A Review of the U.S. Global Change Research Program's Strategic Plan

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A Review of the U.S. Global Change Research Program's Draft Strategic Plan

Committee to Advise the U.S. Global Change Research Program

Board on Atmospheric Sciences and Climate
Division on Earth and Life Studies

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This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the NRC's Report Review Committee. 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:

Robert H. Corell, Global Environment and Technology Foundation, Arlington VA
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Thomas J. Wilbanks, Oak Ridge National Laboratory, Oak Ridge, TN
Steven C. Wofsy, Harvard University, Cambridge, MA
Richard N. Wright, National Institute of Standards and Technology (Ret), Montgomery Village, MD

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 Robert Frosch (Harvard University) and Susan Hansen (Clark University), appointed by the National Research Council, who 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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EXECUTIVE SUMMARY

Since its creation over two decades ago, the U.S. Global Change Research Program (USGCRP) has played an important role in coordinating the efforts of agencies and departments across the federal government that carry out a wide array of observational and research efforts related to global change, and especially climate change. Such efforts have led to major advances in our understanding of the changing global environment and the countless ways in which human society affects and is affected by such changes. In its new 10-year Strategic Plan, the USGCRP proposes to broaden the Program's scope in several directions. It is envisioned that with such an evolution, the Program can both continue to advance basic scientific understanding of global change and can actively support society's efforts to mitigate, adapt, and otherwise respond to those changes.

Building on its long tradition as an independent advisor to the USGCRP, the National Research Council (NRC) appointed a committee to carry out a review of the draft Strategic Plan (as part of its broader, ongoing role in providing whole-program advice to the USGCRP). In this review, the Committee offers an array of suggestions for improving the Plan, ranging from relatively small edits to large questions about the Program's scope, goals, and capacity to meet those goals. The key high-level messages of this review include:

- The Strategic Plan should offer a more coherent summary of past important accomplishments, including an assessment of successes that were possible only because of USGCRP actions and more explicit discussion about the potential value of future research.

- The proposed broadening of the Program's scope from climate change only to climate change and "climate-related global changes" is an important step in the right direction. The Program's legislative mandate is to address all of global change, whether or not related to climate. The Committee concurs that this broader scope is appropriate, but realizes that such an expansion may be constrained by budget realities and by the practical challenge of maintaining clear boundaries for an expanded program. We encourage sustained efforts to expand the scope of the Program over time, along with efforts to better define and prioritize what specific topics are included within the bounds of global change research. As the Program moves in this direction, a high priority is to assure that observing systems are designed to monitor a broad array of global changes, given that valuable information is being lost every year that such efforts are delayed.

- The proposed broadening of the Program – to better integrate the social and ecological sciences, to inform decisions about mitigation and adaptation, and to emphasize decision support more generally – is welcome and in fact essential for meeting the legislative mandate for a program aimed at understanding and responding to global change. Although this broader scope is needed, implementing it presents a grand challenge that should be met with more than just incremental solutions.

- An effective global change research enterprise requires an integrated observational system that connects observations of the physical environment with a wide variety of social and ecological observations. Such a system is a crucial foundation for identifying and tracking

global changes; for evaluating the drivers, vulnerabilities, and responses to such changes; and for identifying opportunities to increase the resilience of both human and natural systems. The Plan needs to describe a clear vision and specific objectives for adding and integrating new types of observations, along with a commitment to some concrete steps towards realizing this vision. The Plan also needs to present an appropriate governance structure and dedicated mechanisms to sustain existing long-term observational systems.

- The USGCRP and its member agencies and programs are lacking in capacity to achieve the proposed broadening of the Program, perhaps most seriously with regard to integrating the social and ecological sciences within research and observational programs, and developing the scientific base and organizational capacity for decision support related to mitigation and adaptation choices. Member agencies and programs have insufficient expertise in these domains and lack clear mandates to develop the needed science.

- In the Committee's judgment, it would be a mistake to postpone phasing in the newer elements of the Program (as is implied in the implementation section of the Strategic Plan). Rather, we suggest that the Program identify some initial steps it will take in the proposed broadening of scope –including steps to develop critical science capacity that is currently lacking and to improve linkages between the production of knowledge and its use. The Program's implementation plan should assign responsibilities and resources to specific entities to lead those efforts.

- The proposed broadening of the Program in the areas of education, communication, and workforce development needs more careful thinking, regarding which of these activities belong within the Program, which are best organized by entities outside the Program, and how the former will link to the latter.

- The Strategic Plan and/or the Implementation Plan to follow should establish clear processes for setting priorities and phasing in and out elements of the Program, especially in relation to the planned broadening of its scope. The USGCRP should employ iterative processes for periodically evaluating and updating the Program and its priorities, including processes for consultation with decision makers inside and outside the federal government, regarding the scientific knowledge about global change that would provide the greatest value for them.

- The USGCRP needs an overall governance structure with the responsibility and resources needed to broaden the Program in the directions outlined in the Plan, including an ability to compel reallocation of funds to serve the Program's overarching priorities. Without such a governance structure, the likely evolution of the Program will be business as usual: a compilation of program elements that derive from each member agency's individual priorities.

1
Introduction

The U.S. government supports a large, diverse suite of activities that can be broadly characterized as "global change research." Such research offers a wide array of benefits to the nation, in terms of protecting public health and safety, enhancing economic strength and competitiveness, and protecting the natural systems upon which life depends. The U.S. Global Change Research Program (USGCRP), which coordinates the efforts of numerous agencies and departments across the federal government, was officially established in 1990 through the U.S. Global Change Research Act (GCRA). In the subsequent years, the scope, structure, and priorities of the Program have evolved (for example, it was referred to as the Climate Change Science Program (CCSP) for the years 2002-2008), but throughout, the Program has played an important role in shaping and coordinating our nation's global change research enterprise. This research enterprise, in turn, has played a crucial role in advancing understanding of our changing global environment and the countless ways in which human society affects and is affected by such changes. Given the nation's current fiscal challenges, it is ever more important that our global change research enterprise advances as a strategically-driven, coordinated whole, rather than a collection of ad hoc, unconnected efforts at different federal agencies. Thus the need for a strong USGCRP is greater than ever.

The National Research Council (NRC) has served as a key advisor to USGCRP planning efforts since the Program's formation. Box 1 lists the previous NRC reports that have offered "whole program" advice to the USGCRP and CCSP (not including the numerous studies carried out during this time that focused on specific federal agency programs and activities).

BOX 1

Previous NRC "Whole-Program" Advice to the USGCRP / CCSP

- Research Strategies for the U.S. Global Change Research Program (1990)
- Global Environmental Change: Research Pathways for the Next Decade (1999)
- Planning Climate and Global Change Research: A Review of the Draft CCSP Strategic Plan (2003)
- Implementing Climate & Global Change Research: A Review of the Final CCSP Strategic Plan (2004)
- Thinking Strategically: The Appropriate Use of Metrics for the CCSP (2005)
- Evaluating Progress of the CCSP: Methods and Preliminary Results (2007)
- Analysis of Global Change Assessments: Lessons Learned (2007b)
- Restructuring Federal Climate Research to Meet the Challenges of Climate Change (2009)

Studies that were not specifically designed as guidance to the USGCRP but that have become important references:

- Informing Decisions in a Changing Climate (2009)
- America's Climate Choices (ACC): Synthesis Report (2011)
- ACC: Adapting to the Impacts of Climate Change (2010)
- ACC: Advancing the Science of Climate Change (2010)
- ACC: Informing an Effective Response to Climate Change (2010)
- ACC: Limiting the Magnitude of Future Climate Change (2010)

In mid-2011, a new NRC Committee to Advise the USGCRP was formed and charged to provide a centralized source of ongoing whole-program advice to the USGCRP. The first major task of this committee was to provide a review of the USGCRP draft Strategic Plan 2012-2021 (referred to herein as "the Plan"), which was made available for public comment on September 30, 2011. The Committee's Statement of Task is shown in Appendix A. The Task Statement questions are addressed in the sections that follow, to varying degrees. Some aspects of the Committee's charge proved to be challenging, because the Plan does not provide enough implementation details to allow us to fairly assess some of the questions asked.

This review was completed in a very short time (roughly eight weeks, concurrent with the public comment period for the Plan), which allowed the Committee to only touch upon numerous complex issues. Rather than providing section-by-section comments and line-by-line editing suggestions, the Committee felt it would be more valuable to focus instead on high-level concerns.

As part of its review, the Committee asked members of the NRC Board on Atmospheric Sciences and Climate (BASC) and its Committee on the Human Dimensions of Global Change (CHDGC), both of which have had long-standing advisory roles with respect to the USGCRP, to examine the draft Plan and offer their input to the Committee orally or in writing[1]. We have drawn on this input in writing the review, and some comments (in particular, detailed editing suggestions) are presented in Appendix C. These members' comments should be viewed as "supplemental" to the main committee's review. We felt it was best to convey these additional comments in their entirety, even though in some cases they overlap with points raised by the main committee.

The draft Plan proposes a significant broadening of the Program's scope from the form it took as the CCSP. As described in more detail later in this report, the Plan envisions a USGCRP that addresses not only climate change but also other climate-related (and human-caused) global changes. It also envisions a Program that would include a more broadly integrated system of observations; more fully integrate the social sciences; undertake scientific analyses related to mitigating and adapting to global changes; and pay greater attention to decision support,

[1] We thank, in particular, Anthony Janetos and Richard Moss, who served as liaisons with BASC and the CHDGC, respectively.

education, communication, and workforce development. All of these forms of broadening of the Program are entirely consistent with, and arguably are necessary for, achieving the purpose of the Program as set forth in the Global Change Research Act of 1990: to be "a comprehensive and integrated United States research program which will assist the Nation and the world to understand, assess, predict, and respond to human-induced and natural processes of global change."

The Committee thus feels that the USGCRP's goals are generally evolving in the right direction. This Plan reflects the substantial effort that the USGCRP leadership made to seek out and incorporate the views of the broader scientific community and the many stakeholder groups that this community seeks to serve. However, while the stated goals are appropriate, the Plan does not always acknowledge the true challenges involved in meeting those goals or offer clear strategies for how to those challenges can actually be addressed. And in an era of increasingly constrained budget resources, those questions of *how* will become paramount.

As discussed later in this review, issues of key importance to the Committee are the need to identify initial steps the Program will take to actually achieve the proposed broadening of its scope, to develop critical science capacity that is now lacking, and to link the production of knowledge to its use; and the need to establish an overall governance structure that will allow the Program to move in the planned new directions.

The Committee offers its support to the USGCRP for its important planning efforts, and we hope that the suggestions raised in the following sections will further strengthen those efforts.

2

Conveying the Importance and Value of Global Change Research

The Strategic Plan discusses the value of global change research in many places in the document – e.g., in the description of individual goals and objectives, in textboxes, and elsewhere in the body of the text – but there is no single place within the document that attempts to lay out the case for why this research is so important to society. We suggest it would make the Strategic Plan more compelling to provide a focused description of the many accomplishments to which USGCRP research has contributed. Some examples may include:

- improving the accuracy and lead times of seasonal climate forecasts,
- quantifying the residence times of ozone depleting and greenhouse gases,
- establishing that clouds and aerosols are the largest sources of uncertainty in modeling the response of the climate system to increasing greenhouse gases, and developing more realistic descriptions of their roles at the process level,
- developing coupled Atmosphere-Ocean General Circulation Models that have successfully simulated the global temperature record for the 20th century,
- demonstrating that changes in global mean temperatures over the past two centuries cannot be explained without anthropogenic greenhouse gas forcing,
- establishing measurement methods and carrying out the first measurements of global tropical deforestation,
- conducting the first experimental field tests of plant and entire ecosystem responses to enhanced concentrations of atmospheric CO_2,
- carrying out national assessments of climate change and its impacts,
- developing emissions scenarios and climate projections for the 21st century, for use in international climate model intercomparison studies and in the IPCC assessment reports.

Numerous additional examples of the successes of global change research can be found in previous NRC reports (e.g., ACC *Advancing the Science*) and in the USGCRP's own "Our Changing Planet" series. In general, the Plan could better articulate the fact that global change research has advanced our understanding of many processes that control the Earth system and the role that human activities have played in altering those processes. It could likewise describe how the Program has developed practical knowledge related to the interactions between natural and human induced changes in coastal environments, the hydrological cycle and water resources, agriculture, urban environments, public health, and land use.

By clearly highlighting such accomplishments, and indicating what accomplishments could only have been achieved by having a USGCRP structure in place, the Program can illustrate how it is helping the nation address issues of critical interest to a wide variety of stakeholders in both the public and private sectors. The Plan's current discussion of such matters is too scattered and vague to make a strong impression. This dilution is particularly problematic in regards to research areas that are relatively new or are being given greater emphasis in the new Plan (e.g., integrated modeling, incorporation of the social sciences, the scientific basis for adaptation and mitigation).

The Plan says that the decisions being made today about systems affected by global change are worth billions of dollars. This is both a drastic underestimate and an imprecise argument for establishing the importance of foundational research in adaptation and mitigation. The countless decisions that are being made – related to infrastructure, natural resource use, water management, agriculture, zoning, and development of our nation's energy system – could easily account for trillions, rather than billions, of dollars in investment in the coming decades. These decisions have the potential to be made more effectively with better knowledge and foresight about future global change, about ways to reduce the inherent vulnerabilities of these systems, and about the ways in which adaptation or mitigation efforts could affect these systems. The Plan does not articulate these sorts of arguments clearly or with sufficient documentation.

Key Message: The Strategic Plan should offer a more coherent summary of past important accomplishments, including an assessment of successes that were possible only because of USGCRP actions, and a more explicit discussion about the potential value of future research.

3
Global Change Versus Climate Change

The scope of the USGCRP has varied over time, particularly regarding whether it is only a *climate* research program, or rather, is a program to study *global change*. The U.S. Global Change Research Act (GCRA) of 1990[2], which established the program, mandates a broad definition:

> "Global change" means changes in the global environment (including alterations in climate, land productivity, oceans or other water resources, atmospheric chemistry, and ecological systems) that may alter the capacity of the Earth to sustain life. "Global change research" means study, monitoring, assessment, prediction, and information management activities to describe and understand
> - the interactive physical, chemical, and biological processes that regulate the total Earth system;
> - the unique environment that the Earth provides for life;
> - changes that are occurring in the Earth system; and
> - the manner in which such system, environment, and changes are influenced by human actions.

It must be acknowledged that the above definitions can be difficult to apply, in terms of deciding what specific kinds of environmental changes qualify as "global change" issues. The first NRC report on the topic, *Toward an Understanding of Global Change,* lists "rapidly evolving changes in the global environment [that] have captured the attention of scientists, policymakers, and citizens around the world: the increase of atmospheric greenhouse gases such as carbon dioxide, methane, and the chlorofluorocarbons; the expected consequent changes in global climate and sea level; global depletion of stratospheric ozone and the observed 'Antarctic ozone hole'; widespread desertification in many parts of the developing world; massive tropical deforestation and reduction in the diversity of plant and animal species; extensive damage to mid-latitude forests; and acidification of lakes and soils in many regions" (NRC, 1988). A later NRC analysis attempted to identify what these sorts of changes have in common, pointing out that they can include both systemic global changes in which actions initiated anywhere on Earth can have effects anywhere else (e.g., atmospheric chemistry) and cumulative global changes in which the accretion of localized changes in natural systems has worldwide effects (e.g., land productivity) (NRC, 1992).

