal 1 as research); this is not just a matter of implementing boundary processes but understanding how they work and how to improve them. This provides motivation for moving to the sustained assessment in the next section.

The text suggests there has been limited progress in integrating social and behavioral research for informed decision making since the 2012 plan. If that is the case, then it would be helpful to explicitly state so and to outline steps that will be taken to ensure that the needed research will be accomplished (see section 2.5 of this report for more extended discussion). The Committee discusses concrete examples of where USGCRP could make progress on this issue through the various federal agency sponsored regional climate centers in Box 4.1.

Boundary organizations are a work in progress, both in practice and in academic research. Unlike conventional mission-driven organizations, boundary organizations connect communities of different cultures and goals—not with the aim of making them more alike, but rather with the aim of sharing understandings in a way that will benefit both science and users, while preserving their respective strengths. Much boundary work

BOX 4.1—Regional Climate Centers

The document is essentially silent on the various regional entities that several federal agencies have developed to make climate change information more useful, some of which are fairly new. There is an opportunity for USGCRP to facilitate communication and coordination across agencies through the work done in these regional entities and to help ensure the whole is greater than the sum of the parts. A detailed inventory of programs and activities of these regional centers would help facilitate communication and collaboration. It would also be useful for the USGCRP to convene thematically and/or geographically organized meetings of the centers. Such activities would help justify the value of the multiple regional centers by demonstrating how they work together across agency boundaries and also how their missions are distinct. There is a natural experiment underway with the various approaches for engaging with decision makers being employed at the regional centers. Assessing these various approaches would allow a great deal to be learned about the most effective methods of providing climate science and ultimate climate services.

The diverse set of federally funded regional climate centers, while varied in the details of their mission and in their capabilities, have a common underlying motivation. They are all intended to make scientific information more useful for decision making around adaptation, thereby reducing vulnerability and increasing resilience. Only a few of these centers have social science capability (Some of the NOAA RISA centers are an exception in that they emphasize social science as an equal partner with physical and ecological science, and other centers also incorporate social science.) Since social sciences study decision making, and there is a growing social science literature on how to make science more useful for decisions making (e.g.,Fischhoff and Kadvany, 2011; Gregory et al., 2012; Manski, 2013; Morgan, 2014; NRC, 2008), it makes sense that the regional science centers should be drawing on social science in the design of the interactions with decision makers and that these interactions in turn be studied as experiments in how to make climate science useful. However, the lack of social science capability at many centers precludes taking advantage of this opportunity to improve both program design and basic knowledge. One way around this might be a competition for projects explicitly designed to engage social science in the work of the regional centers. This might involve partnerships among regional centers, where some centers can bring in social science capacity, or partnerships between regional centers and social science capacity at universities or other research organizations. Such a competition might be structured as a joint activity of NSF and mission agencies. This type of cooperative research funding competition has been carried out successfully in the past.

takes place through networks (Bidwell et al., 2013). Although the rise of social networks via the internet has spawned a vigorous research effort (e.g., Henry and Vollan, 2014; Lessig, 2001), what it means for a boundary spanning network to succeed, and how best to accomplish this, are understood to only a limited degree (see Austin & Seitanidi [2012b; 2012a] for a review of related research).

That means that the pursuit of Goals 2-4 is a source of questions that need to be tackled by the research community. An example, noted earlier, is the opportunity to analyze the experience of regional climate centers to test different models and missions for reaching Goals 2-4 at a regional level. In a similar vein, the regional climate centers are organized into networks, some of which are more tightly coupled than others; the

USGCRP accordingly has an opportunity to study these networks, with the aim of understanding what kinds of cross-agency and cross-sector collaborations advance the national interest in Goals 2-4. This is use-inspired research with the aim of advancing understanding of use-inspired research. The Committee believes a small budgetary commitment could accomplish a lot within the remaining years of the Strategic Plan. The USP is an appropriate place to indicate the interest of the USGCRP and its member agencies in pursuing such a research theme.

4.3 CONDUCT SUSTAINED ASSESSMENT (GOAL 3)

Although the Third National Climate Assessment (NCA3) completed in 2014 has been a major accomplishment of the USGCRP since 2012, the path forward towards a sustained assessment process from NCA3 has been obscure. A special report on sustained assessments (Buizer et al., 2015) was completed and provided to the Agencies by the National Climate Assessment Development and Advisory Committee (NCADAC), but there has not been a systematic response from the Program regarding these recommendations, and the treatment in the draft USP is uneven, making it difficult for the Committee to understand the status of the sustained assessment. The NCADAC special report identifies four critical elements of sustained assessments: (1) establishing mechanisms to support enduring collaborative partnerships; (2) making progress on a number of scientific foundations; (3) providing coordinating infrastructure; and (4) diversifying the resource base and setting priorities. As critical elements (3) and (4) pertain to implementation and are beyond the scope of the Committee's expertise, our report will focus on the first two needs.

As described in the sustained assessment report, establishing and maintaining relationships with external communities will facilitate science translation at scales at which actions are being taken, identification of new research needs, and advances in working collaboratively to co-produce usable science. Importantly, the report points out that the benefit of expanding and maintaining these partnerships is that it has the potential to encourage local jurisdictions, universities, the broader research community, and others such as private voluntary organizations and for-profit firms to assume an increasingly active role in applying USGCRP-produced data, models, decision-support tools, reports, and other products in synthesis and analysis that meets their own needs. The draft USP does not describe progress or next steps related to this key challenge in the sections devoted to this objective of the 2012 Strategic Plan. Given the centrality of this issue, the Committee recommends that the USP address this matter directly or indicate how the Program will do so in the future. We note that much of the information on sustained assessment in the USP refers to preparation of specific special reports, such as the recent assessment of health and climate impacts. These are important to achieving the assessment role mapped out in Goal 3 of the Strategic Plan. However, as the box on p. 36 of the draft USP makes clear, the essential character of sustained assessment is to move beyond production of reports as the primary mechanism for interaction with users. It

would be useful for the USP to set objectives and commit to tracking progress in this regard.

There is a discussion of NCANet and a commitment to continuing it, which is very positive. But NCANet, for all its benefits as a communications network, was not evaluated as a tool for engaging stakeholders outside the government, and relying on it as a stakeholder engagement mechanism might or might not be an efficient use of resources. The draft USP is unclear as to who the stakeholders are that the USGCRP envisions as being especially important in sustained assessment. This is a long-standing challenge for national programs, especially finding an appropriate balance between federal stakeholders, non-federal governmental stakeholders, and private stakeholders. How the USGCRP is going to find this balance is very important, but the Update is silent as to the Program's thinking on this score.

There are several specific challenges in the draft USP's discussion of Goal 3: Conduct Sustained Assessments. The first is the apparent disconnect between the box at the very beginning of the chapter, which outlines four objectives that the USGCRP presumably is committing to, and the text, which does not follow the objectives of the box. Much of the information that would be required to address the objectives seems to exist, but it is difficult to identify from the draft USP what the USGCRP will actually do to implement Goal 3. The text in the draft USP indicates the USGCRP will continue to manage the U.S. participation in IPCC processes, and perhaps other international scientific assessment processes (biodiversity is mentioned, but it is not clear what process is meant by this brief reference). There are references to assessment reports arising in response to particular interests or when scientific information has matured. This portrays a process that relies on a series of special reports along with a quadrennial update. But many important questions are left unanswered in this model; among them is how the decisions will be made about which topics and reports will merit such attention, how stakeholder communities will be involved, what the balance will be between providing information relevant to a range of decision making, who the actors are likely to be, and what the review and communication mechanisms are going to be. Another key issue is in processes used for production of special reports. This was an issue with the Sustained Assessment Products of the former Climate Change Science Program, where agencies used dramatically different processes to conduct, review, and communicate the results of their topical assessments. This is another aspect of production of special reports that the Committee believes the USP should briefly address.

