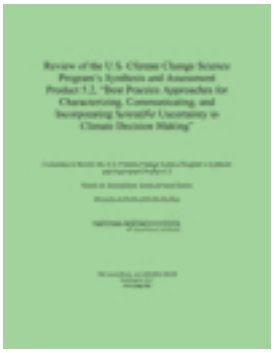

Review of the U.S. Climate Change Science Program's Synthesis and Assessment Product 5.2, "Best Practice Approaches for Characterizing, Communicating, and Incorporating Scientific Uncertainty in Climate Decision Making"

Committee to Review the U.S. Climate Change Science Program's Synthesis and Assessment Product 5.2,
National Research Council

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Board on Atmospheric Sciences and Climate

Division on Earth and Life Studies

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Acknowledgments

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 National Research Council'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 review of this report:

Joe Arvai, Michigan State University, East Lansing
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Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations nor did they see the final draft of the report before its release. The review of this report was overseen by Eric J. Barron, University of Texas, Austin. Appointed by the National Research Council, he was 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.

Contents

Summary

The committee reviewed the draft Synthesis and Assessment Product (SAP) 5.2, focusing on the extent to which the draft document meets the requirements set forth in the prospectus. The current draft was clearly written for an audience of researchers involved in assessment efforts, and it contains material that should be very useful to them: a discussion of cognitive factors in understanding uncertainty; presentation of the methods for expert elicitation under conditions of "deep uncertainty," and useful advice for characterizing and presenting uncertainty in assessments. However, even for this audience the report should contain additional material: a fuller discussion of the range of scientific methods, including frequentist and objective Bayesian approaches for characterizing uncertainty; assessments of research relating to social contextual and emotive factors that, along with cognitive factors, affect the uncertainty judgments of experts and non-experts alike; and introductory and summary material.

There are larger issues in that the draft SAP falls short of the requirements set forth in the prospectus. The draft does not address all of the specified audiences, particularly "policymakers, decision-makers, and members of the media and general public with an interest in developing a fundamental understanding of the issue." In addition, the current draft does not constitute an assessment of the full range of "best practice approaches" for characterizing, incorporating, and communicating uncertainty. It will take a substantial revision of the current document or the production of a companion document, both of which would require the involvement of additional authors, to address these larger issues and additional audiences.

1

Introduction

The U.S. Climate Change Science Program (CCSP) was established in 2002 to coordinate climate and global change research conducted in the United States. Building upon and incorporating the U.S. Global Change Research Program of the previous decade, the program integrates federal research on climate and global change, as sponsored by 13 federal agencies and overseen by the Office of Science and Technology Policy, the Council on Environmental Quality, the National Economic Council, and the Office of Management and Budget. A primary objective of the CCSP is to provide the best possible scientific information to support public discussion and government and private sector decision making on key climate-related issues. To help meet this objective, the CCSP is producing a series of synthesis and assessment products that address its highest priority research, observation, and decision-support needs. The CCSP is conducting 21 such activities, covering topics such as the North American carbon budget and implications for the global carbon cycle, coastal elevation and sensitivity to sea-level rise, trends in emissions of ozone-depleting substances and ozone recovery and implications for ultraviolet radiation exposure, and use of observational and model data in decision support and decision making. Each of these documents will be written by a team of authors selected on the basis of their past record of interest and accomplishment in the given topic. A list of the CCSP SAPs is provided in Appendix A.

The National Oceanic and Atmospheric Administration (NOAA) is the lead agency for CCSP Synthesis and Assessment Product (SAP) 5.2. NOAA's stated purpose for SAP 5.2 is two fold (see Appendix B for full prospectus). The first purpose is to synthesize and communicate the current state of understanding about the characteristics and implications of uncertainty related to climate change and variability to an audience of policymakers, decision-makers, and members of the media and general public with an interest in developing a fundamental understanding of the issue. The second purpose is to provide recommendations for best practices for characterizing, analyzing, and communicating uncertainty for scientists, science managers and technical operational entities involved in conducting research and assessments, including, but not limited to, those participating in future CCSP assessment efforts. According to the guidance provided in the prospectus, SAP 5.2 is to be written in a style consistent with major international scientific assessments. To address these purposes and audiences, SAP 5.2 was given eight key questions to address (see Box 1).

In a review of the U.S. CCSP Strategic Plan, the National Research Council (NRC) recommended that synthesis and assessment products should be produced with

independent oversight and review from the wider scientific and stakeholder communities (NRC, 2004). To meet this goal, NOAA has requested an independent review of SAP 5.2 by the NRC. The NRC appointed an ad hoc committee composed of twelve members (Appendix C). The committee's Statement of Task is included in Appendix D.