Although the concept of global change is not precisely defined at the edges, and remains a matter of active debate, the GCRA clearly calls for a program that encompasses more than climate change alone. In 2002, however, the name was changed to the U.S. Climate Change Science Program, which implies a narrower scope. The new draft Strategic Plan for the program (once again called the USGCRP) defines a scope that is broader than climate change science, although not as expansive as the mandate given in the law. As stated in the Strategic Plan (L.242-248):

[2] http://uscode.house.gov/download/pls/15C56A.txt

> This 2012- 2021 Strategic Plan describes a program that builds from core USGCRP capabilities in global climate observations, process understanding, and modeling to strengthen and expand our fundamental scientific understanding of climate change and its interactions with the other critical drivers of global change, such as land-use change, alteration of key biogeochemical cycles, and biodiversity loss.

The Committee interprets this wording to mean that the Program will encompass climate change and its links to other aspects of the Earth system that contribute to or are affected by climate change, but will not encompass other global environmental changes (e.g., in land productivity or in biogeochemical cycles) except as they link to climate change. If this reading is indeed correct, then the Plan's definition of "global change" is not fully consistent with the definition in the Plan's glossary (taken from the GCRA), which treats changes in land productivity, ecological systems, etc. as integral to the program, even when they do not interact with climate change. The Plan's currently defined scope could perhaps be labeled as a "climate change and related global changes." Such a clarification would help set boundaries on what could be a large and ambiguous universe of issues.

These distinctions are not clear throughout the Plan. The lack of clarity is especially evident where the document refers to global change when it seems to mean only climate change. Some examples of this problem, among many, include:

- The discussion under Objective 1.2 *(Science for Mitigation and Adaptation)* seems to be about mitigation of and adaptation to climate change, even though the term "global change" is used. There is no indication that the intent is to include mitigation or adaptation in relation to, for example, land-cover changes, except perhaps as these changes result from or affect climate change.
- Under Goal 3 *(Sustained Assessments)* the document states that the "USGCRP is required by the Global Change Research Act of 1990 to conduct a National Climate Assessment" (L.2417-2419). However, the language of the Act clearly requires a periodic assessment of trends and effects of *global* change, not only of climate change.
- Box 3 on species' range shifts states that "global change" is driving the shifts of hardwood trees up mountains, when in fact it is specifically rising temperature regimes that are driving upward elevational shifts of most mountain species. Likewise, in Textbox 6, long-term observed changes are stated to be due to "global change," when in fact all of the examples listed are responses either to climatic changes or to increased atmospheric CO_2 directly and not to the multitude of other global change factors.

On scientific grounds alone, a broadly-focused global change research program that fully meets the mandate of the GCRA is more appropriate than a research program focused more narrowly on climate change alone. For example, the global hydrological cycle is under stress, but at present climate change is arguably not the most important stressor. Widespread land use changes and pollution associated with population increases, urbanization, and industrialization, as well as the drilling of wells, and the construction of dams, irrigation systems, and other water projects may be more important. As another example – human activity has dramatically altered the planet's nitrogen cycle, not through climate change but primarily through the transformation of atmospheric nitrogen into fertilizers for agricultural use.

Similar arguments can be made for changes in biodiversity, soil thickness and fertility, and other global changes (e.g., the decline of ocean fisheries, coastal "dead zones", ocean acidification). Climate change exacerbates these issues, but many of them would be creating enormous problems even in the absence of climate change; and in some cases these other global change issues can have more near-term (and perhaps more profound) impacts on human populations than climate change. The global implications of these other global change phenomena thus deserve study as part of a comprehensive global change research program.

At the same time, it should be recognized that the international research community is moving towards a significantly more expansive framework that looks at global environmental change in the context of global sustainability challenges – that considers, for instance, the inexorable interconnections among climate change, energy security, population growth, and economic and social developments; and that seeks to understand the potential for, and the root causes of, exceeding the boundaries for a sustainable planetary system. (See, for instance, the Earth System Sustainability Initiative, the Belmont Forum, and the "Planet Under Pressure" conference.[3])

Some would argue that embracing this substantially expanded research agenda is an appropriate, indeed an essential, next step for the Program in the decade ahead. Such an expansion, however, would require an extensive rethinking of the USGCRP from the ground up, would mean setting priorities among very different areas of science, and would further complicate the existing challenge of setting manageable boundaries on the definition and scope of a "global change" research program.

In light of these considerations, and of the real-world budget constraints facing the Program, the Committee suggests that focusing the near-term USGCRP goals on "climate and related changes" seems like a step in the right direction. It may not be realistic to implement a further broadening of the Program at this time, but the Strategic Plan should at least acknowledge that the long term mission of the Program embraces global change broadly, as defined by the GCRA. And we encourage the Program to devote serious consideration to better defining what sorts of issues "global change" research will and will not encompass. Table 1 in the Strategic Plan serves as a useful initial attempt in this regard, although it contains some items that are unclear or questionable as part of a *global* change agenda.

In the Committee's judgment, the plan for Objective 1.3 *(Integrated Observations)* is much clearer in terms of the implied definition of global change. Many of the observations to be supported under that Objective will enable improved analysis and modeling of a variety of different types of global change (not only those associated with climate change), and thus will inherently be contributing to understanding of global change in the broader (GCRA-defined) sense of the term.

Many of the federal research activities that contribute to understanding the state of water resources, soil fertility, ecosystems, and other globally changing environmental systems (not to mention the many research activities that look at large-scale socio-economic changes) are

3 See further discussion at: http://www.icsu.org/earth-system-sustainability-initiative; http://www.igfagcr.org/images/documents/belmont_challenge_white_paper.pdf; http://www.planetunderpressure2012.net/conferencevision.asp

conducted outside the official purview of the USGCRP. Thus another option, in principle, is that the government could simply declare these programs and their budgets to be part of the USGCRP. Assuming that the government agencies conducting this research agreed to the relabeling, it would at least create the perception that the USGCRP is more faithfully fulfilling its mandate, give the federal agencies that conduct this research increased visibility, and broaden the constituency for the Program. However, fully integrating these additional activities into USGCRP would require additional staff time and funding, which may be infeasible given current budgetary constraints. An informed analysis of this potential broadening strategy requires more time than this review allows; but we do suggest that the matter deserves further discussion as the Program develops.

Finally, as discussed later in this review, the Plan not only proposes expanding its scope from climate change science to "climate and related global changes", but also proposes expanding its scope to increased integration of the social and ecological sciences, increased attention to decision support, and increased attention to matters of education and communication. We strongly support these other areas of expansion, and emphasize that they are closely intertwined with the questions about climate change versus global change. For instance, the CCSP's earlier focus only on climate change, to the exclusion of other global changes, may have inherently constrained the social sciences and decision support components of the Program – because most real-world decisions made by government leaders, businesses, individual citizens, etc. are seldom, if ever, based on consideration of climate change in isolation.

Key Message: The proposed broadening of the Program's scope from climate change only to climate change and "climate-related global changes" is an important step in the right direction. The Program's legislative mandate is to address all of global change, whether or not related to climate. The Committee concurs that this broader scope is appropriate, but realizes that such an expansion may be constrained by budget realities and by the practical challenge of maintaining clear boundaries for an expanded program. We encourage sustained efforts to expand the scope of the Program over time, along with efforts to better define and prioritize what specific topics are included within the bounds of global change research. As the Program moves in this direction, a high priority is to assure that observing systems are designed to monitor a broad array of global changes, given that valuable information is being lost every year that such efforts are delayed.

4

Comments on Specific Topics within Program Goals 1 - 4

The discussion below does not track, one-for-one, all of the specific goals and objectives listed in the Strategic Plan. Rather, we highlight particular aspects of the Program's goals that in the Committee's judgment most require attention, focusing primarily on the newer proposed elements of the USGCRP's work. The final section of this chapter cuts across the other specific topics discussed herein, and discusses how the Program will actually undertake the challenge of expanding its scope.

OBSERVATIONS, MODELING, AND DATA MANAGEMENT

Goal 2 of the Strategic Plan addresses the issues of observations, modeling, and data management. The Plan's objectives in these realms are clearly stated and are all appropriately recognized as important priorities of the USGCRP. There are, however, some issues that the Committee believes do not receive sufficient emphasis in the Plan, discussed below.

Sustaining Satellite Observations. The Plan acknowledges that satellite remote sensing observations are a core foundation of global change research that must be sustained in the coming decades, but the Committee is concerned about the lack of clear strategies for doing so. The NRC Decadal Survey (NRC, 2007c) recommended an ambitious set of remote sensing missions to be undertaken by NASA, to provide a foundation for studying key global change questions. The Decadal Survey also made recommendations for critical climate observations to be continued by NOAA, and for transitioning some measurements from NASA to NOAA. As these goals have been pursued over the past several years, the costs of some missions have grown, in some cases dramatically; and some missions have been set back by launch failures (e.g., the loss of both the Orbiting Carbon Observatory and the GLORY satellite in 2009). Meanwhile, the budgets for these efforts have not been sustained at the expected level.

As a result of such developments, the Nation is currently at risk of having serious gaps in observational capability, for both operational forecasting missions and for key climate records (e.g., sea level observations). For instance, delays in advancing NOAA's Joint Polar Satellite System have led to the possibility of a gap in some key observations that have been collected over the past decade by the Earth Observing System satellites (which are well past their expected operational lifespan). More details about these and other threats to the continuity and integrity of remote sensing observing systems are discussed in a recent position paper of the World Climate Research Program (Trenberth et al., 2011).

These realities are acknowledged to some degree in the Plan (L.1282-1288). The suggested strategy for meeting this challenge is "for agencies to continue working collaboratively through USGCRP to leverage resources and set priorities." This emphasis on general "collaboration" seems insufficient, given the magnitude of this challenge and its enormous ramifications for the future of global change research. The USGCRP needs an appropriate governance structure and clear mechanisms for assuring that long-term satellite-based observing

systems are developed and sustained in a manner suitable for meeting the Program's key science objectives.

A related issue that should be more clearly acknowledged in the Plan is the fact that an increasing array of global change observations are now coming from instruments being developed and operated by other countries. This includes remote sensing observations as well as in situ monitoring systems (e.g., the ARGO ocean profiling network, radiosonde networks to observe the upper atmosphere). As a result, the USGCRP's efforts to foster international cooperation and data sharing may, in the coming years, become as important as its efforts to foster the growth of U.S.-led observations.

Social and Ecological Science Observations. The Committee applauds the USGCRP's intent to broaden its scope beyond the physical sciences; but we do not see sufficient evidence that the Program is prepared to take concrete steps in meeting its stated goals to better integrate social and ecological sciences. In this regard, the Plan needs to broaden its discussion of observational and data management systems.

In the social sciences realm, there is a need for observations and data related to human activities that drive global environmental changes and that affect vulnerability and ability to respond to global change. This may encompass a wide array of factors such as population growth and distribution, economic development trends, technological innovation and adoption, institutions governing natural resource use, disaster response capacity of governments and non-governmental organizations, and changes in the built environment (e.g. location of infrastructure and property in sensitive areas, infrastructure investments made for climate adaptation purposes). In the ecological sciences realm there are a wide array of observational needs, which are well-documented in earlier NRC reports (e.g., NRC, 2010a) and assessments (e.g., the Millennium Ecosystem Assessment).

One specific concern to highlight in this regard is the need to make data on social phenomena more interoperable with environmental data. For example, data on human populations, land tenure, economic activities, disaster losses, pollutant emissions, and so forth are often collected according to political jurisdictions or administrative geography. These data need to be put into a common geographic framework with geocoded biophysical environmental data, in order to allow the different types of datasets to be analyzed in an integrated fashion. There has been progress in advancing this sort of data integration in some social domains (e.g., land cover and population dynamics, see NRC, 1998), but this progress is uneven across types of social data, information is sparse for some geographic areas and time periods, and data comparability is sometimes in question across national boundaries. Moreover, issues of confidentiality and privacy sometimes stand in the way of making data public (in cases where it might make the data providers identifiable as individuals or firms). Such issues can be addressed, but until they are, they impede analysis of social changes and their relationships to environmental change.

Social and ecological monitoring can also be improved by collecting new kinds of data or using new data collection methods. This includes emerging opportunities to use non-traditional data sources (discussed below) as well as "citizen science" research programs. For instance, in the ecological sciences, citizen observer networks have revealed long-term, climate-driven trends in plant phenologies – e.g., from more than 50 years of data on lilac phenology from observer sites

across the United States (Schwartz and Reiter, 2000), from an 800 year long Japanese cherry blossom database (Menzel and Dose, 2005), and from a 500 year long grape harvest database (Menzel, 2005). The Strategic Plan does acknowledge the National Phenology Network (L.3165 - 3210), but it is not clear how the USGCRP intends to integrate these sorts of networks into its broader observational systems.

There are many reasons why a strong initiative in data collection to support social and ecological sciences should be given high priority; including, for instance:

- Every year that data collection is delayed, crucial observations are irreversibly lost, which reduces the base for understanding important, ongoing changes.
- Designing and implementing data collection efforts provides the ideal testbed for working out the complex relationships and shared understandings necessary to a truly integrated earth systems science that draws upon the physical, social and ecological sciences.
- The cost of most social and ecological science data collection is modest compared to the cost of many of the physical science observing systems being supported.
- Social and ecological science communities are poised to answer many questions that are articulated in the Strategic Plan as critical, but are currently stymied by lack of data.

Some initial data collection initiatives in the social sciences could include, for instance, a sequence of national surveys and parallel collection of intensive interviews on public concerns and consumption behavior, or aggregation of case studies and local data sets (as has been pioneered, for example, by the International Forestry Resources and Institutions network[4]). New ecological monitoring initiatives may build on existing efforts at National Ecological Observatory Network (NEON) and Long Term Ecological Research Network (LTER) sites. These existing efforts might also provide a useful testbed for integrating social science observations with ongoing physical and ecological science work.

Building an Integrated Observing System. Even if the Program goals were limited to "simply" understanding and predicting the evolution of the physical Earth system, this alone entails a major challenge for the USGCRP, in terms of the breadth of observations that are needed. (For example, the Global Climate Observing System (GCOS, 2010) identifies fifty "Essential Climate Variables" that require systematic observation.) By expanding the Program's purview to also understanding coupled social-ecological systems and providing the scientific insights needed to support decision making for risk management, adaptation, and mitigation, the USGCRP faces a wide array of additional challenges for building and sustaining an integrated observational system.