It is important to be very clear about these issues, as the transparency and credibility of the assessment processes depend on them. The draft USP refers to a Federal Advisory Committee for Sustained Assessment, and the Committee is aware that the Program has asked for nominations. The Committee encourages the USGCRP to move forward in establishing an advisory mechanism to assist in establishing the critical elements needed for sustained assessment.

The text box under Goal 3 includes a commitment to evaluation. The Committee commends the Program for holding a workshop and issuing a report describing its approach to evaluation. We did not have sufficient time (nor the mandate) to review these evaluation plans but recommend that the scope of the evaluation be reviewed in light of

the USP and this review to ensure the full range of issues requiring evaluation is addressed.

With respect to providing the scientific foundations for sustained assessment (the second critical element described in the NCADAC sustained assessment special report), the USP devotes a fair amount of attention to the development of scenarios. The Committee views this as a positive development, as preparatory reports for NCA3 (Moss et al., 2011) and earlier evaluations (Morgan et al., 2005) have pointed to deficiencies in preparation and use of scenarios in prior assessments. Scenarios were a relatively minor feature of the NCA3, as it focused primarily on current impacts and response strategies. Future discussion of this issue in the next USP would be stronger if there were an evaluation to draw upon to ground the Program's next steps.

Other topics such as indicators are mentioned in the draft USP, but their connection to the assessment process is undefined. The original proposal for indicators from the NCADAC committee in the NCA3 process emphasized that they would provide a baseline from which future change could be evaluated in sectors of interest and importance to a variety of stakeholders. By not including this issue, the USGCRP is missing an important opportunity to connect observations and research to user communities, thus missing a potential benefit of these program components.

Other key scientific foundations, such as specific attention to methods for vulnerability/risk assessment methods, valuation methods, approaches for incorporating international influences and impacts (discussed elsewhere in this review), and methods for uncertainty characterization and confidence communication, seem central to progress in Goal 3. The Committee encourages the Program to address specific objectives for these scientific elements in the future.

Recommendation 8: The Committee recommends that the USP discussion of Goal 3 (sustained assessments) more clearly articulate the Program's efforts to sustain relationships with user communities, provide a wider range of products or services, and develop the scientific foundations for assessment.

4.4 COMMUNICATE AND EDUCATE (GOAL 4)

The objectives for Goal 4 are appropriately ambitious for a Strategic Plan. However, the objectives would be more targeted to the needs of the Nation if they included the range of information needed by users, ensured the information communicated is understandable and useful, and supported multi-disciplinary training of the next generation of leaders and scientists. The resilience of the United States to shifting climate variability and changing climate would be facilitated by considering not just communicating information, but aiming to increase knowledge of climate change, the risks associated with changing weather patterns, and actions that could be taken by individuals, communities, states, agencies, and civil society to reduce and manage those risks. Further, for communication to be effective, there need to be institutions and

organizations with sufficient capacity, human and natural resources, political will, etc. to act on the information provided.

As noted in the comments on the other goals, the needs of the Nation are not just to understand basic information about climate variability and change, but also to understand factors that could increase (or decrease) exposure to those events, and effective actions to increase capacities to manage exposures and reduce vulnerabilities. Flexibility in decisions would be enhanced by understanding effective approaches for incorporating uncertainties and evaluating possible path dependencies. For example, communicating that warmer air temperatures means more heavy precipitation events does not necessarily translate into effective actions.

The examples provided in Maintaining Directions are helpful but lack specificity, so it is not possible to evaluate the importance actually given to this goal. Some indication of the magnitude of the cited activities and measure of their effectiveness would be helpful.

The descriptions under Building on Progress describe what the USGCRP or the agencies can do, but say little about what they will do, making it unclear whether commitments have been made to accomplish the objectives. One theme missing from the discussion is identification of the information needed by users; the text primarily focuses on what information the USGCRP can provide. The processes by which scientific knowledge is generated, repurposed and/or distorted for particular ends constitutes a legitimate, though understudied, arena of global change research and recent analysis. Vörösmarty et al. (2015) suggest that the process of communicating science to public and private sector stakeholders could be substantially improved through investments in systematic, interdisciplinary research, both theoretical and applied. Social and behavioral science research can make significant contributions to understanding of what data and information are needed to inform decisions, and to improve decision-making processes, to improving communications, and in moving from providing information to increasing knowledge. Among these needs are approaches for measuring the effectiveness of communications.

As noted in the introduction to Goal 4, dialogue with stakeholders is critical for effective communication. One could debate whether putting assessments on websites and counting the number of hits is an appropriate metric of usefulness or outreach. It would be helpful to have more information on how USGCRP and the agencies are supporting non-federal communities of practice. It also would be helpful to understand the extent to which the information contained in the various NCAs have informed decision making and with what result.

One objective is to cultivate the scientific workforce, but the only activity listed is training the federal workforce. What about training the next generation of interdisciplinary scientists and decision makers?

The Navigating Challenges section is primarily a list of research needs. Most of these paragraphs would be more appropriate in Building on Progress, along with indications of how these research gaps will be filled. Several of these paragraphs address points raised above, such as understanding the needs, motivations, and learning styles of

stakeholders, or training the next generation of interdisciplinary scientists. It is not clear why an interagency task force on communication cannot be formed.

The last paragraph states that USGCRP efforts over the past decade resulted in many positive results. Some illustrative examples would be helpful. As noted in comments on the other goals, there is inconsistency across the goals in what points are raised under the sub-headings.

4.5 INTERNATIONAL COOPERATION (CHAPTER IV)

The Committee has been following the Future Earth initiative, and we regard it as an emergent international research program. It may provide a useful arena for coordination for some USGCRP agencies, but the broad U.S. mandate implied in the Global Change Research Act should not be constrained by any particular international research initiative. The Committee is deeply concerned about the singular focus of the draft USP on Future Earth when there are many international organizations involved in climate change that are not part of Future Earth activities. It is the sense of the Committee that a more multi-organizational approach will be required to be successful.

There are already ongoing international research activities in the USGCRP programs and the Committee believes that those should be supported and better highlighted in the USP, in particular the collaborations required to maintain the international observation systems, which are crucial to improving the science. In addition, the Committee recommends that specific collaborations with other nations and international research programs be included in the description of specific research priorities (see Section 3.1). Lastly, the Committee also believes that the work within the USGCRP Strategic Plan should be expanded to include research support for U.S. involvement in international negotiations and agreements, especially in light of the recent Paris Agreement.

Chapter 5: Concluding Comments

The draft Update to the Strategic Plan (USP) takes up the goals of the Strategic Plan in three sections: Goal 1, Goals 2-4, and international activities. The Committee observes that the grouping of Goals 2-4 is sensible, and that it points to a significant learning of the Program since 2012. What is being learned should be included in the Strategic Plan via the USP.