The committee conducted its work by first carefully reading the draft SAP 5.2 report Best Practice Approaches for Characterizing, Communicating, and Incorporating Scientific Uncertainty in Climate Decision Making (draft dated October 16, 2006). The committee then met with the lead author to ask questions about the authoring team's research and formulation of the draft document. During this meeting, the committee also interacted with NOAA and CCSP personnel, who outlined for the committee their expectations for SAP 5.2. An external panel of stakeholders, defined to mean people from organizations who might use information about uncertainty in their work, was invited to share additional perspectives on the draft document. This present document constitutes the committee's review report, resulting from its careful study of the draft SAP 5.2 document and its interactions with those present at the aforementioned meeting. Herein the committee provides its review findings, and recommendations, suggestions, and options for the authors to consider in revising the draft SAP 5.2. In its review, the committee focused on substantive matters of content and did not proofread the document for grammatical or typographical errors.

It became apparent during the discussions with the lead author, NOAA, and the CCSP that the draft SAP 5.2 document originated before the prospectus itself was finalized. In some respects this has led to an apparent disconnect between the final description of what the document should be and what the authors finally produced. This disconnect made the review especially difficult, as the committee was charged to respond to the extent to which the draft SAP 5.2 meets the various goals as outlined in the prospectus -- goals which may never have been articulated completely until after the document was essentially finished. In particular, the proposed audiences for the document appear to have been much expanded at some point in the process. However, the draft reviewed by the committee is written largely for an audience of those persons involved in assessment efforts. To address the additional intended audiences of such persons as "policymakers, decision makers, and [interested] members of the media and the general public" would require a significant investment in ongoing two-way effective communication between scientists and the members of these audiences. These additional audiences are of great importance, and need to be addressed; however, this appears to have been well outside the scope originally assigned to the authors. In order to address these and other concerns as outlined in this review, significant revisions of SAP 5.2 will be necessary. This review does not recommend specifically how to enact these revisions and meet the requirements for target audiences set forth in the prospectus. Options include greatly expanding the scope of the current document or producing a second, companion document to address the additional audiences.

BOX 1-1
Questions to be Addressed by CCSP Synthesis and Assessment Product 5.2

According to guidance in the CCSP prospectus outlining the purpose of SAP 5.2, the report may be used as (i) a relatively sophisticated summary and assessment of the state-of-the-art understanding of the characteristics of uncertainty and the illumination of some potential approaches to decision making under such uncertainty, and (ii) decision analysis and social science-based guidelines for future CCSP assessment and decision-support activities and for researchers participating in broader assessment activities, such as the Intergovernmental Panel on Climate Change (IPCC). The key questions to be addressed by SAP 5.2 are:

1. How is uncertainty estimated and measured?
2. What are the sources and types of uncertainty that influence the way scientific information is communicated and understood by non-scientists?
3. Why is an enhanced understanding of uncertainty important for communicating and utilizing climate information?
4. What are some of the cognitive challenges in estimating uncertainty (e.g., the role of human judgment) and the relevance of these challenges to addressing climate?
5. How is uncertainty analyzed, and how can it be applied in analyses of adaptation options?
6. What are some effective methods for communicating uncertainty?
7. How can decision-makers consider and incorporate uncertainty?
8. What are considered to be the best practices for the incorporation and communication of uncertainty in scientific assessments?

2

Major Overarching Comments

Characterizing scientific uncertainty about climate change, effectively communicating that uncertainty to decision makers, and incorporating it in the decision making process are important tasks. The climate research community recognizes and understands the importance of characterizing uncertainty in research and assessment efforts, and decision-makers can benefit greatly from improved communication of uncertainty by the research and assessment communities. Thus the Climate Change Science Program's (CCSP) Synthesis and Assessment Product (SAP) 5.2 will potentially be very beneficial to all stakeholders of climate change science. The committee commends CCSP and the National Oceanic and Atmospheric Administration (NOAA) for emphasizing the need to address this important topic.

This chapter provides an enumerated discussion of the major issues that, from the point of view of the review committee, the authors should strongly consider addressing in the revised version of SAP 5.2. In some cases, findings are simply noted without explicit recommendations. In other cases, the committee provides either a direct recommendation or alternatives for the authors to consider as they address the review findings. In subsequent chapters of this report, the committee provides further overarching thoughts on the draft document and then findings and recommendations specific to individual chapters of the draft. The major overarching comments follow.

1. The draft provides a good treatment of cognitive challenges and expert elicitation issues. The committee finds that the draft SAP 5.2 provides a well-written and concise synthesis of some of the key issues regarding the characterization of scientific uncertainty vis-à-vis climate decision making. The draft provides a particularly good synthesis of the issues regarding cognitive challenges on an individual basis to characterizing uncertainty, the potential implications of those challenges for CCSP and other assessment efforts, and a method of characterizing uncertainty when conventional methods are not practical or adequate (expert elicitation).