The Plan effectively articulates these challenges and acknowledges the need to monitor diverse factors (e.g., land use, agricultural productivity, economic activity, human population characteristics, disease incidence, and hazard exposure). But the Plan is weak in describing a concrete vision or offering clear guidance regarding the goals, structure, and mechanics of the integrated observing system that is needed. For instance, the Plan does not offer clear strategies to identify what specific observations are most needed, to integrate existing observations available from sources outside of the USGCRP, to meet the unique technical challenges associated with this observational mandate, or to ensure that the resulting data are available in useable form for

[4] http://www.sitemaker.umich.edu/ifri/home

research and decision support needs. An observational system that integrates relevant social, ecological, and physical data (and that can cope with the rapidly evolving needs and capabilities in satellite and in situ observations) is an indispensable foundation for understanding and informing societal responses to global change. We strongly underscore the need for the USGCRP to play a leadership role in developing such a system.

One way the Program can help to meet this challenge is by supporting broad-based planning efforts among the relevant research and user communities to identify top priorities for data collection and data linkage, with special emphasis on social and ecological science observing systems and their integration with existing/planned physical science systems. In addition, the USGCRP's existing interagency working group structure might provide a valuable forum for discussion about the integrated observing systems needed to support use-inspired research on specific topics (e.g., vulnerability of food production and delivery systems, water resources, health) and specific geographically-oriented concerns. Such cases studies may yield important information about the specific cases in question, as well as general "lessons learned" that help guide the broader process. Regardless of what specific engagement approaches are used, the USGCRP needs to work with research and user communities to develop a clearer vision – and the Strategic Plan should describe how this will be done.

Emerging Data Sources. The nature of global change observations is changing rapidly. Real-time data streams from thousands to millions of sensors on "unconventional" platforms are now becoming available. Some of these data streams consist of traditional observational variables (e.g., atmospheric pressure can be measured in automotive fuel injection systems; accelerometers in smartphones can be used to detect seismic activity). Other types of data streams may offer significant new opportunities for social science research, for instance through internet blogs, geo-located photos, and surveys conducted in real time via smartphones (e.g., Lai et al., 2009; Peytchev, 2010; Maisonneuve et al., 2010).

Transforming these unconventional data streams into useful scientific information is a cutting-edge research challenge that could have significant impact on both natural and human systems research in the coming decades. They will allow much finer-grain spatial and temporal analysis of social and environmental change and thus reveal much that is invisible to periodic surveys and remotely-sensed data. In some instance, these new data sources may be critical for developing and validating higher resolution models, and for allowing more subtle analyses than are possible with current methods. While on the one hand offering exciting new research opportunities, these unconventional data sources can, on the other hand, pose new challenges related to data quality and standardization.

The Plan does briefly allude to such developments in a paragraph on using advances in information technology to harness public participation in research (L.1936 – 1942), but the Committee suggests there should be a greater emphasis on developing new capabilities to accommodate real-time data streams as part of USGCRP's portfolio of data management tools. This could be done in part by leveraging ongoing research on new data-collection opportunities taking place other disciplines outside of global change research.

Integrated Data Management. Objective 1.5 (*Information Management and Sharing*) does a good job of discussing some important developments related to data management that have taken place since the previous Strategic Plan (e.g., the rapidly expanding capabilities to collect, store, and process data). The Committee agrees with the Plan's emphasis on organizing distributed databases and developing tools to improve access to, and interoperability among, datasets of interest. This discussion, however, seems to call for only incremental improvements to the data management developments already underway. A more imaginative, forward-looking perspective would help ensure that USGCRP plays a leadership role in the coming decades. In particular, the Plan should acknowledge and strive to help advance the profound new ideas and opportunities that are emerging around the concept of data-intensive science (e.g., Hey et al., 2009).

Large data collection activities may continue to be organized around collaborative teams, but analysis of enormous data sets is now within reach of individual scientists. Individual users now have data, storage, and computation capabilities that dwarf what used to be available only at government and university centers. For example, ability to access and process one petabyte of data is now within the range of university department or even an individual scientist; but traditional database architectures often cannot be simply scaled up to accommodate such enormous (and often unstructured) data sets. The USGCRP should acknowledge these new data management challenges and work with other organizations engaged in developing state-of-the-art architectures to enable data-intensive science. The Department of Energy's Earth System Grid (which is mentioned in the Plan) offers a prototype of the type of data access systems that are increasingly needed.

Development and Application of Integrated Models. Objective 1.4 in the Strategic Plan emphasizes increasing model resolution to obtain more realism in global change simulations. While such advances will indeed be valuable to future research efforts, this does not represent the full range of modeling advances that are needed. Some examples of other issues that need to be considered:

- There is a need is to improve models' representation of ecological and social processes, which is a far more complex challenge than increasing resolution. For instance, many social processes are driven by rule-based systems developed within a particular societal context, as opposed to physical processes that are driven by conservation laws.
- Scenario-based modeling approaches will continue to be an important direction for global change research. But the application of this approach in decision support efforts requires careful explanation of the assumptions that underlie the scenarios used, and requires quantitative estimates of uncertainties both in the environmental processes being modeled and in the models themselves.
- As the USGCRP's modeling efforts are increasingly used to support important policy and economic decisions, there needs to be a high level of confidence that scenario projections are internally consistent and based upon credible assumptions. High resolution, multi-dimensional, and coupled models are extraordinarily complex. Scientific confidence will come in part from the ability of independent groups being able to reproduce the results of

these models. The USGCRP should develop approaches to ensure that the model outcomes can be reproduced.

Issues Raised by Increasing Data and Model Resolution. As our technological capabilities for collecting, storing, and processing enormous volumes of observational data have rapidly advanced, there has emerged a widely-held strategic tenet of global change research (suggested in the Plan at L.1585-1602) that the complexities of global change can be better understood and better managed by finer resolution data and models.

This may be correct in a theoretical sense; and one can, in fact, point to many examples of where increasing model resolution has yielded important new insights (e.g., more realistic representation of storms and rainfall in mountainous regions, and of hurricane/cyclone statistics). However, increases in resolution rapidly multiply the data needing to be managed and the complications of modeling and analysis. And putting more resources into increasing resolution may force tradeoffs in terms of support for other important Program goals. On what basis can the USGCRP make decisions about where it is most worthwhile to increase the resolution of data collection and modeling efforts?

The Committee suggests that one possible basis for making such decisions is to explicitly consider the value of information to be gained by increasing observational/modeling resolution. Of course, scientific research cannot be rigidly programmed to maximize return on investment without undermining the creativity and productivity of the scientific enterprise. That said however, it may still be possible to at least set a lower bound on the value of global change research knowledge by asking: If a certain research advance could in fact provide the answer to some given question, what difference would it make? For example, accurate estimates of sea level rise or storm surge height can inform decisions by local governments, businesses, and property owners about where to locate or to move human settlements and infrastructure in the coastal zone. These decisions entail large economic choices—and the value of knowing whether sea level rise in this century will be one meter or three could be enormous as a result. (This implies, of course, a need for social science research to help understand how decisions are made in key sectors and how more detailed information would affect those decisions.)

Explicit valuation of the knowledge being produced by USGCRP would help to clarify when greater spatial and temporal resolution is worthwhile or exceptionally promising as ways to make better decisions. When there is substantial benefit in terms of the effectiveness of the choices being made, the additional costs can be well worthwhile. This "value of information" approach will not provide simple answers about how to set priorities, but it can at least provide important perspectives on how to do so. In some cases it will be possible to quantify the value of information with some precision; but even in cases where it is only a general qualitative characterization is possible, such analyses could be of considerable value in guiding USGCRP investments.

SOCIAL SCIENCES RESEARCH

The Strategic Plan directs the USGCRP to produce research that creates new scientific knowledge about climate change and "other critical drivers of global change" and that simultaneously makes that knowledge "more readily usable in decision making" (L.242-248). The Plan calls for more effective integration of the social sciences, as well as more investments in fundamental social science research that contributes to global change science. Recent NRC studies, including the *America's Climate Choices* reports (NRC, 2010a, b, c, d; NRC, 2011) and reviews of the CCSP (NRC 2007, 2009b), have strongly argued that without strong contributions from the social sciences, many salient USGCRP research questions cannot be adequately addressed. These reports offer numerous examples of research questions across different problem-inspired or sectoral areas (water, urbanization, agriculture, etc) that require integration of social, ecological, and physical sciences.

The Committee re-emphasizes the same basic point here – that research in the social sciences and effective integration of social science knowledge are essential if the USGCRP is to achieve the goals stated in the Strategic Plan. Box 2 offers an illustration (taken from an earlier NRC report) of how scientific analysis that integrates physical, ecological, and social sciences is necessary to understand and inform decision making about environmental hazards that can be affected by global changes such as climate variability, climate change and sea level rise. (It also illustrates that even the best science is not sufficient to ensure an effective response.)

BOX 2

Vulnerability of New Orleans to Hurricane Katrina

The Mississippi River, especially in and around New Orleans, has been intensively engineered to control flooding and provide improved access for ships to the port of New Orleans. These hydraulic works significantly reduce the river's delivery of sediments to the delta between the city and the Gulf of Mexico, and thus the land-building processes that would otherwise offset the gradual subsidence and erosion of the delta. In addition, the construction of channels and levees and other changes in the lower delta have affected vegetation, especially the health of cypress swamps. Together, these changes in elevation and vegetation have weakened the capacity of the lower delta to serve as a buffer to storm surges from the Gulf of Mexico.

Various assessments of the condition of the lower Mississippi Delta—which together form a quasi-integrated vulnerability study—revealed that in the event of a direct hurricane strike, the vegetation and land areas south of New Orleans were insufficient to protect the city from large storm surges, and also that various hydraulic works would serve to funnel flood waters to parts of the city (Costanza et al., 2006; Day et al., 2007). Despite this knowledge, little was done to reduce the region's vulnerabilities prior to 2005. When Hurricane Katrina struck in late August of that year, the human-induced changes in the region's hydrology, vegetation, and land-building processes, together with the failure to maintain adequate protective structures around New Orleans, resulted in extensive flooding of the city and surrounding area over the following week. This, combined with a lack of institutional preparedness and other social factors, led to a well-

documented human disaster, especially for the poorest sections of the city (Costanza et al., 2006; Day et al., 2007; Kates et al., 2006).

Source: NRC, 2010a.

While the Plan does recognize the importance of social science in achieving USGCRP goals, the Committee is not convinced that, as written, the Plan will actually help foster significant advances in this regard. In particular, it is almost entirely silent about how social science research will be implemented, how it will be coordinated with research in the physical and ecological sciences, and who will take lead responsibility for these efforts. Without clear targets, and identified parties held accountable for meeting these targets, the Plan is likely to repeat its earlier unsuccessful efforts to integrate the social sciences.

The Committee's skepticism results from of a history of failures to make good use of social science knowledge in global change research, both by the USGCRP and its member agencies. Statements of good intentions have been made numerous times. The initial USGCRP Strategic Plan identified "human interactions" as one of the Program's seven interdisciplinary science elements, noting that "Understanding the role of human dimensions in global environmental change requires fundamental research on human social, economic, and institutional behavior" (USGCRP, 1989, p.72). NRC reviews of the Program since its inception have repeatedly identified "human dimensions" or similarly named topics as needing development and funding (NRC, 1988, 1992, 1999, 2003, 2007, 2009, 2010a). The 1992 NRC review found that this research domain accounted for only three percent of the USGCRP budget and recommended that it be ramped up to five percent over three years. An examination in 2007 found that, by that time, expenditures for human dimensions research were less than two percent of the total budget of the Climate Change Science Program. That review concluded that "Progress in human dimensions research has lagged progress in natural climate science….This disparity in progress likely reflects the inability of the CCSP to support a consistent and cogent research agenda as recommended in previous studies." (NRC, 2007).

The small and declining share of investment in social science in the USGCRP, despite the continually expressed need and the far lower cost of social science research compared with capital-intensive physical observing systems, reflects two important factors. First, the USGCRP member agencies have limited capacity in the social sciences, resulting in limited understanding of how to translate a core scientific question (how do humans drive and respond to global change?) into a concrete research effort. This is a challenge that persists today. Second, the development of the social science community focusing on environmental questions over the last three decades has been slowed by limited and unreliable funding and by a lack of common data resources (relative to the substantial investments in training and data resources that have been made in other areas of global change science, and in other areas of social science).

The Strategic Plan needs to recognize the significant opportunities to be developed in the social science research community, while strengthening the federal government's capacity to draw upon that community as a full intellectual partner in global change research. In this context, the Committee has identified several weaknesses in the Plan's treatment of the social sciences; for instance:

- The "social sciences" are not clearly defined in the Plan, and are referred to inconsistently with a variety of terms (socio-economic sciences, social and behavioral sciences, economics and social sciences, human dimensions, natural science and human components). These terms have quite different implications for research specialties that need to be engaged. While the Plan offers some discussion of the role of economists, there is little sense of the wide range of other social sciences fields that need to be engaged, such as anthropology, demography, geography, history, political science, psychology, sociology, and urban and regional planning.
- Modeling, data, and observational systems are often described without regard to the social sciences. For instance, Objective 1.3 (Integrated Observations) focuses almost entirely on platforms to monitor biophysical systems.
- The discussion of geoengineering does not mention important social science questions regarding public acceptance, governance and institutional challenges, and international relations. As pointed out in most assessments of geoengineering research needs, such questions will play a crucial role in determining whether geoengineering can be a feasible tool for responding to climate change.
- The Plan's discussion of observations (P.33-34) suggests a lack of "maturity" in social science observing systems (L.1418). This comment suggests that the USGCRP is unaware of the 40 years of consistent research data collection carried out in the General Social Survey, the 60 year history of the American National Election Study, or the 50 year history of the Inter-University Consortium on Political and Social Research (not to mention the Census and the National Accounts statistics). There is likewise little mention of social science data in the discussion of international cooperation, despite the long and successful history of efforts like the World Fertility Survey, the International Social Survey Program, and ongoing programs within various United Nations agencies, the International Energy Agency, and the International Monetary Fund. These and other existing social science data series (that are either fully or partly relevant to global change research) meet standard scientific criteria such as reliable, accurate, and precise measurement that is relevant to users' needs; affordable costs of measurement, processing, and interpretation; and sustainable institutional structure for observation and analysis.
- The Plan discusses social science research mainly in relation to impact, vulnerability and adaptation. But there are many other aspects of global change research where social sciences can advance understanding of important issues; e.g, consumption patterns for food, water, energy and other basic resources; drivers and economics of climate change (e.g. human modifications of the carbon cycle); costing of mitigation and adaptation; public acceptance of mitigation options; and decision support (e.g. integrated assessments, institutions and governance).

The Committee suggests that the Program could begin to change past practices (e.g., in terms of organizational structure, budgeting, priority setting mechanisms), even in light of an uncertain budgetary future, by strengthening the Plan in three key areas, discussed below.

(i) ***Identify the types of social science observations and data that are required for a research program that supports global change decision making, and identify specific initial steps to advance collection and integration of these data.***

Developing and sustaining observational systems, and managing and disseminating observational data are core activities of the USGCRP. To date, the Program's efforts have focused largely on physical science data. In an earlier section of this review, we discuss the numerous motivations for supporting social science and integrated social/physical research, and we suggest initial steps the Program could take to foster such progress.