We see in the draft USP evidence of increasing tension between the need for answers to a broadening range of scientific questions and limited budgets and agency capabilities. Historically, the USGCRP was rooted in the physical sciences of climate dynamics. Advances along this line of science have generated new research questions and will no doubt continue to do so. These essential questions deserve attention and research funds. In particular, some of the observational and research initiatives of the Program have required long-term support, and it is a continuing challenge to balance long-term investments against emerging new demands.

Climate-related events, many of them anticipated by an increasingly sophisticated climate science, have brought additional scientific questions to the fore that have not previously been central to the USGCRP's research portfolio and that also deserve attention and research funds. As evidenced in the draft USP, these include questions about the costs and benefits of various mitigation and adaptation options and how best to achieve their objectives; about the feasibility, costs, and benefits of options for climate intervention; about the multiple stresses a changing climate and other global changes put on ecological and socioeconomic systems; about ways to better inform decision making in the face of climate change and uncertainties about its specific future consequences; and about the processes of decision support and what makes some decision support tools and approaches more effective. These developments call for better engagement and integration of multiple additional branches of science into the USGCRP, particularly the social sciences. The need for answers to this broadening range of scientific questions is pressing against tight budgets and limited engagement of some of the relevant sciences within the research programs of most USGCRP agencies.

The draft USP deserves credit for identifying many increasingly pressing scientific needs and for proposing to address them. The Committee does note, however, that some of these needs have been identified in previous strategic planning documents, but the USGCRP budget has not reflected any major changes in emphasis. The budgetary trajectory of the USGCRP, with few and limited exceptions, is best described by the laws of inertia: Good intentions for change have gone largely unrealized. The increasing tension between the Program's traditional research priorities and emerging scientific needs requires more explicit attention in the strategic planning process. Within a tight budget, tradeoffs will be required. We do not see the tough choices addressed in the draft USP.

The Committee also sees in the draft USP a growing and unresolved tension between the dual roles of the Program as it has evolved. One is its original, classical role as a coordinator of science programs on global change among the agencies. The other is

the growing responsibility of the USGCRP to assure that boundaries are spanned between the research community and a wide variety of user groups both within the federal government and beyond. To an important degree the Program is playing a role as a boundary organization itself, one that is attempting to provide actionable science, for example in the National Climate Assessment. The Program needs also to catalyze research on the processes that foster successful boundary spanning. It is not surprising that these tensions are unresolved—the institutional experiment is playing out in real time. But the USP needs to be clear that this is one of the challenges that the USGCRP faces as it matures, and as the Nation faces both increased climate impacts and more and more urgent decisions about adaptation, mitigation, and perhaps in time climate intervention.

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Appendix A: Statement of Task for This Report

The Advisory Committee will conduct an independent review of the U.S. Global Change Research Program's draft update to the strategic plan (USP). The Advisory Committee's review will take place concurrent with public review. The Advisory Committee will address the following questions about the draft update:

1. Does the USP adequately document the status of USGCRP efforts to achieve the goals and objectives laid out in the Strategic Plan for responding to the Nation's needs for information on climate change and global change, their potential implications, and the potential effects of different response options?
2. Does the USP appropriately identify areas where USGCRP should continue to put emphasis, as well as areas that require increased attention? If the USP identifies any new areas of emphasis or areas needing increased attention for the USGCRP, are these topics and the efforts identified for approaching them appropriate for the Program?
3. Does the written document describing the program effectively communicate with both stakeholders and the scientific community?

Appendix B: Overall Charge for the Advisory Committee to the U.S. Global Change Research Program

An expert committee will provide ongoing and focused advice to the U.S. Global Change Research Program (USGCRP). The committee will be broadly constituted to bring expertise in all the areas addressed by the multi-agency, multi-dimensional USGCRP and will be supported by expertise housed in many units across the National Research Council. The committee will, over time, organize ongoing discussions, take on specific tasks, and issue reports.

In its role as a single entry source of contact to the National Research Council and source of strategic discussion with appropriate experts, the Committee to Advise the U.S. Global Change Research Program will:

1. Provide ongoing, integrated advice to the USGCRP on broad, program-wide issues when requested. This began with a review of the 2011 USGCRP Strategic Plan, will include other tasks such as a review of the National Climate Assessment (NCA) and evaluation of USGCRP progress toward its Strategic Plan objectives.
2. Provide a forum for informal interaction between the USGCRP and the relevant scientific communities.
3. Provide a forum for exchange of experience and insights for integrating across science communities and improving linkages between officials of the Program and the science communities.
4. Improve the internal coordination across existing and future NRC entities related to global change (including coordination across NAS, NAE, and IOM).
5. Help identify issues of importance for the global change research community. This implies a proactive role that goes beyond simply responding to requests from the USGCRP.
6. Interact with and help USGCRP with its international activities, such as shaping the future of relevant international global environmental change programs.
7. In addition to producing NRC reports as tasked, the committee may help develop other work requests and ensure that they are conducted by the appropriate NRC units in a collaborative fashion.

Appendix C: Committee Biographies

Warren M. Washington (NAE, Chair) is a Senior Scientist at the National Center for Atmospheric Research (NCAR). He has published more than 150 papers in professional journals and co-authored a book entitled, An Introduction to Three-Dimensional Climate Modeling. He has served on the National Science Board (chair, 2002-2006), the NOAA Science Advisory Board, President's National Advisory Committee on Oceans and Atmosphere, several panels of the National Research Council, the Secretary of Energy's Advisory Board, among others. Washington areas of research are in the development and use of climate models for climate change studies. He has also served as President of American Meteorological Society and a member of the AAAS Board of Directors. He is a member of the National Academy of Engineering, American Philosophical Society, and the American Academy of Arts and Sciences. He has received many awards, including the Le Verrier Medal of the Societe Meteorologique de France, the National Weather Service Modernization Award, and the AMS Dr. Charles Anderson Award. He has honorary degrees from the Oregon State University and Bates College, University of Massachusetts, Amherst. In 2010 he was awarded the National Medal of Science by President Obama.

Kai N. Lee (Vice Chair) is the Rosenburg Professor of Environmental Studies, emeritus, at Williams College. He retired in 2015 from the David and Lucile Packard Foundation, where he led the Science program for eight years. He taught at Williams College from 1991 to 2007 and he directed the Center for Environmental Studies from 1991 to 1998 and 2001 to 2002. He also taught from 1973 to 1991 at the University of Washington in Seattle. He is the author of *Compass and Gyroscope* (1993) and coauthor of *Our Common Journey* (NRC, 1999) and *Humans in the Landscape* (2012). He is a National Associate of the National Research Council. He was a member of the National Academies Roundtable on Science and Technology and served as vice-chair of the National Academies panel that wrote Informing Decisions in a Changing Climate (2009). Earlier, he had been a White House Fellow and represented the state of Washington as a member of the Northwest Power Planning Council. He was appointed in 2009 to the Science Advisory Board of the EPA. He holds a Ph.D. in Physics from Princeton University and an A.B., Magna Cum Laude in Physics, from Columbia University.