(ii) ***Commit to invest in specific areas of fundamental social science research related to global change and integrated research across the physical, social and ecological sciences.***

We suggest that the Strategic Plan identify and commit to funding research in at least one or two substantive areas of social science research (or at least develop a process for doing so, as suggested earlier). NRC, 2009b (Appendix D) suggested five priorities for fundamental research that is crucial to understanding global change.

- "Improving the understanding of environmentally significant consumption[5].
- Improving fundamental understanding of risk-related judgment and decision making under uncertainty.
- Improving the understanding of how social institutions affect resource use.
- Improving the understanding of socioeconomic change as context for climate change impacts and responses.
- Valuation of climate consequences and policy responses."

The report further suggested five priorities for action-oriented human dimensions research, which could engage the full range of social science disciplines:

- "Understanding climate change vulnerabilities: Human development scenarios for potentially affected regions, populations, and sectors.
- Understanding mitigation potential: Driving forces, capacities for change, and possible limits of change.
- Understanding adaptation contexts, capacities for change, and possible limits of change.
- Understanding how mitigation and adaptation combine in determining human systems risks, vulnerabilities, and response challenges associated with climate change.
- Understanding decision support needs for climate change responses and how to meet them."

The Plan's discussion of modeling (P.35-41) recognizes that the development of models that integrate social and natural science will improve capacity to characterize uncertainty and will provide decision makers with a better understanding of available options. (A good example of this can be found in the DOE Integrated Assessment Research Program.) The Plan, however, does not discuss strategies for actually advancing this sort of integration in specific mission or research

[5] See *Environmentally Significant Consumption: Research Directions* (NRC, 1997)

areas. As mentioned above, we suggest that the Plan include a few examples that show how integration across social, physical and ecological sciences can be achieved, and the benefits that can result from such efforts. For example, it could cite NOAA's RISA program, which has yielded an impressive body of research and practice focusing on understanding and meeting stakeholders' decision needs in areas such as water management, agriculture, and disaster response.

(iii) ***Provide a clear plan for phasing in efforts toward accomplishing stated goals for increasing the role of social sciences and for integrating across physical, social and ecological sciences, including specific commitments for the next few years.***

Of particular concern is the fact that the Plan's Implementation section suggests that the USGCRP will only consider phasing in newer priorities– presumably including the expansion of social sciences research– at some unspecified point in the future when new resources make it feasible. Given that there has not been significant progress in integrating the social sciences in the 20 year history of the USGCRP, it seems likely this point may not come in the next 10 years either.

It is not clear from the Strategic Plan who will take the lead, and be held accountable for, developing and implementing climate-related social science and integrated research. This reflects a long-recognized problem that few of the USGCRP mission agencies have any strength in the social sciences. While economics and to some degree sociology have a presence in the resource agencies, this strength is typically not in the parts of the agency that deal with global change. The one agency with considerable strength in the social sciences, NSF, continues to organize nearly all of its social science research program around individual disciplines. There have been some successful efforts at NSF to move past this (e.g., in the *Decision-Making Under Uncertainty Centers*; the *Dynamics of Coupled Natural and Human Systems* Program; the now defunct *Human Dimensions* program; and the *Water, Climate and Sustainability* initiative); but there is no indication of a long-term plan to enhance and consolidate these kinds of initiatives within the overall Program.

As initial steps, the Plan could propose establishing research programs in one or two priority areas. We suggest a few possible strategies for developing initial efforts, despite the paucity of social science expertise within the Program:

- The Program could support social science research focused on specific areas of concern (e.g., water resources, energy, agriculture) through collaborations across agencies (for instance, NSF and DOE) and within them (for instance, linking DOE's Office of Science more effectively to programs in the Office of Energy Efficiency and Renewable Energy that could benefit from improved analysis of valuation and decision support).
- The Program could establish joint grants competition between two agencies, emulating past efforts to link the social science expertise in NSF to needs and interests of mission agencies such as EPA. Typically in such efforts, the mission agency has provided a set of priority research questions and the majority of funding, and NSF has run the grants completion (especially the peer review process) with input from the mission agency.

- The Program could champion the incorporation of social sciences research into major existing global change research efforts, such as the LTERs, NEON, and the DOI climate centers.

The Plan has made a strong case for integrating the social sciences, but has not backed that up by identifying specific priority activities or indicating specific agencies that would support them. Unless the Plan acknowledges the current lack of "ownership" of social sciences by the agencies and takes concrete steps to assign responsibility and resources to specific agencies in specific priority areas, we cannot be optimistic that the USGCRP will succeed in providing the kind of science the nation needs to support decision making in the face of global change.

ECOLOGICAL SCIENCES RESEARCH

As understanding of the roles of key ecosystems (e.g., rain forests, Arctic tundra) in shaping Earth's climate system has emerged, it has become clear that biological systems both affect and are affected by climate change. In order to respond effectively, it will be necessary to have a better understanding of the interactions among biological systems, human uses of ecosystems, and changes in climate. The USGCRP could help to address numerous gaps in biological understanding (at levels ranging from individual species to populations to ecosystem processes), which currently impede our ability to make sensible, effective decisions about how to sustain and manage natural systems under a changing climate. Among the key needs are enhanced observational systems (discussed earlier in this review); relevant organism, population, and community-level ecological research; and representation of coupled social-ecological systems in earth system models. These and additional issues discussed below are implicit in parts of the draft Plan, but require more explicit recognition and integration into the research agenda.

Multi-level ecological research. Considering ecological research in its broadest sense, the Strategic Plan is strong in recognizing and integrating essential research streams at the ecosystem level – that is, research pertaining to materials exchange (e.g., CO_2) between biosphere and atmosphere, and to ecosystem-level properties and processes (e.g., water storage and filtration, carbon storage). However, there is little inclusion of organismal-level ecological research, which relates to individual organisms, to populations of individuals, and to interacting communities of multiple species.

The USGCRP research goals should include research designed to illuminate processes at the population, species, and community levels that link to ecosystem functioning (e.g., carbon storage or water filtration and storage), resilience and integrity. Some important ecosystem services, such as crop pollination, can be understood only through population and community level ecological studies. Ecosystem ecology is but one end of the spectrum of ecological disciplines and cannot, on its own, address all of the important questions that fall under the USGCRP mission.

Studies of populations, species, and ecological communities are already being sponsored by many of the USGCRP member agencies; but there is no coherent analysis of how such organism-level studies can best contribute to an understanding of climate change (or global change more generally). The Strategic Plan could suggest concrete steps to perform such analyses, with special

attention to ecosystems of concern to the United States (e.g., coastal oceans that harbor commercially-harvested fish, croplands, forests, estuarine wetlands, temperate lakes and rivers, wilderness).

Restoration Ecology. Maintaining ecosystem integrity in the face of climate change is likely to require both the restoration of disturbed ecosystems, and the construction of ecosystems that are resilient to climatic changes (Jackson et al, 2009; Connelly et al, 2009). The Plan does contain a brief reference to the concept of restoration ecology (L.1094), but it would be helpful to see some additional explanation of how the USGCRP can help develop this nascent branch of ecology into a rigorous science. Restoration ecology, as the most recently emerged branch of ecology, has the weakest scientific foundations (Dobson et al, 1997; Cabin, 2007; Giardina et al, 2007; Weiher, 2007).

Significant research opportunities include both the "green" carbon of terrestrial systems (e.g., restoration of native prairie from abandoned farmland) and the "blue" carbon of marine systems (e.g., restoring native seagrass beds along denuded coastlines; or restoring areas of coral reef with large carbon storage capacity). Restoration to native conditions in both "green" and "blue" realms could contribute substantially towards increased carbon sequestration and play a role in lowering atmospheric levels of carbon dioxide.

Likewise, many natural systems store more carbon per meter-squared than disturbed systems such as agricultural lands (Fargione et al. 2008, Nelleman et al. 2009), and thus research on restoration of degraded areas may offer an important approach to increasing carbon sequestration. By developing a more pragmatically useful science of restoration ecology, the USGCRP could also help pave the way for new, superior sources of biofuels that come from natural systems, which lack the pitfalls of crop biofuels (NRC, 2008; Searchinger et al. 2008, Fargione et al. 2008).

Use of Ecological Knowledge in Assessments. A number of recent multi-disciplinary assessments (e.g., Grifo and Rosenthal, 1997; Millenium Ecosystem Assessment, 2005; Pongsiri and Roman, 2007; Sala *et al.* 2009*)* illustrate how the knowledge base from organismal ecological research can be effectively integrated into assessments that lead to more informed, effective decision making. Assessments usually provide scenarios for estimating climate change impacts on ecosystem-level processes; but it is important to also incorporate ecological dynamics at the individual, population, and community levels in analyzing those scenarios. This has been a difficult challenge in the past, and integrating organismal science into the modeling of ecosystems has not been supported as part of global change research. USGCRP could help lead such efforts by summarizing the current state of practice and laying out directions to pursue in the next decade.

Ecology as a communication tool. Awareness of global change is often communicated in ecological terms—from crop failure to dwindling populations of polar bears. As the nation's authoritative scientific voice on global change science, the USGCRP has an opportunity to improve public understanding through strong support for research on the ecological impacts of global change and through efforts to ensure that this research is communicated to entities – either within or outside of the Program – that do outreach to the media, to the general public (e.g., in popular venues such as zoos and aquaria), and in formal educational programs.

Finally, as with many other areas discussed in this review, the ACC *Advancing the Science* report (NRC, 2010a) offers numerous examples of specific research questions that could be incorporated into the Plan. See in particular Chapters 9 (Ecosystems, Ecosystem Services, and Biodiversity) and 10 (Agriculture, Fisheries, and Food Production).

MITIGATION AND ADAPTATION

The Strategic Plan's discussion of mitigation and adaptation are discussed primarily under Goal 1 (Objective 1.2 – *Science for Adaptation and Mitigation*) and Goal 2 (Objectives 2.1 – *Informing Adaptation Decisions*; and Objective 2.2 – *Informing Mitigation Decisions*). The identified goals are appropriate ones for the USGCRP; but the Committee does have concerns about missing elements. In addition to the concerns discussed here, the concerns discussed in our later section on decision support are directly relevant to mitigation and adaptation as well.

One general issue, noted earlier in this review, is that the Plan is ambiguous about whether the USGCRP intends to advance mitigation and adaptation efforts just for climate change, or for global change more broadly. While there are logical reasons to focus primarily on climate change (since this is where most adaptation / mitigation efforts are currently developing), there are of course also many other types of global change concerns that may require mitigation and adaptation responses. To be effective in meeting stakeholder needs, USGCRP efforts may eventually need to encompass this broader scope.

Defining the research agenda. Objective 2.1 (*Inform Adaptation Decisions*) is too vague to provide much help in shaping priorities in an adaptation research program. The discussion in general seems to be focused more on process needs to inform decision makers than on research needs to advance fundamental understanding. While acknowledging that this is a relatively new research area, we believe the Plan can go further than it does in defining specific research topics. Some examples of important adaptation research topics that could be mentioned include:

- developing and validating indicators of sensitivity and adaptive capacity to environmental changes (for particular places, sectors, population groups) for use in decision making;
- research on decision-making methodology (see discussion below on research for iterative decision making);
- examining how adaptation efforts at different levels (national, state, local) can be coordinated and mutually supportive (i.e., what types of information flow and data are needed?), how to facilitate social learning across levels, and how to learn from the experience being gained from adaptation currently underway;
- defining the appropriate relationship between adaptation planning efforts and disaster risk management efforts;
- providing evidence to support the idea (commonly stated) that unabated climate change will "overwhelm" the capacity to adapt, even for the richest countries.

Objective 2.2 (*Inform Mitigation Decisions*) likewise seems vague and incomplete. There is no mention, for instance, of the need for research on the effectiveness, costs, or technical, economic, or social feasibility of many mitigation options that decision makers will be considering; or research on the socio-economic, cultural, and behavioral factors that affect efforts to reduce major greenhouse gas emission sources (understanding that is crucial for crafting effective mitigation strategies).

The discussion of science for mitigation (under this objective and Objective 1.2) offers some details on what is needed in terms of better models, projections, and other tools; but here too the Plan offers only a vague sense of what research questions will be pursued to provide the scientific basis for improving such tools. It is not clear, for instance, what new research and metrics would allow us to better determine the value of mitigation efforts or inform tradeoffs among mitigation options.

The Plan contains a few statements about technologies and energy systems (L.1101), but it seems that the Program is intending to focus primarily on mitigation research related to forest and soil carbon sequestration. While energy technology R&D is (as suggested in the Plan) more appropriately housed within the Climate Change Technology Program (CCTP), there are many technology-related research questions that would be appropriate, and indeed very important, to include in the USGCRP agenda. This includes questions about the factors that determine how new technologies are accepted and used (or not) in different societal contexts. For instance, the lack of adoption by households and businesses of readily-available, cost-effective technologies is an important research question, as it appears to be a "low hanging fruit" for mitigation. The Plan's references to "the human actions that lead to greenhouse gas emission changes" (L.1086-1087) and the need to understand "choices about energy usage and technological change that lead to changes in emissions" (L.1103-1104) do at least suggest the need for research that could inform mitigation choices in the energy domain, but the Plan offers no specifics.

A related gap is the lack of acknowledgement that mitigation and adaptation will require transformation of infrastructure and the built environment (e.g., homes and office buildings, and facilities for energy production and distribution, industrial activities, transportation, waste management, water supply and waste water treatment). The design of the built environment is both a driver of global change (through impacts on resource consumption, land use and habitat destruction, greenhouse gas emissions, air and water pollution, storm water runoff from impervious surfaces, etc.) and is a source of vulnerability to extreme weather events affected by global change (e.g., impacts from drought, flooding, storm surges, heat waves, storm winds).

Thus a research program on assessing and responding to global change should include the research needed to support the development of standards and regulations that shape the built environment. This requires extending the integrated research efforts discussed earlier (i.e., among physical, ecological, and social scientists) to also include integrative research with engineers, architects, builders, landscapers, urban planners, regulators and others (in both the private and public sectors). Advancing such linkages will likely require that the USGCRP engage with numerous Agency programs/divisions that conduct and support research related to the built environment – including, for instance, the U.S. Army Corps of Engineers, the DOI Bureau of Reclamation, the DOE Office of Energy Efficiency and Renewable Energy, the NIST Engineering Laboratory, and the NSF Directorate of Engineering.

The CCTP will presumably continue to have purview over technological development related to improving energy efficiency and conservation in the building sector, and developing technologies and infrastructure for energy production, distribution, and carbon capture and storage (CCTP, 2006). But the success of such efforts will hinge not only on technological advancements, but also on public understanding and acceptance, and on the development of efficient, streamlined regulatory practices. These sorts of research questions (grounded primarily in the social, economic, political sciences) need to have a clear home in either the USGCRP, the CCTP, or linked programs in both.

The ACC reports offer numerous additional examples of research questions for advancing the science of adaptation and mitigation (see Box 3). While some prioritization among those many research questions is likely necessary, it would be helpful for the Plan to include at least this level of detail and to explain how the Program will begin developing the selected research areas.

BOX 3
Examples of Research Needs for Climate Change Mitigation and Adaptation

Given the breadth of societal actors and economic sectors that are affected by mitigation and adaptation efforts, there are, accordingly, a wide array of research questions that need to be explored. The following are suggestions of key research needs from ACC *Advancing the Science of Climate Change* (NRC, 2010a).

Examples of Research Needs Related to Limiting the Magnitude of Climate Change:

- Advance the development, deployment, and adoption of energy and transportation technologies that reduce greenhouse gas emissions.
- Develop and evaluate strategies for promoting the use of less-emission-intensive modes of transportation.
- Characterize and quantify the contributions of urban areas to both local and global changes in climate, and develop and test approaches for limiting these contributions.
- Continue to support efforts to improve energy efficiency in all sectors and develop a better understanding of the obstacles to improved efficiency.
- Improve understanding of behavioral and sociological factors related to the adoption of new technologies, policies, and practices.
- Develop integrated approaches for evaluating energy services in a systems context that accounts for a broad range of societal and environmental concerns, including climate change.
- Develop and improve technologies, management strategies, and institutions to reduce net greenhouse gas emissions from agriculture, while maintaining or enhancing food production potential.
- Assess the potential of land, freshwater, and ocean ecosystems to increase net uptake of CO_2 (and other greenhouse gases) and develop approaches that take advantage of this potential without major adverse consequences.
- Improve understanding of links between air quality and climate change and develop strategies that can limit the magnitude of climate change while improving air quality.

- Improve understanding of the potential efficacy and unintended consequences of solar radiation management approaches and direct air capture of CO_2, provided that this research does not detract from other important research areas.
- Establish and maintain monitoring systems capable of supporting evaluations of actions and strategies taken to limit the magnitude of future climate change, including systems that can verify compliance with international greenhouse gas emissions-reduction agreements.

Examples of Research Needs Related to Vulnerability and Adaptation:

- Expand the ability to identify and assess vulnerable coastal regions and populations and to develop and assess adaptation strategies, including barriers to their implementation.
- Assess food security and vulnerability of food production and distribution systems to climate change impacts, and develop adaptation approaches.
- Develop and improve technologies, management strategies, and institutions to enhance adaptation to climate change in agriculture and fisheries.
- Develop vulnerability assessments and integrative management approaches and technologies to respond effectively to changes in water resources.
- Assess vulnerabilities of ecosystems and ecosystem services to climate change.
- Assess current and projected health risks associated with climate change and develop effective, efficient, and fair adaptation measures.
- Assess the vulnerability of cities and other parts of the built environment to climate change, and develop methods for adapting.
- Advance understanding of how climate change will affect transportation systems and how to reduce vulnerability to these impacts.
- Develop improved vulnerability assessments for regions of importance in terms of military operations and infrastructure.

International information. The Plan does contain considerable discussion about international engagement in a general sense; but it does not acknowledge some of the areas where such engagement is most needed in regards to science for climate change adaptation and mitigation. Adaptation is often about learning how people already cope elsewhere, and that "elsewhere" extends far beyond U.S. borders. A huge repository of relevant experience and information can be found in the efforts of other countries and in international organizations. There are important opportunities for the U.S. to both contribute and benefit through active international engagement, as systematic analysis of the various forms of adaptation and mitigation being adopted around the globe provides a valuable opportunity for learning what works in what context. For example, relatively modest investments in the database of the International Forestry Resources and Institutions network have yielded substantial scientific and practical insights (e.g., Phelps et al, 2010; Persha et al, 2011).

The Plan needs to more clearly recognize that information about other countries' climate change response policies and actions, and their participation in international institutions and agreements, is a necessary input to any projections of future global changes. It is also necessary to track trends and projections for international commodity markets (especially for fossil fuels), and consumption patterns, as this has important long-term effects on the trajectories of many global changes. Some specific places in the Plan where this sort of international focus could be added include Objective 1.1 (*Earth System Understanding*) at L.673-680, Objective 1.4 (*Integrated*

Modeling) at L.1647-1653, Objective 2.2 (*Inform Mitigation Decisions*) at L.2126-2166, and Chapter IV (*Coordinating with Other Nations*) at L.3377-3385.

An integrated approach. The Committee suggests that the USGCRP take an integrated approach to considering research needs of "Impacts, Vulnerability, Adaptation, and Mitigation" holistically. The Plan does contain a few references to the interactions and tradeoffs between mitigation and adaptation (e.g., L.1109), but identifying Objectives 2.1 and 2.2 separately may obscure attention to the relationships between mitigation and adaptation that decision makers need to consider. It should be recognized, for instance, that the value of adaptation efforts depends on the magnitude and timing of mitigation efforts; and that both are components of reducing risk (risk equals probability times consequence; mitigation reduces the probability of adverse effects and adaptation reduces their consequences). It is particularly important to explore how mitigation efforts may interact with adaptation efforts and vice-versa. (As just one example, promoting the increased use of air conditioning as an adaptation strategy may increase energy use and thus undermine mitigation efforts).

Prioritizing key vulnerabilities. We suggest that the Plan more directly confront the question of how research into key vulnerabilities can be prioritized across the country, to more efficiently spend scarce research resources of time, funding and talent. Given that every source of concern cannot receive the same detailed level of attention, there is a need for "triage" mechanisms that would allow the USGCRP to scan the country for significant changes in the incidence of important global change impacts, and superimpose the geographic distribution of those changes (likelihood) over the distribution of vulnerable sectors, locations and activities (consequence), in order to locate places and contexts where detailed analyses of potential adaptation strategies are most needed. An example of research that uses geographic analysis to evaluate vulnerability is presented in Box 4.

BOX 4

Example of the Use of Geographic Analysis in Assessing Climate Change Risks

Strzepek et al. (2010) explores how one might evaluate the geographic variations in climate-driven changes in drought frequency. Drought frequency projections vary widely across climate models and climate sensitivity estimates, particularly over the longer term and in the higher (IPCC) emission scenarios. The initial spatial and temporal distributions of drought frequencies could, however, support the identification of local/regional "hot spots" by "overlaying significant changes in drought frequencies (and/or widening disagreement of those changes across climate projections) over geographically explicit distributions of water sensitive sectors and population centers."

The results from Strzepek, et al. suggest that lower greenhouse gas concentrations are consistently associated with lower drought frequency across the country. Their results demonstrate the potential value added of tracing geographically distributed measures of a physical impact of climate change (and select downstream measures of socio-economic risk for key vulnerabilities for which adaptation options might be explored) for alternative mitigation futures. This opens a door for exploring the degree to which mitigation and adaptation can complement

one another *and* the degree to which current mitigation decisions lock us into the more severe ends of the distributions of future risks.

Research to support iterative risk management. Given the enormous uncertainties that cloud our understanding of the climate system and what will drive it into the future, responding to the associated risks requires iterative decision-making. This concept is discussed in IPCC, 2007; and a common theme of all the ACC reports is the need for iterative approaches and a national commitment to monitoring and learning from emerging evidence (i.e., evidence about climate change impacts, societal reactions to such impacts, and the effectiveness of response actions). Iterative decision-making is required both for mitigation and for adaptation decisions. For mitigation, it is necessary to monitor and respond to a wide array of factors such as socio-economic developments, international participation in mitigation efforts, energy sector developments, consumption patterns, and the efficacy of mitigation policies. For adaptation, it is necessary to better understand the forces that determine how responses can adjust to changing conditions (i.e., why in some cases adjustment can be quick and are nearly costless, while in other cases adaptation is slow and costly).

But the iteration process itself needs to be explored and understood more fully. We do not have a full understanding of what to monitor as we contemplate iterative decisions, or what metrics of risk are most useful to decision-makers. Nor do we have internally consistent indictors of risk for localities or methods to aggregate such indicators to national or international levels. The USGCRP can both help to build iterative learning processes and explore the important research questions embedded in such processes.

The Plan does an admirable job in noting that we must learn by doing. But it does not clearly identify the need for systematic research to learn what is succeeding (or not) in terms of communications, outreach, information sharing, and a variety of other efforts essential to iterative risk management. While there is a long history of evaluation research to assess the merits of social, educational, and health programs, such evaluations have been much less common for environmental programs. Learning from experience requires institutionalizing a national learning process in ways that have not been attempted before. It also requires a serious commitment of resources. It would be appropriate, for instance, to suggest that that a fixed percent of the budget for mitigation and adaptation efforts be devoted to monitoring, data management, and evaluation research so that the lessons to be learned from these experiences are not lost.

DECISION SUPPORT

Decision support, which has been defined as "organized efforts to produce, disseminate, and facilitate the use of data and information in order to improve the quality and efficacy of climate-related decisions" (NRC, 2009) is a major objective in the USGCRP Strategic Plan. The concept is discussed most explicitly in Goal 2 *(Informing Decisions)*, but it also relates to Goal 3 *(Sustained Assessments)*, and to Goal 4 *(Communicate and Educate)* which is discussed in the next section of this review.

Informing Decisions in a Changing Climate (NRC, 2009b) suggested the following principles of effective decision support: "(1) begin with users' needs; (2) give priority to process

over products; (3) link information producers and users; (4) build connections across disciplines and organizations; (5) seek institutional stability; and (6) design processes for learning". The report also recommends that "the nation needs to establish a coordinated system of climate services that involves multiple agencies and regional expertise, is responsive to user needs, has rigorous scientific underpinnings (in climate research, vulnerability analysis, decision support, and communication), performs operational activities (timely delivery of relevant information and assessments), can be used for ongoing evaluation of climate change and climate decisions, and has an easily accessible information portal that facilitates coordination of data among agencies and a dialogue between information users and providers."

The USGCRP has an important role to play in informing decisions about global change. In order to play this role effectively, we suggest a number of key areas that deserve attention:

- The Plan needs to demonstrate a clear, consistent understanding of what is needed for effective decision support and make clear how it will develop the scientific underpinnings required to provide the kinds of information that decision makers need. For example, the discussion of informing mitigation decisions mentions that decision makers need to "understand the effects of policy options on greenhouse gas emissions, the costs of reducing emissions, and the benefits of avoiding greenhouse gas emissions" (L.2119-2121). The Plan should indicate support for the lines of research that would provide a necessary foundation for such information, but it includes only one sentence on advances in the social, behavioral, and economic sciences of mitigation [L.1102-1105]. If the intent is to rely on integrated assessment modeling, the Plan needs to more clearly articulate the research efforts that would help advance these models.

- The discussion under Goal 2 defines a broad, ambitious set of roles that includes decision support processes ("engagements between scientists and decision makers"), provision of decision support products, research coordination, and provision of decision support services to federal agencies and departments (L.1966-1979). These different roles (in particular, the need for both processes and products) need to be more consistently addressed in the subsequent discussions. For instance, the Plan defines climate services as "the development and timely provision of information products" (L.2173), ignoring the distinction between process and product and the need for communication processes to ensure that products are useful and usable.

- The Plan needs to establish a clear division of responsibility between the Program and other entities regarding decision support service provision. The Plan does not demonstrate that the USGCRP is ready or able to make effective links to the many boundary organizations[6] inside and outside the federal government that can connect climate change

[6] Guston (2001) described boundary organizations as units that link the different social worlds of science and decision-making, which "involve the participation of actors from both sides of the boundary, as well as professionals who serve a mediating role; [boundary organizations] exist at the frontier of the two relatively different social worlds of politics and science, but they have distinct lines of accountability to each." Also see Clark et al (2010).

research to user constituencies. Such linkages are mentioned several times in the Plan, but never with sufficient detail to suggest that the Program is ready to meet the challenge.

As concluded in an ACC study (NRC, 2010d) "there is an urgent need to improve the coordination of climate information, decisions, assessment, and programs across federal agencies to ensure an effective response to climate change across the nation." This report suggested that an expanded USGCRP might contribute to this effort, but that leadership at a higher level would be needed to achieve effective federal coordination. The Strategic Plan should be more specific about the roles the Program will play in meeting this challenge and about how it will coordinate with decision support efforts among the federal agencies and with other boundary organizations.

The Plan likewise should set a consistent boundary between research activities and non-research activities. A set of general guidelines for setting such boundaries can be derived from a series of recent NRC reports (NRC, 2009, 2009b, 2010a), which distinguish research (which develops knowledge) from services (which make the knowledge useful for decision making). Some key elements of the Plan, such as advancing mitigation and adaptation, involve both science and services. Decision support likewise involves both. Science, services, and the connections of the two are all critically important, but they need not all be performed by the same organizations.

As a general guideline, the Committee suggests that that the primary role of the USGCRP with respect to decision support should be research *for* decision support and research *on* decision support (see Box 5 for examples). Research for decision support provides knowledge about choices (e.g., about possible options for meeting mitigation or adaptation goals and the feasibility, benefits, and costs associated with each option); while research on decision support uses knowledge from the decision sciences (e.g., Kahneman et al., 1982; Raiffa, 1968) to help to make choices more systematic and well-considered.

BOX 5
Recommendations on Research *for* and Research *on* Decision Support

The following are recommendations from the report *Informing Decisions in a Changing Climate* (NRC, 2009a) that may prove helpful to the USGCRP.

"The research for decision support should have five substantive foci:

- understanding climate change vulnerabilities: human development scenarios for potentially affected regions, populations, and sectors;
- understanding the potential for mitigation, including anthropogenic driving forces, capacities for change, possible limits of change, and consequences of mitigation options;
- understanding adaptation contexts and capacities, including possible limits of change and consequences of various adaptive responses;
- understanding how mitigation and adaptation interact with each other and with climatic and ecological changes in determining human system risks, vulnerabilities, and response challenges associated with climate change; and

- understanding and taking advantage of emerging opportunities associated with climate variability and change.

The research on decision support should have five substantive foci:

- understanding information needs;
- characterizing and understanding climate risk and uncertainty;
- understanding and improving processes related to decision support; including decision support processes and networks and methods for structuring decisions;
- developing and disseminating decision support products; and
- assessing decision support "experiments".

In contrast, operational-level decision support should be the responsibility of boundary organizations throughout the public and private sectors that serve constituencies affected by global change. These services should be provided by the organizations best positioned for the role. These sometimes lie within the USGCRP. For example, NOAA could appropriately provide climate-related decision support to its constituencies in the coastal management community, USDA to farmers and foresters, and DOI to managers of public lands. In many cases, however, the most appropriate service providers are not part of the USGCRP. The general principle is that decision support should come from scientifically informed organizations that are easily linked to target audiences.

The USGCRP should provide mechanisms to link research to the appropriate boundary organizations. Box 6 suggests some criteria that the USGCRP could use in working with boundary organizations, to identify the contexts in which decision support efforts will be most feasible and effective.