Doug Arent is Executive Director of the Joint Institute for Strategic Energy Analysis at the National Renewable Energy Laboratory (NREL). He specializes in strategic planning and financial analysis competencies; clean energy technologies and energy and water issues; and international and governmental policies. In addition to his NREL responsibilities, Arent is Sr. Visiting Fellow at the Center for Strategic and International Studies. Arent was recently appointed as a Coordinating Lead Author for the 5th Assessment Report of IPCC. He is a member of Policy Subcommittee of the National Petroleum Council Study on Prudent Development of North America Natural Gas and Oil Resources, and the American Academy of Arts and Sciences Steering Committee on Social Science and the

Alternative Energy Future. Arent served from 2008 to 2010 on the National Academy of Sciences Panel on Limiting the Magnitude of Future Climate Change. Arent is, a Member of the Keystone Energy Board and is on the Advisory Board of E+Co, a public purpose investment company that supports sustainable development across the globe. He served on the Executive Council of the U.S. Association of Energy Economists from 2008 to 2010. Prior to coming to his current position, Arent was Director of the Strategic Energy Analysis Center at NREL from 2006 to 1010. Prior to joining NREL, he was a management consultant to clean energy companies, providing strategy, development and market counsel. Dr. Arent has a Ph.D. from Princeton University, and an MBA from Regis University.

Susan K. Avery took office as President and Director of the Woods Hole Oceanographic Institute in 2008. She holds a Master's in Physics and a Doctorate in Atmospheric Science from the University of Illinois. Avery was on the faculty of the University of Colorado at Boulder from 1982 to 2008, most recently holding the academic rank of Professor of Electrical and Computer Engineering. Her research interests include studies of atmospheric circulation and precipitation, climate variability and water resources, and the development of new radar techniques and instruments for remote sensing. She also has a keen interest in scientific literacy and the role of science in public policy. She is the author or co-author of more than 80 peer-reviewed articles. A Fellow of CIRES since 1982, Avery became its Director in 1994. In that role, she facilitated new interdisciplinary research efforts spanning the geosciences and including the social and biological sciences. She spearheaded a reorganization of the institute and helped establish a thriving K-12 outreach program and a Center for Science and Technology Policy Research. She also worked with NOAA and the Climate Change Science Program to help formulate a national strategic science plan for climate research. Recently she served on two NRC panels: One produced a decadal plan for earth science and applications from space, and the other provided strategic guidance for the atmospheric sciences at the National Science Foundation. Avery is a Fellow of the Institute of Electrical and Electronics Engineers, the American Association for the Advancement of Science, and of the American Meteorological Society, for which she also served as President. She is a past chair of the board of trustees of the University Corporation for Atmospheric Research.

Arrietta Chakos is a public policy advisor on urban resilience, working on community resilience strategies and multi-sectoral engagement. Her work with the Association of Bay Area Governments focuses on disaster and climate resilience planning with 101 cities and nine counties in the San Francisco Bay Area. The regional program focuses on development of common resilience policies and implementation measures sponsored by the Federal Emergency Management Agency and the 100 Resilient Cities Initiative launched by the Rockefeller Foundation. She is a member of the Resilience Roundtable at the National Academy of Sciences and chairs the Housner Fellow committee at the Earthquake Engineering Research Institute. Ms. Chakos served as research director at the Harvard Kennedy School's Acting in Time Advance Recovery Project. She worked extensively in local government to direct innovative risk mitigation initiatives,

intergovernmental coordination, and multi-institutional negotiations at the City of Berkeley, California.

Peter Daszak, President of EcoHealth Alliance, is a leader in the field of conservation medicine and a respected disease ecologist. EcoHealth Alliance is a global organization dedicated to innovative conservation science linking ecology and the health of humans and wildlife. EcoHealth Alliance's mission is to provide scientists and educators with support for grassroots conservation efforts in 20 high-biodiversity countries in North America, Asia, Africa, and Latin America. Nine years ago, Dr. Daszak became the Executive Director of EcoHealth Alliance's Consortium for Conservation Medicine (CCM), a collaborative think-tank of institutions including Johns Hopkins Bloomberg School of Public Health, The University of Pittsburgh Graduate School of Public Health, The University of Wisconsin-Madison Nelson Institute for Environmental Studies, Tufts Cummings School of Veterinary Medicine Center for Conservation Medicine, and the USGS National Wildlife Health Center. The CCM is the first formal inter-institutional partnership to link conservation and disease ecology. Dr. Daszak's research has been instrumental in revealing and predicting the impacts of emerging diseases on wildlife, livestock, and human populations. He is originally from Britain, where he earned a B.Sc. in zoology and a Ph.D. in parasitology.

Thomas Dietz is Professor of Sociology, Environmental Science and Policy, and Animal Studies at Michigan State University, where he was founding director of the Environmental Science and Policy Program. His current research examines the human driving forces of environmental change, environmental values and the interplay between science and democracy in environmental issues. He is a Fellow of the American Association for the Advancement of Science, and has been awarded the Sustainability Science Award of the Ecological Society of America, the Distinguished Contribution Award of the American Sociological Association Section on Environment, Technology and Society. He has served on numerous National Academies' panels and committees and chaired the Committee on the Human Dimensions of Global Change and the Panel on Public Participation in Environmental Assessment and Decision Making. He holds a Bachelor of General Studies degree from Kent State and a PhD in Ecology from the University of California at Davis.

Kristie L. Ebi is a Professor in the Department of Global Health and in the Department of Environmental and Occupational Health Sciences, University of Washington; a Guest Professor at Umea University, Sweden; and Consulting Professor at Stanford University and George Washington University. She conducts research on the impacts of and adaptation to climate change, including on extreme events, thermal stress, foodborne safety and security, waterborne diseases, and vectorborne diseases. Her work focuses on understanding sources of vulnerability and designing adaptation policies and measures to reduce the risks of climate change in a multi-stressor environment. She has worked on assessing vulnerability and implementing adaptation measures in Central America, Europe, Africa, Asia, the Pacific, and the United States. She is co-chair with Tom Kram (PBL, The Netherlands) of the International Committee On New Integrated Climate change

assessment Scenarios (ICONICS), facilitating development of new climate change scenarios. She was Executive Director of the IPCC Working Group II Technical Support Unit from 2009 -2012. She was a coordinating lead author or lead author for the human health assessment for two U.S. national assessments, the IPCC Fourth Assessment Report, the Millennium Ecosystem Assessment, and the International Assessment of Agricultural Science and Technology for Development. Dr. Ebi's scientific training includes an M.S. in toxicology and a Ph.D. and a Masters of Public Health in epidemiology, and postgraduate research at the London School of Hygiene and Tropical Medicine. She edited fours books on aspects of climate change and published more than 150 papers.

Baruch Fischhoff (IOM) is Howard Heinz University Professor, in the Departments of Social and Decision Sciences and of Engineering and Public Policy at Carnegie Mellon University, where he heads the Decision Sciences major. A graduate of the Detroit Public Schools, he holds a BS in mathematics and psychology from Wayne State University and an MA and PhD in psychology from the Hebrew University of Jerusalem. He is a member of the Institute of Medicine of the National Academies and is a past President of the Society for Judgment and Decision Making and of the Society for Risk Analysis. He chaired the Food and Drug Administration Risk Communication Advisory Committee and the National Research Council Committee on Behavioral and Social Science Research to Improve Intelligence Analysis for National Security. He has been a member of the Eugene, Oregon Commission on the Rights of Women, the Department of Homeland Security Science and Technology Advisory Committee, and the Environmental Protection Agency Scientific Advisory Board, where he chaired the Homeland Security Advisory Committee. He has written or edited several books: Acceptable Risk (1981), A Two-State Solution in the Middle East: Prospects and Possibilities (1993), Preference Elicitation (1999), Risk Communication: The Mental Models Approach (2001), Intelligence Analysis: Behavioral and Social Science Foundations (2011), Risk: A Very Short Introduction (2011), Communicating Risks and Benefits: An Evidence-Based User's Guide (2011), Judgment and Decision Making (2011), Risk Analysis and Human Behavior (2011), and Counting Civilian Casualties (in press).