BOX 6
Criteria for Assessing the Value of Decision Support

Goal 2 of the Strategic Plan indicates that USGCRP will have responsibility for guiding its member agencies to produce scientific knowledge that is credible, while working with users of that knowledge to assure that it is also salient and legitimate. What makes knowledge salient in a decision making context is that it be relevant and timely. Such salience is often in tension with scientific credibility, earned by careful testing, peer review, and publication in the open literature. The challenge is to reconcile these tensions in a way that honors the values of both users and researchers. We present below some examples of factors that the USGCRP should consider in managing the difficult balancing act of setting priorities for decision support. These lists are drawn from other contexts (e.g., global assessment processes, foundation grant-making processes) that are not entirely analogous to the USGCRP, but nonetheless seem quite relevant (Packard Foundation, 2010; Clark et al, 2006, 2010).

Whether a decision situation is ripe:

- Are there openings for rethinking, in which decision makers are seeking new information?

- Can new information be provided in time for the decision-making window?
- Are there good prospects that new information will be influential?

Whether the boundary between science and use can be spanned:

- Do stakeholders agree that the questions to be investigated are important, even when they disagree on desirable answers?
- Is there a boundary object, like an assessment, on which users and researchers can collaborate?
- Are actors who can influence success engaged by scientists or those working at the boundary?

Whether the actors have appropriate capabilities:

- Do researchers have the capacity to conduct the inquiry? If the questions to be answered require an interdisciplinary approach, is the research team capable of integrating knowledge across disciplines?
- Do those conducting the research have the interest and capacity to work with stakeholders?
- Are early adopters of the knowledge identified? Are they able to use it and communicate their experiences to other decision makers and stakeholders?

Whether the conditions for joint production of knowledge by users and researchers exist:

- Do potential users believe that the information process took account of concerns and insights of relevant stakeholders and was procedurally fair (Legitimate)?
- Do potential users believe that the scientific knowledge is relevant to their decision-making and timely in its availability (Salient)?
- Do potential users believe that the information has taken into account issues of data reliability, appropriate methods and validity of inferential claims, consideration of alternative hypotheses (Credible)?

Whether behavioral changes can be observed when knowledge is used:

- Are there changes in behavior and policies of relevant actors?
- Are there changes in actor goals, interests, beliefs, strategies and resources?
- Is there increased willingness and capacity to learn?

Expansion of the Program to help support decisions by conducting research, linking research to action, and providing decision support services to certain constituencies is highly appropriate. Such an expansion, however, does raise feasibility concerns, in terms of competition for scarce resources and the capacity of USGCRP agencies. The Program will need to increase scientific expertise that is scarce in member agencies (particularly in the social sciences), and to provide resources for improving links between producers and users of the science. As noted in NRC (2009), ”for many of the agencies that need to be involved, decision support research or services are not part of their current missions, and they lack offices and personnel with the responsibilities and expertise to manage the research.”

Assessment as Decision Support. The Plan’s discussion of the National Climate Assessment (Goal 3) is admirably clear and consistent. It recognizes that the assessment needs to be a process and also to generate products, and it articulates a way to do both, while maintaining

the process over time. It also articulates a strategy for using the assessment process to inform research that will, in turn, feed into future assessment products.

One issue that may merit further explanation in the Plan is that (as noted earlier), the GCRA does actually mandate a *global* change assessment, not one restricted to climate change. We recognize that expanding the bounds of the National Climate Assessment may not be feasible within current budgetary constraints or given the current scientific scope of the program, which does not encompass all of global change. But we encourage the USGCRP to explore the possibility of expanding the scope of its assessment efforts over time, and in the interim, to use the assessment process to expand understanding of how climate change affects and interacts with other aspects of global environmental change.

The Plan states that "Assessments support achievement of all the other goals of the USGCRP Strategic Plan" (L.2554). This should frame a discussion of how the assessment process can engage users and set priorities within USGCRP. The Plan mentions a wide range of audiences (L.2428-2515) but does not create clear expectations of how the USGCRP will work with them. The assessment process is called "ongoing" (L.2472) but the ongoing participation of users is not described. At a minimum, the Plan should articulate how it will link its ongoing assessment activities to its decision support tasks.

The discussion of Goal 3 could be strengthened by recognizing that subsections 3.1-3.4 are each organized around different aspects of jointly producing useful knowledge. Section 3.1 (*Integrating Science*) emphasizes scientific credibility in the content of assessments. Section 3.2 (*Ongoing Capacity*) describes efforts to engage stakeholders and to improve transparency, in order to build the legitimacy of the assessments. Section 3.3 (*Inform Responses*) is about providing knowledge that is salient to a diverse range of users. Section 3.4 (*Evaluate progress*) highlights the role of assessment as a means for social learning (i.e., reviews of the state of understanding naturally lead to an appreciation of knowledge gaps and limitations, which is useful both for planning future research.) By framing the discussions of Sections 3.1-3.4 in this way, the Plan would make clear that the assessment process entails balancing different, sometimes conflicting aims in the production of knowledge that is useful in decision making.

Goal 3 does not spell out how demand for assessments would be identified, beyond noting the legal mandate for a National Climate Assessment. Processes like the IPCC and Millennium Ecosystem Assessment are grounded in an authorizing environment; that is, they respond to an official request to convene representatives of the relevant scientific communities to provide a report on the current state of knowledge. The importance of having a clear authorizing environment that identifies primary users of the assessment outcomes was noted in the NRC report *Analysis of Global Change Assessments* (NRC, 2007b). If the USGCRP is working within a framework of use-inspired research, it is essential to identify key users at the outset (beyond just the American public in a generic sense), because those users need to be partners in defining the scope of the assessment. This joint production mechanism is what gives the knowledge produced the chance to be salient, legitimate, and scientifically credible.

COMMUNICATION, EDUCATION, AND WORKFORCE DEVELOPMENT

Goal 4 of the Plan discusses the need for research on communication and education to expand knowledge and inform public decision making, for evaluation of educational efforts, for identifying best practices, for reaching diverse audiences, and for engaging stakeholders. These are all generally appropriate as goals for the Program, but in the Committee's judgment, much of this content (e.g., research assessing the effectiveness of communication efforts; understanding best practices in communication and education) is more logically discussed under Goal 2 (*Informing Decisions*). Perhaps communication and education were separated into a distinct Goal in order to elevate their importance as elements of the Program. But the Committee suggests that it makes sense to place the objective to "Strengthen Communication and Education Research" under Goal 2, and to have Goal 4 focus just on the actual practice of communication and education.

A more substantive concern is that the Plan does not clearly define a division of labor between the USGCRP and other entities, both within and outside of the federal government, that also engage in communication and education about global change. It difficult to determine which of the proposed activities are considered core elements of the USGCRP, as opposed to activities that may be accomplished largely outside the USGCRP framework; and likewise is difficult to determine how USGCRP efforts will be coordinated with externally-driven activities.

For all of the different activities discussed in this section, it would be helpful to see a clearer identification of the specific roles planned for the Program (e.g., Will USGCRP agencies take on specific activities? Will other activities be performed jointly or entirely by entities outside the Program?). We suggest the same general guideline for education and communication as we suggested earlier for decision support efforts – they should be the responsibilities of boundary organizations that are best positioned for the role, which in many cases may be organizations that are not part of the USGCRP.

The Plan should clearly state that a primary role for the USGCRP is to build a sound scientific foundation for global change communication and education. And it should make clear that public communication and education efforts need to be evidence-based, two-way processes aimed at improving the capacity of target audiences to make informed choices, not at simply delivering information or persuading these audiences to accept government positions. These ideas are further discussed in past NRC work on environmental communication and science education (NRC, 1989, 1996, 2007e, 2008b, 2011b).

Some of the communication and education activities proposed in the Plan seem appropriate and feasible as parts of the Program. These include for instance, research on the effectiveness of global change communication and support for "communities of practice." But the Plan also appears to promise that the Program will do things that it may not be appropriately organized or realistically able to do; for instance, "improving educational materials and resources" (L.3113) and "developing programs and forms of engagement to facilitate communication and education among citizens, stakeholders, partners, and the participating agencies" (L.3145-3146).

The stated intention to "coordinate an effort to raise environmental literacy and develop a future workforce that actively integrates global change and environmental considerations into future activities" (L.3244-3246) could engage the Program in everything from sponsoring museum exhibits to changing the K-12 science curriculum. Objectives in this domain should be defined

more clearly, and should identify a division of labor between activities conducted within the Program and possible collaborations with other federal agencies, with organizations in state and local government, and with the education community. There should be a much more focused description of the specific roles to be played by the USGCRP itself.

In the education domain, the Program might appropriately co-sponsor (in collaboration with other federal education and science agencies) research on public understanding of climate change and on teaching strategies for improving such understanding. In the communication domain, it might support research to improve decision support products or communication processes, or training for researchers on how to explain climate change information and uncertainties to various audiences, as was recommended in the ACC studies (NRC, 2010d).

The writing in this section of the Plan is overly vague in important places. For example, "USGCRP will employ appropriate methods and processes for engaging with and seeking feedback and input from partners, participating agencies, and constituents" (L.3156-3157). Such language is not sufficiently specific to know how to evaluate or implement the Plan. Also, the Plan does not distinguish between different categories of education audiences (including, for instance: (i) climate change scientists, (ii) stakeholders who make real-world mitigation and adaptation decisions and thus need some familiarity with the science, and (iii) the general public. Educating the next generation of global change researchers is materially different from educating the general public or engaging stakeholders, but this distinction is not made clear in the Plan.

Finally, this section also makes promises that are neither supported elsewhere in the Plan nor adequately justified. For example, the Plan states that "A major goal for USGCRP is to understand the connections among the environmental knowledge, opinions, attitudes, and behaviors of its diverse audiences" (L.3000-3001). But there is no indication that the Program will support research on global change knowledge, attitudes, and behavior, and no argument is presented that supporting such research would help with communication about global change. The Committee commends the USGCRP for highlighting this important area of research, but suggests that the rationale for it be stated more directly, and that a clear strategy for supporting research in this area be articulated (for instance, see Marquart-Pyatt et al, 2011).

The overall goal of Objective 4.4 (*Cultivate Workforce*) is to "cultivate a capable, diverse workforce that is knowledgeable about climate and global change." The Plan speaks to three elements of workforce: new scientists and future leaders, federal employees and contractors, and a next-generation workforce (which would appear to include training for workers in the "green jobs" or alternative energy sector). The needs for these different kinds of workers are quite different, and the roles that the Program would play in cultivating these different parts of the national workforce are not clearly specified. (Further, these are not mutually exclusive categories, since many climate change scientists are federal employees).

This section of the Plan includes some elements that seem appropriate and feasible, and others that do not. The USGCRP has a major role to play in development of the *scientific* work force needed to further its goals, including a workforce of social scientists and interdisciplinary researchers. This section of the Plan appropriately targets workforce development efforts at the undergraduate, graduate, and postdoctoral levels to develop a next generation of scientists in the range of research fields related to climate and related global changes.

The Committee questions, however, the feasibility of the ambitious goal "to coordinate an effort to raise environmental literacy and develop a future workforce that actively integrates global change and environmental considerations into future activities." Doing this would go considerably beyond the original intent of the GCRA and the capabilities of the Program. In particular, engagement in job training for "green jobs," which is implied by some of the language, would go beyond what we judge to be the proper purview of the USGCRP.

The same is true for the professional development of educators in the STEM fields (Science, Technology, Engineering, and Mathematics) and the social sciences. While NSF support of professional development for educators is appropriate for that agency, such efforts are not (to our knowledge) an element of the USGCRP. We do, however, think it appropriate for the USGCRP to engage with NSF and other science education agencies in helping to develop curriculum and provide scientific content for educators who will be teaching about global change. Likewise, we do support strong programs to foster global change research in elementary schools, high schools, colleges and universities and among the general public (i.e., citizen science). Such efforts are a reasonable extension of USGCRP research, and are also essential to recruit the next generation of global change scientists.

KEY MESSAGES REGARDING THE BROADENING OF THE PROGRAM

The Plan makes strong cases for increasing the integration of social and ecological sciences and for expanding research to support mitigation and adaptation decisions and the enhancement of climate services. The Committee agrees that broadening in these ways would help the Program better fulfill its mission under the GCRA. The increased emphasis on informing decisions is particularly important and long overdue. Broadening the Program in the areas of education, communication, and workforce development is also appropriate, to the extent that these efforts follow the suggestions made earlier, for linking to activities outside of the USGCRP.

In addition to the proposed broadening of the Program into relatively new areas, the Plan also calls for expanding existing program elements to deal with growing needs in physical climate science; for instance, to keep up with the rapid expansion of physical climate data, to expand modeling efforts, and to intensify observational activities that allow for development of climate models with finer spatial and temporal resolution.

An obvious challenge is how to broaden the Program's scope in the planned ways and also expand efforts in traditional areas, all within a declining budget. The Plan suggests, in its section on implementation, that it will use "a phased approach" (L.3463) that will "ensure continuing strength at the scientific foundations of USGCRP (observations, modeling, and process research)" and "develop flexible plans for phasing in new activities and priorities over the decade" (L.3471-3473). This would seem to indicate that the ongoing strengths of the Program in physical climate science will get first priority and that new elements could be put on indefinite hold.

A second challenge concerns the limited capacity of the USGCRP agencies to broaden the Program into new areas related to decision support and integration of ecological and social sciences. Necessary scientific expertise (outside of economics) is scarce within the USGCRP member agencies and programs. Ideally, the USGCRP agencies should expand direct hiring of scientists with the needed expertise; but to the extent that hiring constraints make this approach

impossible, we encourage the Program to explore alternative ways of accessing that capacity – for instance, through engagement of the broader research community in universities and other laboratories, using a variety of grants and contracts. Unless the capacity issue is specifically addressed in this Plan, the USGCRP will likely fail to achieve the promised broadening of its scope.

In the Committee's judgment, the implied strategy of putting all the new elements of the Plan on hold until the funding situation improves is a mistake. The Strategic Plan itself makes compelling arguments for broadening the Program now to strengthen science for decision support, to more broadly integrate all the sciences of global change for earth system understanding, to develop science to inform climate change mitigation and adaptation decisions, and so forth. Unless the Program begins to invest in these new elements now, it runs the risk of supporting only research that (while of high scientific merit) may not deserve highest priority in terms of meeting the nation's needs for responding to global change. Moreover, without progress now, the Program will lack capacity to develop these areas later, if and when the funding situation improves. As suggested earlier, many of the initial investments that would help the Program broaden its scope are relatively low in cost and need not be postponed. Scientific priority setting should focus on the value of the information likely to be produced, more than on maintaining the momentum of past efforts.

The Committee believes that the Plan should explicitly acknowledge the challenges of phasing in new elements of the Program. The Program could face these challenges by: (1) establishing an appropriate interagency governance structure that has the authority, responsibility, and resources needed to implement the broader Program; and (2) identifying a set of specific, relatively low-cost initial efforts that lay the groundwork for a broader Program and improving the capacity of the participating agencies to undertake the planned work. Such an approach would, we believe, be feasible within the current budgetary context, and it would turn the planned broadening of the Program from what may seem like dubious promises into a credible Strategic Plan.

Key Messages:

The proposed broadening of the Program – to better integrate the social and ecological sciences, to inform decisions about mitigation and adaptation, and to emphasize decision support more generally – is welcome and in fact essential for meeting the legislative mandate for a program aimed at understanding and responding to global change. Although this broader scope is needed, implementing it presents a grand challenge that should be met with more than just incremental solutions.

An effective global change research enterprise requires an integrated observational system that connects observations of the physical environment with a wide variety of social and ecological observations. Such a system is a crucial foundation for identifying and tracking global changes; for evaluating the drivers, vulnerabilities, and responses to such changes; and for identifying opportunities to increase the resilience of both human and natural systems. The Plan needs to describe a clear vision and specific objectives for adding and integrating new types of observations, along with a commitment to some concrete steps towards realizing this vision.

The Plan also needs to present an appropriate governance structure and dedicated mechanisms to sustain existing long-term observational systems.

The USGCRP and its member agencies and programs are lacking in capacity to achieve the proposed broadening of the Program, perhaps most seriously with regard to integrating the social and ecological sciences within research and observational programs, and to developing the scientific base and organizational capacity for decision support related to mitigation and adaptation choices. Member agencies and programs have insufficient expertise in these domains and lack clear mandates to develop the needed science.

In the Committee's judgment, it would be a mistake to postpone phasing in the newer elements of the Program (as is implied in the implementation section of the Strategic Plan). Rather, we suggest that the Program identify some specific initial steps it will take in the proposed broadening of scope, including steps to develop critical science capacity that is currently lacking and to improve linkages between the production of knowledge and its use. The Program's implementation plan should assign responsibilities and resources to specific entities to lead those efforts.

The proposed broadening of the Program in the areas of education, communication, and workforce development needs more careful thinking, regarding which of these activities belong within the Program, which are best organized by entities outside the Program, and how the former will link to the latter.

5
Process, Structure, and Implementation Issues

Although the last section of the Plan is labeled implementation, it offers much less detail than previous Strategic Plans, which provided a clearer picture of how implementation would be developed through program management and review – including explicit discussion of what groups were making decisions, how the Office of Management and Budget and the Office of Science and Technology Policy would collaborate in providing leadership, the role of interagency programmatic working groups in prioritizing specific areas of research, and the role of the NRC and other external bodies in providing external review and validation of the program. The current Plan lacks transparency about such issues. The intent to move to a more integrated approach across the sciences and to better link science producers and users makes it particularly important to provide some insight into how decisions and coordination related to particular research areas will be handled. (For instance, will the current configuration of USGCRP Interagency Working Groups be discontinued? Will a different configuration of Working Groups be formed?)

The Committee understands that some of these details will be provided in a forthcoming Implementation Plan. At present, however, we have only the draft Strategic Plan to comment on. We suggest that the final Strategic Plan or the subsequent Implementation Plan should more fully address the key implementation issues described below.

Governance structure. The Plan calls for a fundamental reorientation of the Program in ways that will require new forms of interagency collaboration and the subordination of some agency priorities to overarching, program-wide goals and national needs. The draft Plan needs to suggest a governance structure that can make the proposed changes reality. This includes a need to spell out the commitments of member agencies to carry out the parts of the Plan (both singly and jointly with other agencies), and a need to discuss processes for priority setting (discussed below) and criteria for phasing in various efforts over time.

To be effective, this governance structure needs to be a committed partnership among the participating departments and agencies of the USGCRP, the relevant Administration offices (including, at a minimum the Office of Management and Budget, the Office of Science and Technology Policy, the Council on Environmental Quality, and the Domestic Policy Council), the Global Change Research Sub-Committee representatives, and the USGCRP Office leadership. It is not clear that this sort of broad-based partnership currently exists.

On a related note, it would be useful for the Plan to mention something about mechanisms for interaction with Congress. This may include, for instance, describing how USGCRP committees, working groups, staff, etc. will help meet Congressional requests for briefings and updates on the Program; and discussing how the Program will seek opportunities for hearings, staff briefings, and other means to keep the Congress as fully informed as possible (as appropriate with respect to Administration policies).

Defining an appropriate, effective governance structure for the USGCRP is, of course, a complex challenge. The Committee itself does not necessarily have the expertise to offer specific

recommendations in this regard (especially in the context of this very quick review process), but we do suggest that this matter be given explicit consideration by an independent expert group.

Setting priorities. The Plan states commitments to many important new research directions – for instance, to improve understanding of how natural and social conditions interact to affect resilience and vulnerability; to develop methods for valuing ecosystem goods and services; to improve characterization of uncertainty in ways that enable decision makers to evaluate options. In fact, the Plan states directly that the USGCRP will pursue some important endeavor at least 177 times, not counting numerous additional commitments for action stated in textboxes throughout the document. Yet the Plan gives no clear indication of an approach to prioritizing these numerous commitments in a manner that will move beyond business-as-usual.

The Plan needs to identify what criteria and management structure will enable the Program to prioritize across existing and new research. The three criteria listed at L.3547 -3551 are too general to provide enough guidance to prioritize. (For instance, would such criteria help in choosing between an existing project on aerosol-cloud interactions versus a new activity that integrates social and natural science to support improved management of air quality and its linkages to global change?)

More specific criteria for prioritization, such as those discussed in ACC *Advancing the Science* report (NRC, 2010a; P.156-158) would be a step in the right direction. We particularly note that report's emphasis on criteria related to the value of science for informing decision making. Consideration of decision makers' needs might lead the Program to consider thematic approaches to defining research goals (i.e., science to address choices about providing clean water, sustaining marine ecosystems, providing better public health warnings, etc.).

Evaluation and updating. The Plan appropriately notes the value of using an adaptive management approach to evaluate progress and update the Plan based on input from those using research to inform decisions. However, it needs to be clearer about the specific questions the Program will address and expected outcomes and milestones against which it could be evaluated in the near-term (3-5 years). It should include specific mechanisms for periodic review and updating of the Plan in light of changes in international circumstances, technological developments, and budget appropriations, and in light of what is learned about what has and has not worked well within the Program's operations. The Plan would also be strengthened by identifying steps to make the Program more resilient to the expected funding turbulence ahead. Ideally, there should also be consideration of plans for assessing the USGCRP itself – not of the science the Program produces, but of what has and has not worked well within the Program's operations (including consideration of the governance questions mentioned above). This sort of assessment, which has not been done in the Program's 20 year history, could help the USGCRP to establish priorities and implementation strategies.

Key Messages:

The Strategic Plan and/or the Implementation Plan to follow should establish clear processes for setting priorities and phasing in and out elements of the Program, especially in relation to the planned broadening of its scope. The Program should employ iterative processes for periodically evaluating and updating the Program and its priorities, including processes for consultation with decision makers inside and outside the federal government, regarding the scientific knowledge about global change that would provide the greatest value for them.

The USGCRP needs an overall governance structure with responsibility and resources to broaden the Program in the directions outlined in the Plan, including the ability to compel reallocation of funds to serve the Program's overarching and long-term priorities. Without such a governance structure, the likely evolution of the Program will be business as usual: a compilation of program elements that derive from each member agency's individual priorities.

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A

Statement of Task for the NRC Committee to Advise the U.S. Global Change Research Program

An expert committee will provide ongoing and focused advice to the US 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 US Global Change Research Program will:

1. Provide ongoing, integrated advice to the USGCRP on broad, program-wide issues when requested. This will begin with a review of the 2011 USGCRP Strategic Plan (see below) and is expected to include other tasks such as a review of the national climate assessment and/or an 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.

Statement of Task for the Review of the Draft USGCRP Strategic Plan

The committee will conduct an independent review of the U.S. Global Change Research Program's draft strategic plan (concurrent with public review). The review will address the following questions about the draft plan:

1. Is the plan responsive 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. Are the plan’s goals clear and appropriate?
3. Is there an appropriate balance between short-term and longer-term goals, among

substantive research areas, and between research and non-research activities, such as observations, modeling, and communication?

4. Are there adequate mechanisms for coordinating and integrating issues that involve multiple disciplines and multiple agencies?
5. Does the plan adequately describe the relationships between the Program and its agency participants, and between the Program and the public, the private sector, academia, state/local governments, and international communities?
6. Does the written document describing the program effectively communicate with both stakeholders and the scientific community?
7. Are there any content areas missing from the plan that should be present if the Program is to achieve its overall vision and mission?

B

Committee Member Biographical Sketches

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. In 2010 he was awarded the National Medal of Science by President Obama.

Kai N. Lee (*Vice Chair*) leads the Science subprogram in Conservation & Science at The David and Lucile Packard Foundation. The science subprogram provides support for science that informs decision making in the near term, advancing the strategies guiding the conservation activities of the Foundation. He also provides program support and liaison for the Monterey Bay Aquarium Research Institute, the Center for Ocean Solutions, and the Aldo Leopold Leadership Program. He taught at Williams College from 1991 - 2007 and is the Rosenburg Professor of Environmental Studies, emeritus. He directed the Center for Environmental Studies at Williams from 1991–1998 and 2001–2002, and taught from 1973 - 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). 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.

Mark R. Abbott is dean of the College of Oceanic and Atmospheric Sciences at Oregon State University, Corvallis. His research focuses on the interaction of biological and physical processes in the upper ocean, remote sensing of ocean color and sea surface temperature, phytoplankton fluorescence, and length and time scales of phytoplankton variability. He deployed the first array of bio-optical moorings in the Southern Ocean as part of the United States Joint Global Ocean Flux Study (JGOFS). Dr. Abbott chairs the U.S. JGOFS Science Steering Committee and was a member of the MODIS and SeaWiFS science teams. He is currently a member of the board of trustees for the Consortium for Ocean Leadership and a member of the National Science Board. Dr. Abbott has also served as the chair of the SSB's Committee on Earth Studies. Other prior NRC

service includes the Committee on Indicators for Understanding Global Climate Change, the Committee on the Role and Scope of Mission-Enabling Activities in NASA's Space and Earth Sciences Missions, and the Panel on Land-Use Change, Ecosystem Dynamics, and Biodiversity for the 2007 decadal survey on Earth science and applications from space. Dr. Abbott is currently a member of the NRC's Committee on an Assessment of NASA's Earth Science Program, which is carrying out a mid-decade assessment of the implementation of the Earth science and applications from space decadal survey. He is also a member of the board of trustees for the University Corporation for Atmospheric Research.

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 2008-2010. Prior to coming to his current position, Arent was Director of the Strategic Energy Analysis Center at NREL from 2006-1010. 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 - 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.

Robert E. Dickinson (NAS,NAE) is a respected leader in dynamic meteorology, physical climatology and climate modeling for the last four decades. He first delineated the way planetary scale Rossby waves interact with the mean flow--a process central to understanding the general circulation of the atmosphere. He has also established the major role of foliage in climate dynamics and made major contributions to other problems. His areas of interest include the dynamics of atmospheric planetary waves, stratospheric dynamics, models of global structure and dynamics of terrestrial and planetary thermosphere, NLTE infrared radiative transfer in planetary mesopheres, global climate modeling and processes, the role of land processes in climate systems, the modeling role of vegetation in regional evapotranspiration, and the role of tropical forests in climate systems. His recent research has focused on climate variability and change, aerosols, the hydrological cycle and droughts, land surface processes, the terrestrial carbon cycle, and the application of remote sensing data to modeling of land surface processes. He is an elected member of both the US National Academy of Sciences and the National Academy of Engineering, an honorary member of the European Geophysical Society and the European Geo-sciences Union and a Foreign member of Chinese Academy of Sciences. He has been a member of numerous scientific advisory organizations, including the National Research Council. He holds a M.S. (1962) and Ph.D. (1966) in Meteorology from the Massachusetts Institute of Technology.

Thomas Dietz is Assistant Vice President for Environmental Research, Professor of Sociology, Environmental Science and Policy, and Animal Studies at Michigan State University. His current research examines the human driving forces of environmental change, environmental values and the interplay between science and democracy in environmental issues. Dietz is also an active participant in the Ecological and Cultural Change Studies Group at MSU. 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, and the Outstanding Publication Award, also from 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.

Henry D. Jacoby is Professor of Management in the M.I.T. Sloan School of Management and former Co-Director of the M.I.T. Joint Program on the Science and Policy of Global Change, which is focused on the integration of the natural and social sciences and policy analysis in application to the threat of global climate change. He oversees the design and application of the social science component of the Joint Program's Integrated Global System Model – a comprehensive research tool for analyzing potential anthropogenic climate change and its social and environmental consequences – and he is a leader of M.I.T. research and analysis of national climate policies and the structure of the international climate regime. An undergraduate mechanical engineer at the University of Texas at Austin, Professor Jacoby holds a Ph.D. in Economics from Harvard University where he also served on the faculties of the Department of

Economics and the Kennedy School of Government. He has been 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 made extensive contributions to the study of economics, policy and management in the areas of energy, natural resources and environment, writing widely on these topics including seven books. He currently serves on the Scientific Committee of the International Geosphere-Biosphere Program.

Maria Carmen Lemos is Professor of Natural Resources and Environment at the University of Michigan, Ann Arbor and Senior Policy Scholar at the Udall Center for the Study of Public Policy at the University of Arizona. She has MSc and PhD degrees in Political Science from the Massachusetts Institute of Technology, MIT. During 2006-2007 she was a James Martin 21st Century School Fellow at the Environmental Change Institute at Oxford University. Her research focuses on environmental public policymaking in Latin America and the U.S., especially related to the human dimensions of climate change, the co-production of science and policy, and the role of technoscientific knowledge and environmental governance in building adaptive capacity to climate variability and change response. She is a co-founder of Icarus (Initiative on Climate Adaptation Research and Understanding through the Social Sciences), which seeks foster collaboration and exchange between scholars focusing on vulnerability and adaptation to climate change. She is a lead author of the Intergovernmental Panel on Climate Change (IPCC) and a contributor to the US Climate Change Science Program Synthesis Reports. She has served in number of NRC/NAS committees including Restructuring Federal Climate Research to Meet the Challenges of Climate Change, America Climate Choice Science Panel and the Human Dimensions of Environmental Change Committee.

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.

Camille Parmesan's early research focused on multiple aspects of population biology, including the ecology, evolution and behaviors of insect/plant interactions. For the past several years, the focus of her work has been on current impacts of climate change in the 20th century on wildlife. Her work on butterfly range shifts has been highlighted in many scientific and popular press reports, such as in Science, Science News, New York Times, London Times, National Public Radio, and the recent BBC film series "State of the Planet" with David Attenborough.The intensification of global warming as an international issue led her into the interface of policy and science. Parmesan has given seminars in DC for the White House, government agencies, and NGOs (e.g., IUCN and WWF). As a lead author, she was involved in multiple aspects of the Third

Assessment Report of the IPCC (Intergovernmental Panel on Climate Change, United Nations). Parmesan received her B.S. degree from the University of Texas at Austin in 1984 and received a Ph.D. in Biological Sciences from UT Austin in 1995.