Nancy B. Grimm studies the interaction of climate variation and change, human activities, and ecosystems. Her long-term research focuses on how disturbances (such as flooding or drying) affect the structure and processes of desert streams, how chemical elements move through and cycle within both desert streams and cities, and how storm water infrastructure affects water and material movement across an urban landscape. A professor in the School of Life Sciences at Arizona State University, Grimm is director of the Central Arizona–Phoenix LTER program—an interdisciplinary study of urban social-ecological system sustainability by ecologists, engineers, physical and social scientists. She is co-director of a new Sustainability Research Network focused on resilience of cities and their infrastructure to weather-related extreme events (UREx SRN). She was president and is a fellow of the Ecological Society of America (ESA), is a fellow of the American Association for the Advancement of Science, and was a lead author for the 2nd and 3rd National Climate Assessments.

Henry D. Jacoby is the William F. Pounds professor of management (emeritus) in the Sloan School of Management and former co-director of the Joint Program on the Science and Policy of Global Change, both at the Massachusetts Institute of Technology (MIT). His work has focused on the integration of the natural and social sciences and policy analysis in application to the threat of global climate change. Previously, he served on the faculties of the Department of Economics and the Kennedy School of Government, both at Harvard University. He has also served as director of the Harvard Environmental Systems Program, director of the MIT Center for Energy and Environmental Policy Research, associate director of the MIT Energy Laboratory, and chair of the MIT faculty. He has an undergraduate degree in mechanical engineering from the University of Texas at Austin and a Ph.D. in economics from Harvard University.

Anthony Janetos is the director of the Joint Global Change Research Institute, a joint venture between the Pacific Northwest National Laboratory and the University of Maryland. Prior to this position, he served as vice president of the H. John Heinz III Center for Science, Economics, and the Environment. Dr. Janetos also directed the center's Global Change program. Before coming to The Heinz Center, he served as vice president for science and research at the World Resources Institute and senior scientist for the Land-Cover and Land-Use Change Program in NASA's Office of Earth Science. He was also program scientist for NASA's Landsat 7 mission. He has had many years of experience in managing scientific research programs on a variety of ecological and environmental topics, including air pollution effects on forests, climate change impacts, land-use change, ecosystem modeling, and the global carbon cycle. He was a co-chair of the U.S. National Assessment of the Potential Consequences of Climate Variability and Change, and an author of the IPCC Special Report on Land-Use Change and Forestry, the Fourth Assessment Report of IPCC, the Millennium Ecosystem Assessment, and the Global Biodiversity Assessment. Dr. Janetos recently served on the NRC Committee for the Decadal Survey for Earth Sciences and Applications from Space, and has been a member of several other NRC Committees, including the NRC Committee for Review of the U.S. Climate Change Science Program Strategic Plan, the Committee on Review of Scientific Research Programs at the Smithsonian Institution (2002), and the Committee on Ecological Indicators for the Nation.

Haroon S. Kheshgi is a Distinguished Research Associate at ExxonMobil's Corporate Strategic Research. He studied chemical engineering at the University of Illinois (Urbana, B.S. 1978) and the University of Minnesota (Minneapolis, Ph.D. 1983). He pursued research at Lawrence Livermore National Laboratory (1983-1986) before joining ExxonMobil Research and Engineering Company in 1986. At ExxonMobil Corporate Strategic Research his research addresses many aspects of global climate change including carbon cycle, detection and attribution of climate change, paleoclimate implications, and the mitigation of greenhouse gas emissions. He has contributed to the Intergovernmental Panel on Climate Change (IPCC) as lead author, contributing author, and review editor in the IPCC's last four assessment reports and its Special Reports on Carbon Dioxide Capture and Storage, and on Land Use Change. Recent activities have include chairing IPIECA's

Climate Change Working Group, the Society on Petroleum Engineering's Committee on Carbon Capture and Storage, and the first Carbon Management Technologies Conference of the Engineering Founder Societies. He is currently an Associate Editor of the journal Adaptation and Mitigation Strategies for Global Change, and a member of AIChE's Center for Energy Initiative Executive Committee, and has been member of the U.S. Carbon Cycles Science Steering Group, and NRC's Climate Research Committee and Board on Atmospheric Sciences and Climate.

Richard H. Moss is senior research scientist with the Joint Global Change Research Institute at the University of Maryland, visiting senior research scientist at the Earth Systems Science Interdisciplinary Center, and senior fellow with the World Wildlife Fund (WWF). He has served as director of the Office of the U.S. Global Change Research Program/Climate Change Science Program (2000-06), vice president and managing director for Climate Change at WWF (2007-09), and senior director of the U.N. Foundation Energy and Climate Program (2006-2007). He also directed the Technical Support Unit of the Intergovernmental Panel on Climate Change (IPCC) impacts, adaptation, and mitigation working group (1993-1999) and served on the faculty of Princeton University (1989-91). He was a coordinating lead author of Confronting Climate Change and Realizing the Potential of Energy Efficiency, led preparation of the U.S. government's 10-year climate change research plan, and has been a lead author and editor of a number of IPCC Assessments, Special Reports, and Technical Papers. Moss remains active in the IPCC and currently co-chairs the IPCC Task Group on Data and Scenario Support for Impact and Climate Analysis. He serves on the U.S. National Academy of Science's standing committee on the "human dimensions" of global environmental change and the editorial board of Climatic Change. He was named a fellow of the American Association for the Advancement of Science (AAAS) in 2006, a Distinguished Associate of the U.S. Department of Energy in 2004, and a fellow of the Aldo Leopold Leadership Program in 2001. He received an M.P.A. and Ph.D. from Princeton University (Public and International Affairs) and his B.A. from Carleton College in Northfield, Minnesota. Moss' research interests include development and use of scenarios, characterization and communication of uncertainty, and quantitative indicators of adaptive capacity and vulnerability to climate change.

Ian Roy Noble has spent 10 years with lead responsibility for the World Bank's activities in adaptation to climate change. He has also worked with the Carbon Finance Unit on emissions reductions through reduced deforestation and forest degradation. Before coming to the Bank in 2002 he was Professor of Global Change Research at the Australian National University. He has had senior roles in the IPCC process and in international cooperative research on climate change as part of the IGBP (International Geosphere Biosphere Program) including chairing the Global Change and Terrestrial Ecosystems for some years. An ecologist by training, he holds a PhD from the University of Adelaide, and his research interests cover animal behavior, vegetation and biodiversity management, ecosystem modeling, expert systems and the science-policy interface. In 1999 he was elected as Fellow of the Australian Academy of Technological Sciences and Engineering.

Margo Oge served the United States Environmental Protection Agency for more than 30 years from 1980 to September 2012. She is widely recognized as having been a key architect of the EPA's efforts to reduce air pollution and greenhouse gas emissions. During her recent 18-year tenure as Director of the Office of Transportation and Air Quality, Ms. Oge led the EPA's first ever national greenhouse gas emission standards for cars and heavy-duty trucks to double fuel efficiency by 2025, reduce GHG emissions by 50% and save consumers $1.7 trillion at the pump. In parallel, she also helped to establish the renewable fuels standard, which will significantly increase the volume of biofuels in our nation's fuel supply. These new rules are viewed as some of the most significant steps forward in improving the sustainability of the U.S. transportation sector. Ms. Oge earned her Master's Degree in Engineering from the University of Massachusetts, Lowell. She also attended George Washington University and the John F. Kennedy School of Government at Harvard University.

Kathleen Segerson is a Professor of Economics at the University of Connecticut. She was the Head of the Department of Economics from 2001 to 2005. Dr. Segerson specializes in natural resource economics, and in particular, the economics of environmental regulation. She is currently a member of both the Chartered Executive Board of the Environmental Protection Agency's Science Advisory Board, and the Vice Chair of the Advisory Board's Committee on Valuing the Protection of Ecological Services and Systems. She was a member of the U.S. General Accounting Office's Expert Panel on Climate Change Economics from 2007 to 2008 and frequently serves on external review committees for the U.S. Department of Agriculture. She has also served on three National Research Council study committees: the Committee on Assessing and Valuing the Services of Aquatic and Related Terrestrial Ecosystems (2002-2004), the Committee on the Causes and Management of Coastal Eutrophication (1998-2000), and the Committee on Improving Principles and Guidelines for Waste Resources Planning by the U.S. Army Corps of Engineers (2008- present). In 2008, she was named a Fellow by both the American Agricultural Economics Association and the Association of Environmental and Resource Economists. Dr. Segerson earned a PhD from Cornell University in 1984.

Kathleen J. Tierney is the Director of the Natural Hazards Research and Applications Information Center at the University of Colorado. Dr. Tierney is a Professor of Sociology and Director of the Natural Hazards Research and Applications Information Center at the University of Colorado. The Hazards Center is housed in the Institute of Behavioral Science, where Prof. Tierney holds a joint appointment. Dr. Tierney's research focuses on the social dimensions of hazards and disasters, including natural, technological, and human-induced extreme events. With collaborators Michael Lindell and Ronald Perry, she recently published Facing the Unexpected: Disaster Preparedness and Response in the United States (Joseph Henry Press, 2001). This influential compilation presents a wealth of information derived from theory and research on disasters over the past 25 years. Among Dr. Tierney's current and recent research projects are studies on the organizational response to the September 11, 2001 World Trade Center disaster, risk perception and risk

communication, the use of new technologies in disaster management, and the impacts of disasters on businesses.

Charles J. Vörösmarty is a Professor of Civil Engineering, a Distinguished Scientist with NOAA-Cooperative Remote Sensing Science and Technology Center and Director of The City University of New York's Environmental Crossroads Initiative at The City College of New York. His research focuses on the development of computer models and geospatial data sets used in synthesis studies of the interactions among the water cycle, climate, biogeochemistry and anthropogenic activities. His studies are built around local, regional and continental to global-scale modeling of water balance, discharge, constituent fluxes in river systems and the analysis of the impacts of large-scale water engineering on the terrestrial water cycle. He is a founding member of the Global Water System Project that represents the input of more than 200 international scientists under the International Council for Science's Global Environmental Change Programs. He is spearheading efforts to develop global-scale indicators of water stress, to develop and apply databases of reservoir construction worldwide and to analyze coastal zone risks associated with water diversion. He recently won one of two national awards through the National Science Foundation to execute studies on hydrologic synthesis. Dr. Vörösmarty also is on several national and international panels, including the U.S. Arctic Research Commission, the NASA Earth Science Subcommittee, the National Research Council Committee on Hydrologic Science, the National Science Foundation's Arctic System Science Program Committee and the Arctic HYDRA International Polar Year Planning Team. He also was on a National Research Council panel that reviewed NASA's polar geophysical data sets, the decadal study on earth observations, and is Co-Chair of the National Science Foundation's Arctic CHAMP hydrology initiative. He has assembled regional and continental-scale hydro-meteorological data compendia, including the largest single collection, Arctic-RIMS (covering northern Eurasia and North America).

Appendix D: Line-by-line Comments Submitted by Committee Members

Comments in this section were prepared by individual Committee members. These generally reflect more specific conceptual or editorial points.

Executive Summary

- P. 4, Para 1: Mention infestations spread (pine beetle), disease spread/vector changes, etc…not just physical and heat. How about ocean acidification?
- P. 4, Line 13 "Prepare for them" implies adaptation only, vs "prevent and prepare"?
- P. 4, line 21-24: Need to do more than observe, model, and understand a changing climate; there is a critical need for the Nation to be able to prepare for possible impacts.
- P. 4, Line 28: Only adaptation mentioned.
- P. 4, line 28: Scope of NCA seems to be limited to adaptation.
- P. 4, line 29-30: Any other data being made available?
- P. 5, line 14: It would be helpful to include a table of some key accomplishments in the executive summary.
- P. 5, line 19: And how could this information be used to support decision making?
- P. 5, Downscaling should be in line 21, not 22.
- P. 5, line 25: Who decides which models are appropriate (and how)?
- P. 5, What does "they" refer to in line 34.

Chapter 1

- P. 6-8: The introduction serves to recognize the many streams of contributions to the Strategic Plan, from across the government and beyond. If the intent it to reach a general reader, it would be helpful to add a box highlighting important components contributed by the 13 participating agencies. This would inevitably raise the profile of some efforts and ignore many others, but it would also leaven the complicated and often bureaucratic prose of the current draft—as valuable as that is for the internal purposes of the federal agencies.
- P. 6, line 17: Here it is stated that the Update alone is focused on climate, but some recognition of other the broader global change question is in order.
- p. 7, line 3-12: It would be helpful to more specifically describe how this information would inform decisions.
- p. 7, line 22: What does the ability to use seasonal climate predictions allow?
- p. 7, line 30-32: It would be helpful to link this with how this helps the Nation prepare for and better manage the risks of climate change.
- p. 8: line 1-3: Some illustrative examples would be helpful.

Chapter 2

- p. 9, line 25-28: Scope of "global change" limited to economy (not society) and natural resources (not nature or life-support systems) as affected by climate change (not other components of global change).
- P. 10, line 4: "Science can be harvested for decision support"—passive voice leaves unclear who is doing the harvesting. Use seems like the right concept here, and the user should be involved in identifying what is useful. A better wording might be "These foci set priorities for the Program, so as to advance the understanding of global change and to enable the Program to work constructively with users so that the emerging understanding informs decisions effectively."
- P. 10, line 25. Replace policy with decision.
- P. 11, line 6-44: Would be clearer to present as two bullet lists.
- P. 11, line 15-16: "USGCRP alone" is unclear. Does this mean that the federal global change effort (including individual agencies) cannot provide what's needed (e.g., because other nations' science is essential for downscaling)—or that USGCRP is inadequate but the federal government can do this?
- P. 11, 16-26: Plan could talk about resiliency, resilient pathways that account for adaptation and mitigation.
- P. 11, line 34-35: It could be helpful to identify some of the challenges.
- P. 11, Box: Is this the data needed for decision making? Why and how? One could argue the extent to which the climate and health report substantially advances understanding; it synthesizes published information.