Karen C. Seto is an Associate Professor of the Urban Environment, in the School of Forestry and Environmental Studies, Yale University. She studies the human transformation of land and the links between urbanization, global change, and sustainability. Her research focuses on characterizing urban land-use dynamics, understanding the process of urbanization, examining the environmental consequences of land-use change and urban expansion, and forecasting urban growth. Professor Seto's geographic expertise is Asia, especially China and India. Professor Seto is Co-Chair of the Urbanization and Global Environmental Change Project of the International Human Dimensions Programme on Global Environmental Change, and a Coordinating Lead Author for Working Group III of the IPCC Fifth Assessment Report. She also serves on the U.S. Carbon Cycle Science Steering Group and the NRC Geographical Sciences Committee. She is the Executive Producer of "10,000 Shovels: Rapid Urban Growth in China," a documentary film that integrates satellite imagery, historical photographs, and contemporary film footage to highlight the urban changes occurring in China. Professor Seto is an Aldo Leopold Leadership Fellow and recipient of a NASA New Investigator Program Award, a NSF Career Award, and a National Geographic Research Grant. She has a Ph.D. in Geography from Boston University.

Kathleen J. 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. Vorosmarty is a Professor of Civil Engineering, a Distinguished Scientist with the 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 two hundred 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. Vorosmarty also is on several national and international advisory 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).

John M. Wallace (NAS) has directed his research at improving our understanding of global climate and its year-to-year and decade-to-decade variations, making use of observational data. He has contributed to the identification and understanding of a number of atmospheric phenomena, including the vertically propagating planetary waves that drive the quasi-biennial oscillation in zonal winds in the equatorial stratosphere, the 4-5-day period easterly waves that modulate daily rainfall over the tropical oceans, and the dominant spatial patterns in month-to-month and year-to-year climate variability, including the one through which the El Nio phenomenon in the tropical Pacific influences climate over North America. He has contributed to documenting the existence of El Nino- like variability on a decade to decade time scale (the so called 'Pacific Decadal Oscillation'). He earned a B.S. in Naval Architecture (1962) from the Webb Institute of Naval Architecture. He then went on to earn a Ph.D. in meteorology from the Massachusetts Institute of Technology in 1966.

Gary W. Yohe is the Huffington Foundation Professor of Economics and Environmental Studies at Wesleyan University; he has been on the faculty at Wesleyan for more than 30 years. He received his PhD in Economics from Yale University in 1975. Most of his recent work has focused on bringing risk-management perspectives to the mitigation and adaptation/impacts sides of the climate issue. Involved with the IPCC since the mid 1990s, he served as a Lead Author for four different chapters in the Third Assessment Report and as Convening Lead Author for the Fourth Assessment Report. In the Fourth Assessment, he also worked with the Core Writing Team to prepare the overall Synthesis Report. He is now serving as a Lead Author in one chapter and a Convening Lead Author in another for the Fifth Assessment Report. Dr. Yohe is a member of the New York City Panel on Climate Change and the NRC Standing Committee on the Human Dimensions of Global Change. He also served on the NRC's America's Climate Choices Adaptation Panel, the NRC Panel on Addressing the Challenges of Climate Change through the Behavioral and Social Sciences, and the NRC Committee on Stabilization Targets for Atmospheric Greenhouse Gas Concentrations. He is co-editor of Climatic Change and a Vice-Chair of the National Climate Assessment Development and Advisory Committee.

C

The Committee asked individual members of the NRC Board on Atmospheric Sciences and Climate (BASC) and the Committee on the Human Dimensions of Global Change (CHDGC) to examine the draft Plan and offer input to the Committee orally or in writing. What follows is a collection of their comments. The viewpoints compiled below should not be construed as the consensus views of BASC/CHDGC, the Committee to Advise the U.S. Global Change Research Program, or the National Research Council.

Comments from Individual BASC members

Overarching Concerns

1) **Observations:** A major concern revolves around the treatment of observations within the document and includes the following talking points:
    a. There is a serious conceptual omission in the document regarding the purpose of climate observations. The key point that is currently not covered is that observations are essential for research that expands our knowledge of processes and mechanisms in the climate system.
    b. The document currently seems to downgrade the use of observations such that they are only of use for comparison to models.
    c. Observations are in fact *needed* to directly learn about the climate system. Only then can it be modeled with any acuity.
    d. Given that both space-based and in situ measurement programs are in dire circumstances at the moment, and indeed are on completely unsustainable trajectories going forward, there is an urgent need to address how these programs might be maintained and sustained.
    e. By not confronting this fundamental dilemma, the USGCRP has left a serious omission in the document. The Strategic Plan could be dramatically improved by providing the framework to support these crucial observation systems into the foreseeable future.

2) **USGCRP Assessment:** As written, the document appears to be setting up an entirely new program. Given that the USGCRP already has a good track record spanning multiple decades, it is thought that the Strategic Plan could be improved by providing an assessment to help justify the current expenditures. To our knowledge, the last time this was done was in 1995. This could include:
    a. A work up of the major research findings and the subsequent policy and decision-making influence that the USGCRP and its constituent agencies have been responsible for over the past 20 years.

b. A frank and full assessment of not only accomplishments, but remaining challenges.
c. An integration of the lessons learned, and how the past experience of the program provides a strong backbone for the USGCRP going forward.

3) **Disciplinary Expertise:** Fostering an interdisciplinary program addresses an important need, but the importance of disciplinary expertise is being unrealistically minimized. Some specific concerns include:
   a. Though clearly the need exists for more interchange at the cross roads of various disciplines, a community made up solely of generalists will never develop new parameterizations that are necessary for skillful Earth Systems models.
   b. Focusing solely on breadth in disciplinary training leads us to well integrated, but ultimately faulty attempts to fully understand the Earth System.
   c. A logical improvement might be for the USGCRP to provide a postdoctoral program to help train a new generation of young researchers from science, technology, and social science to carry out the disciplinary integration which is a stated goal.

General Comments

1) Sustained Assessments, while admirably conceived, might take more in human and financial resources than are necessary. Rather than full length Synthesis and Assessment Products (SAPs), perhaps a short report every three or four years is more practical with a full report every third period. This keeps the sustained assessment cycle, but limits the large report to a scale that is more appropriate for that kind of in-depth review.
2) There seems to be an assumption that every geographic area is equally important in the USGCRP Strategic Plan. As 90% of the population lives in urban areas that represent less than 3% of the land area, perhaps an acknowledgement of targeted systems (urban, agricultural, etc.) should be included in all four goals.
3) The document is highly repetitive, and as result, probably ~30% too long. There are many instances of repetition and overlap across sections. This is probably the result of the multiple authorships of various chapters, but the entire document could use a single editing in this regard.
4) There are a number of factual and semantical errors in this document. Some will be listed below, but a rigorous proof read is in order.
5) The section on implementation seems much too brief and reads like a placeholder for a chapter that has yet to be written.
6) How are the boundaries between research and operational activities to be discerned from this plan?

7) By having four goals with equal weight, a reader could interpret that they are equal with regards to urgency, importance, and fraction of the allocated budget. Is there a subtle way to prioritize these without minimizing the importance of the other goals?
8) There are repeated references to high frequency and extreme events, but the word *weather* is not used at all.
9) Given the current political climate in D.C., it might be useful to substitute "climate services" with "climate information" everywhere in the document. There is a lot of confusion about what climate services are or should be, but climate information is more straightforward and carries none of the current negative connotations.
10) The phrase "use-inspired research" implies there is "useless research" that should be cut in favor of "use-inspired research". Is any scientist going to say he/she is doing useless research? Program managers shouldn't be funding useless research in the first place.

Edits

1) The document starts out by outlining four specific goals, each with a set of concise objectives, summarized in Box 1. On P. 12 the goals are stated in the text. Then the next two sections ("Unifying ideas" and "Cross-linking activities") appear out of nowhere, are vague, disjointed, don't fit in the flow of the presentation. All the items listed in these two sections are discussed in a more relevant fashion under the various objectives later. Recommend deleting these sections in their entirety (i.e. from P. 12, line 384 through the end of P. 15).
2) Table 1 – this seems to be an integration of research that falls under both objectives 1.1 and 1.2. This table should be split into two to mesh better with the two objectives. That is, Table 1 should have all the boxes except the one in the middle at right, and Table 2 should be just the box from the middle right of Table 1. Splitting into 2 tables to correspond to the two objectives makes the presentation more clear.
3) Text Box 3, Line 545 – The paragraph refers to "Text Box 2" rather than 3.
4) Line 586 – change "understanding of key of aspects…" to "understanding of key aspects…"
5) Line 639 – change "integrating of the social…" to "integrating the social…"
6) Lines 685-686 – A paleoclimate expert like John Kutzbach should be consulted, but it seems counter-intuitive that the glacial-interglacial cycle could transition "over periods as short as a decade". This is not much time to build or melt a massive land ice sheet.
7) Box 4, Line 713 – There is nothing close to sufficient evidence that "Currently, ocean acidification is affecting the growth and lifespan of carbonate shell-forming organisms such as many plankton, mollusks, crustaceans, and urchins." Studies in laboratories in isolation suggest that OA will affect these organisms, but these studies do not deal with natural oceanic systems. The effects observed have been summarized in Kroeker et al. 2010.

8) Box 5, Line 767 – "We know from scientific measurements that sea level has been rising steadily over the past few decades (see Figure B5.2.). This rise is due primarily to expansion of the ocean as it warms and melting of land ice (glaciers and ice sheets), with each of these factors making a roughly equal contribution to the current rate of sea level rise." The current estimate of the relative contribution of warming to the global sea-level rise rate shown in B5.2 is about 30%, not 50%. The 50% estimate was biased high due to XBT fall errors (Wijffels et al. 2008). The 30% estimate is based on Levitus et al 2009, Ishii and Kimoto 2009, and Church et al 2011.
9) Line 1354 – Delete "entirely". It is incorrect to state that decadal prediction depends "entirely" on data assimilation. There are many more factors, like model fidelity, systematic errors, and so on.
10) Text Box 6
    a. Line 1392 – the "Antarctic ozone hole is starting to recover" is probably correct, though this year was the 9th largest on record. It is not expected to return to 1978 levels until 2070, so recovery is expected to be slow with interannual variation.
    b. Line 1393 – change "then decreased following the 1987 Montreal Protocol" to "then decreased following the 1987 Montreal Protocol and additional amendments agreed upon between 1990 and 1999."
11) Box 9, Line 1314 – the credit is wrong. It should be "…and Aqua and its Advanced Microwave Scanning Radiometer for EOS." Although the background of figure B9.2 is MODIS, the sea ice observations are from Nimbus 7/SMMR (left) and Aqua/AMSR-E (right).
12) Text Box 7, Line 1582 – decadal climate predictability. This box doesn't address two additional issues related to decadal climate variability:
    a. The characteristics of this variability may interact with changes brought about by underlying global change.
    b. Decadal variability may at times act to either amplify, or damp, the underlying anthropogenically forced climate changes. This point has implications for our ability to estimate accurately the underlying global changes during particular decades and introduces uncertainly that needs to be resolved.

Comments from Individual CHDGC Members

Objective 2.3 "Enhancing climate services"

This section defines "climate services" as the "provision of information products" (line 2173), which is an overly narrow formulation (see NRC, 2009 [Informing Decisions] for a more comprehensive discussion of climate-related decision support). A key to decision support is the role of climate communication networks, and an appropriate Objective 2.3 for the Program might be called "Enhancing Climate Communication Networks".

Climate information is being generated and communicated to research, resource managers, decision makers, and the public through various organizations and various forms. Climate information needs to be translated and delivered in ways which the end-user community has defined as most suitable for their use. However, in delivering these products care must be exercised in maintaining the integrity of the climate information and insuring that the best available information and technologies are used in providing this information to the user communities. The delivery system and development of the translational expertise need to be jointly evolved to insure user satisfaction and product integrity.

To meet the legislative mandate of Program, it will need to engage with agencies that are not now part of the program, and particularly with centers of social science expertise in government. These can be found in the Departments of Housing and Urban Development, Education, Homeland Security, Treasury, Labor, etc.

Earth System Understanding

The Plan proposes to include efforts to advance fundamental understanding of the human components of the Earth system. Including the human components in Earth system science presents something of a "grand challenge" to the Program that requires more than incremental changes. For example, the need for process research, observations, modeling, and assessment applies to socio-economic and social-ecological systems, as well as the physical systems that have been the core of the Program in the past—and to the total Earth system of which all of these are components.

Instead of the thorough rethinking of the Program that seems likely for meeting the challenge, the Plan indicates incremental changes and in some cases does not specify even these in detail. There is a general reference to "the significant role that human activities play in global climate change" (lines 623-624), but no further detail. In this area, the Plan might additionally reference the need to understand the social-ecological interactions related to consumption choices, governance and institutional structures, and valuation of natural resources that intersect with earth system dynamics and change. It needs to recognize the need for fundamental research by the social science community and for integrating social, biological, and physical sciences in advancing Earth system science and global change research. These needs exist across scales, and such research is essential to understanding the nature and determination of critical thresholds and cascading interacting processes.

The Plan also needs to recognize the need for research support for further study of valuation of ecosystem services relative to societal factors, attention to "slow variables" associated with social-ecological systems (e.g., education, social networks, and ecosystem supporting services). Integrating adaptation and mitigation research will also be needed during the period when the social-ecological system will be changing due to global changes in the physical Earth system. A concerted research effort in the coming decade will be necessary to frame institutional and educational responses for coming century regarding such evolving changes as Arctic Ocean opening, sea level rise, increasing environmental migration, invasive species expansions, ocean acidification, loss of biodiversity on land and the oceans, changes in international trade and cultural values, etc.

Complexity

"Social system dynamics" are mentioned here, but there is no elaboration. Recent events associated with the global recession, "Arab spring", and La Niña-drought connections in SW United States provide apt examples of the global teleconnections operating of social-ecological systems across the world today. Compared with the 20th Century, the 21st Century presents a much more interconnected Earth system sometimes called the anthropocene era. The research enterprise needs to reflect this transition of Earth system dynamics and thresholds. The ability to transition without global collapse is dependent on how our integrative research approach guides the adaptation and mitigation decision landscape and public awareness.

CCTP

The connections and integration of the CCTP and the USGCRP research and implementation strategies deserves careful attention in the Plan. It may require a task force under a Presidential Executive Order to develop an appropriate strategy.

Carbon Cycle

Box 8 contains no reference to the 2011 Carbon Cycle Science Plan.

Integrated Modeling

It would be useful to further clarify the goals of more sophisticated Earth system, models and to distinguish what is meant by an Earth system model from integrated assessment models and other model types. The usage in some places suggests models more of type used in current GCM's rather than integrated assessment models or other Earth system models that more explicitly incorporate the social aspects of the earth system dynamic. Research at the interface between sub-components of the Earth system as well as improved process representation of the subcomponents, will need particular attention to advance the integrated system modeling. The use of simplified "toy models" can provide a framework to develop an integrated modeling system more rapidly than building more complex versions of fully resolved models.