Chapter 3

- P. 12, line 5: "Foster" is odd. How about "Build"?
- P. 12, line 7-8: Social science is necessary to do this.
- P. 12: Within this section (Goal 1) it seems like the NSF Water Sustainabiity & Climate Program, which hits several of these Objectives directly, could be cited as a prime example of recent USGCRP investments.
- P. 13, line 14: Seems very generic. Could the writing be more specific/substantiate the assertion?

Objective 1.1

- P. 13, line 42: The structure of the "Building On Progress" Sections, here and those that follow are not standardized and only partially link to the trio of issues (bullets on p. 10). Thus water is no systematically mentioned despite the expectation set-out on p. 10 (see Section 2.4 of this report).
- P. 13, line 47: What is meant by tipping point is not clear. Consider adding an example of a tipping point (end of an ice age?). Indeed, it might be better to put the discussion of thresholds after the subsection on long-term datasets, since it is those that define what a tipping point is.
- P. 14, line 2: The report needs to substantiate this...use an example or two.

- P. 14, line 35: A recognition here of USGS long-term stream gauge records seems relevant.
- P. 14, line 48-51: This sentence is particularly troublesome. For a decision maker who needs to adapt to a changing climate, why is it so important to understand human versus natural contributions? What seems to be missing in the discussion is the articulation of the change in thinking about how one characterizes attribution, i.e., to the probability of occurrence of events (heat waves, droughts, storms, precipitation extremes, etc.) in a warmer world compared to an early 20th century world. Discussion of this point can be more straightforward: which weather patterns can be attributed, in whole or part, to human-caused changes in climate?
- P. 15, lines 24-26: How is this different from the existing analyses? What additional value will it add?
- P. 16, line 4: Explain in a few words how carbon cycle and ecological modeling fit together.
- P. 17, line 17: Might wish to highlight investments in satellite systems (even if failed, e.g., SMAP) and USGS real-time and archival station data base.
- P. 17, line 35-47: Commendably open statement, though interest in social sciences seems to be aspirational still.
- P. 17, line 38: To the Committee's knowledge, there has been a de-funding of Arctic Social Sciences based on whims of Congressional oversight. This is certainly a challenge to be navigated. Some carefully worded text—sensitive to the politics in play—is nonetheless in order.
- P. 17, line 38-39: This could be highlighted in the executive summary.
- P. 18, line 5-6: Is there a typo here? "community and plot scale" does not make sense.
- P. 18, line 12: This seems like an odd add-on, the river basins modifier, that is.

Objective 1.2

- P. 18, line 18: Philosophically?
- Page 18; line 23: Global Change is more than just the carbon cycle.
- P. 18, line 27: What are the specific mitigation strategies that are resulting in intervention?
- P. 18, line 32: A statement is here needed on how to coordinate such research.
- P. 18, line 40-42: Why is this activity listed under mitigation? It's more of an impact
- P. 18, line 47-49: An example would be helpful.
- P. 19, lines 13-18: Give an example.
- P. 19, line 20: These are not models for decision making.
- P. 19; lines 28-33: Include mitigation in the decision sphere.
- P. 19; line 39: Again limited to adaptation responses vs more comprehensive.
- P. 19, line 41-44: At what scale?
- P. 19, lines 46-50: An example would be helpful.

- P. 20, line 7+ : This section could use a discussion of data needs, short-term to describe current vulnerability and long-term to understand possible future vulnerabilities.
- P. 20; lines 13-14: Why limited to adaptation decisions only?
- P. 20, line 25-28 / line 40-41: The Nation needs useful information, not just to have information that can be used. It could be helpful to discuss how communication can support informed decision making.
- P. 20, line 29: Indigenous knowledge is not really applied research.
- P. 20, line 40ff: Discussion of urban opportunities points to catalytic efforts by USGCRP. It would be helpful to bring out the added value of USGCRP in the earlier topical subsections on modeling and translational research.
- P. 21, line 10: Seems to ignore the whole biofuels question, which includes important H2O linkage issues. In fact biofuels is mentioned not a single time in the whole report.
- P. 22, line 1: Decision makers need more than climate information.
- P. 22, lines 11-13: Who are the decision makers? Throughout the document the report refers to decision makers but it is unclear as to who they are.
- P. 22, line 11-13: Good. Although this is a major focus of Goal 2, it's great to have this sentence.
- P. 22, line 19-22: What are the mitigation technologies? Why do we keep referring to mitigation technologies if the topic is outside the charter of the committee?
- P. 22, line 21: Somewhere in this section could be a mention of the analysis of "energy-for-water" and "water-for-energy."
- P. 22, line 40-42: ?? Should we be flagging things like this throughout and asking for public comment?

Objective 1.3

- P. 23, line 5: Human systems are more than land-use change (mentioned later in this section, such as page 28, line 32).
- P. 24, line 33-47: "Leveraging International…" includes a long list of coordinating mechanisms (that are repeated in the international section). Nothing is stated about what is being coordinated with these groups, or how coordination is occurring and is reflected in the program's priorities.
- P. 25, line 19: Both sustaining time series and developing partnerships (next paragraph) provide opportunities for social scientists to contribute to the work of USGCRP. Assessing the value of time series is a problem addressed in the economic theory describing the value of information. The social dynamics of partnerships, in which partners have differing commitments to continuity, precision, and accuracy of observations, is another area in which sociologists studying networks could make pragmatically valuable contributions.

Objective 1.4

- P. 26, line 19: Strangely, no nexus studies mentioned (energy-food-water-climate).

- P. 26, line 22-23: GCMs and ESMs are not the only members of the modeling community.
- P. 26, line 36: There is a tacit assumption that more resolution means better models. There certainly are contrasting views that hold that requisite process understanding to support work at that scale is lacking, as well as computational burden issues, etc.

Objective 1.5

- P. 29, line 3: No mention of the NOAA-National Water Center, which has data provision responsibilities. From their prospectus: "Scientists at the Center will collaboratively research, develop and deliver state-of-the-science national hydrologic analyses, forecast information, data, decision-support services and guidance to support and inform essential emergency services and high-value water management decisions."
- P. 30, line 6: Some recognition of non-governmental data consortia could be made here (CUAHSI-HIS [Hydrologic Information System]), which both uses and creates value-added products from agency data sets.
- P. 30, line 16+: Need for vulnerability data.

Goals 2, 3, and 4

- P. 31, line 29: "Easily accessible and useful" is a distortion of the spirit of actionable science. Typically, the knowledge needed to make a good decision is not obvious nor ready to hand. It must be found, often through co-production of (usable) knowledge.
- P. 31, line 29-32: Who are the decision makers/users?
- P. 31, line 44: Showing the integration with Goal 1 would be very helpful. Fundamental research is not just in climate science.
- P. 32, line 3: Just climate science?
- P. 32, line 32-34: Again, not just climate science.

Goal 2

- P. 33, line 3-25: This would be helpful framing in the Introduction.
- P. 33, line 17: Not just climate science needed for adaptation decisions.
- P. 33, line 21: Also, need to know about likely future socioeconomic stresses.
- P. 33, line 22-25: Expand as to what has been done to date
- P. 33, line 27ff: The substance of this paragraph is correct, but the role of the member agencies is not brought out, and that obscures the real contribution of USGCRP. Interaction with users occurs mainly through the agencies' existing networks of constituents. USGCRP plays a key role in synthesizing questions being asked, in a form that can guide work on Goal 1 across the government. USGCRP also promotes clearer, more coherent discussion of risk and vulnerability, so that stakeholders working with different agencies receive consistent and helpful

perspective on scientific knowledge and uncertainties. To bring out these USGCRP roles, the roles of the agencies should be discussed more, though briefly.

- P. 33, line 28-30: Expand as to what has been done to date.
- P. 33, line 35: Not just climate science.
- P. 34, line 5: Goal #1 had its Objectives explained in more detail under "Building on Progress". The report would benefit from some standardization. The headers here do no correspond to the Objectives of Goal #2.
- P. 34, line 25-28: This could be discussed in Goal 1.
- P. 34, line 48: Not just climate science translation.
- P. 35, line 4+: Challenges also exist in vulnerability science, including long-term data sets.
- P. 35, line 9ff: The "threat multiplier" example is a good one. It is worth noting, in addition, that an important contribution of USGCRP lies in understanding and communicating opportunities in which a specific agency-focused research enterprise provides benefits beyond the scope of the agency's perceived mandate. Studies of wetland function in the coastal zone, for example, have contributed to an understanding of the way that natural functions of coastal ecosystems bring economic benefits and protection to human communities. The broader lesson is that global change research does not have to be comprehensive or integrated to bring significant social benefit.
- P. 35, line 16-17: This is an example where the statement is vague as exactly what the plan is; statements like this are found throughout the report.

Goal 3

- P. 36, line 42: "Sequentially"? Isn't the point that the assessments will be done as the ripening of understanding warrants? One has the impression, reading the discussion of Goal 3, that the task of sustained assessment remains indistinct.
- P. 37, line 49-51: Other drivers, such as urbanization, also are needed (see SSPs).
- P. 37, line 6-16: It could be appropriate to take a more nuanced approach to describing the climate and human health report. Some chapters were primarily written by federal agencies, with limited engagement of the scientific community. This approach resulted in an uneven document. Also, the report summarizes published literature, not necessarily increasing understanding.
- P. 38, line 6-10: Not just climate science.
- P. 38, line 25: This subject keeps coming up (e.g., p. 34). If deemed important, it might merit its own Box graphic to highlight the need. Appearing repeatedly (but inconsistently) detracts from its presumed necessity.
- P. 38: line 46: Not just climate science.

Goal 4

- P. 40, line 5: How will stakeholders be engaged?
- P. 40, line 10: Not just climate literacy.

- P. 40, line 20: Same observation as before re: non-parallism under "Building on Progress" vis a vis this Goal's Objectives vs the headers that are given immediately below.
- P. 40, line 31-32 and 45-49: Basic research in sociology and international relations on a) knowledge formation and transmission through networks, and b) collaborative action among partners that retain their organizational identity and separate missions could contribute to the mission of USGCRP by improving understanding of co-production of knowledge (decision support). Such research, conducted via NSF and through applied programs in USDA, Interior, and NOAA, would be modest in cost but could yield benefits within the time frame of the Strategic Plan.
- P. 41, line 26: Seems "thin" compared to preceding sections of text.
- P. 41, lines 36-42: This is a very important area but don't see a specific recommendation. Could the report ask for public comments on this?
- P. 41, line 44-45: This is a challenge that could be highlighted in the executive summary.
- P. 42, line 7-8: Not just climate science.
- P. 42, line 13: The preceding paragraphs read as though there are immense needs, yet this paragraph suggests the solutions are already in place and working. Seems to me contradictory.

Chapter 4

- P. 43, line 15: Just say "organized under the aegis of the Earth System Science Partnership", including..."
- P. 43, line 36-38: The sentence is backwards. Consider: "International cooperation is an integral component of the four goals of the Strategic Plan. Global change science is global: the product of observations and deliberations around the world. As the nations of the world respond to a changing climate and other manifestations of global change, the international research enterprise has evolved toward Goals 2 and 3, in part as a reflection of continued American leadership in all four goal areas."
- P. 44, line 36-38: And what now?
- P. 44, line 37: There will also be an IPCC-like assessment process for biodiversity and ecosystem services (IPBES), through which the U.S. research establishment will make contributions.
- P. 45, line 8+: This section should discuss more than climate science.
- P. 45, line 24: One arena is the Arctic, and with the U.S. chairmanship of the Arctic Council (which reaches to the highest levels of gvts among the Arctic & observer states) there is at least some hope of creating a spirit of scientific collaboration, esp. involving otherwise potential adversaries in other arenas (read: United States and Russia). If not achievable in the short-term, science diplomacy could be used under the umbrella of the Arctic Council to facilitate international

scientific collaboration in this focus region of the USGCRP (as stated in this report—see p. 10).

- P. 45, line 46: How?
- P. 46, line 29: In this context, it seems now sensible to mention—and provide sufficient detail on—the new commitments associated with the Paris Accords on rich nation funding of climate adaptation and climate impact mitigation to assist the world's poor. This will have a direct impact on the international research portfolio.

Chapter 5

- P. 48, Box: This is the only mention of adaptive management in the document.
- P. 49, line 1-3: This basic pipeline structure does not work for the social sciences. It would be useful to acknowledge that in one of the many brief discussions of USGCRP's intent to engage more with social scientists and social science knowledge.
- P. 49, line 29-31: Are the indicators being piloted adequate to track vulnerability and adaptation effectiveness?
- P. 49, line 40: Presumably this must include a budget crosscut, not mentioned here.
- P. 50, line 11-24: This paragraph is not necessary to the Strategic Plan update.
- P. 50, line 40: Prepare for and respond.
- P. 51, line 22: Not just climate science.
- P. 51, line 42-43: "The USGCRP's interaction with stakeholders, and understanding of their needs, comes largely 42 through two avenues: via the agencies and through the National Climate Assessment." This good statement might be made much closer to the beginning of the report—perhaps in the initial introduction of Goal 2.
- P. 51, line 44: I understand how the NCA3 does so, but how do "the agencies" (as referred to here) feed the interests into the USGCRP planning process more generally than through the NCA (also mentioned in this way on page 52, line 5)?

Appendix E: Goals and Objectives in the 2012 USGCRP Strategic Plan

Goal 1—Advance Science—Advance scientific knowledge of the integrated natural and human components of the Earth system to understand climate and global change.

- Objectives:
    - 1.1 Earth System Understanding
    - 1.2 Science for Adaptation and Mitigation
    - 1.3 Integrated Observations
    - 1.4 Integrated Modeling
    - 1.5 Information Management and Sharing

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

- Objectives
    - 2.1 Inform Adaptation Decisions
    - 2.2 Inform Mitigation Decisions
    - 2.3 Enhancing Climate Services
    - 2.4 Enhancing International Partnerships

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.

- Objectives
    - 3.1 Scientific Integration
    - 3.2 Ongoing Capacity
    - 3.3 Inform Responses
    - 3.4 Evaluate Progress

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

- Objectives
    - 4.1 Strengthen Communication and Education Research
    - 4.2 Reach Diverse Audiences
    - 4.3 Increase Engagement
    - 4.4 Cultivate Workforce