2. All of the audiences outlined in the prospectus are not addressed. The committee finds that the draft is written largely for an audience of those people involved in assessment efforts. Indeed, that is one key audiences for SAP 5.2. The intended audiences as outlined in the prospectus also include those people engaged in scientific research, the media, policymakers, and members of the public. The committee suggests that the authors might also acknowledge and discuss the unique needs of the private sector, which are quite different from those of researchers, academia, and the assessments

community. The private sector and policy and decision-makers in the public sector (e.g., congressional staff) fall into the category of *users* of assessments and need to understand the implications of uncertainty, in contrast to the research science community, who are *generators* of assessments and associated uncertainty information. The draft provides relatively little information for an audience of users, particularly information that could be used as guidelines for effective communication techniques.

3. The range of best practices for characterizing uncertainty is not represented. The document fails to review the range of methods used to characterize uncertainty as called for in the study prospectus. Instead, it focuses almost exclusively on expert elicitation for use in a subjective Bayesian analysis. This focus neglects assessments, including other Synthesis and Assessment Products, associated with the observational record. There is a need to discuss more traditional frequentist methods, which remain dominant in scientific work, and objective Bayesian methods based on non-informative prior distributions. By focusing exclusively on the subjective Bayesian approach, the document also fails to elucidate 'Best Practices' for characterizing uncertainty as called for in the study prospectus. The committee understands this elucidation to involve a description of alternative approaches and a discussion of the strengths and weaknesses of each. The addition of a statistician to assist with the elucidation of traditional scientific methods would address a significant weakness in the report. This addition to the authorship team should be strongly considered, regardless of whether the current document (and its authorship team) is greatly expanded to address the additional audiences and issues described in the prospectus.

4. The influence of social context and emotional factors is absent. Although some of the important cognitive factors in understanding and evaluating uncertainty are discussed in Chapter 3, this discussion is incomplete in two senses. First, the draft SAP 5.2 neglects the social context in which such understandings and evaluations are made; even within the narrow focus of discussing expert elicitation, responses will be influenced by how the questions are asked, the context of the interview, the expectations and knowledge of experts about what their peers are saying, and the cultural set of norms that attend the social groups (scientific institutions, universities and departments, etc.) to which respondents belong. Moreover, emotions have been shown to play scientifically measurable roles in estimations of uncertainty. Second, the discussion of cognitive biases, and the missing discussion of the social context and emotive factors in evaluating uncertainty are highly relevant to the communications and decision making chapters but are almost entirely absent in these too-brief chapters. In the communications chapter, the emphasis is on presentation of materials to an amorphous non-technical audience rather than on understanding the needs of multiple audiences within their social contexts, as specified in the prospectus. The decision making chapter neglects the large literatures on decision making in institutional settings where scientific uncertainty is only one of many factors influencing decisions.

5. Introductory material is lacking. The draft would be improved if the brief paragraph at the top of page 1 was expanded into a formal introduction section that provides framing and context for the rest of the document. The authors could define who climate decision-makers are and discuss the importance of characterizing,

communicating, and incorporating scientific uncertainty for the decision making process. This could be done using an example of decision making under uncertainty, where the optimal decision depends on the characterization of uncertainty, and also an example of scientific inference, where uncertainty needs to be characterized to go beyond point estimation (i.e., to test an hypothesis or provide a confidence interval)." In its current form, the transition to technical material is far too abrupt. The introduction section could also outline the charge to the authors as they perceived it, and clearly define the goals and objectives of the document. As an alternative, this material could be included in a foreword. The foreword or introduction could also state explicitly what the document does *not* address vis-à-vis the broader contexts of scientific uncertainty and climate decision making.

6. An executive summary is essential but has not been prepared. The committee finds that the lack of an executive summary hinders its accessibility to the audiences named in the prospectus. A concise and readable summary of the document, including key findings and recommendations, would enable all audiences -- producers of synthesis and assessment products, scientific researchers, decision-makers, media, and the general public -- to glean the main points and to locate further information that may be of interest to them. The summary should not be descriptive, but informative on the main points of the document.

3

Additional Overarching Comments

1. *Types of model-related uncertainty:* In discussing the types of scientific uncertainty, particularly in the context of model-based estimation and prediction, it would be useful to exploit the conventional formulation involving observable quantities, models, and parameters. This formulation provides a convenient way to distinguish among non-modeled variability in observables, uncertainty over parameter values, and uncertainty over model specification.

2. *Support for conclusions:* There is not always a clear connection between the material presented and the findings, recommendations, and conclusions. This comment pertains to conclusions stated within the body of the draft and also to the recommendations listed in Chapter 8 of the draft. Concerning the latter, the committee finds that it is difficult to distinguish which of these statements are the opinions of the author and which are conclusions supported by the material discussed within the report. The committee suggests that the authors take steps to ensure that findings and conclusions in the final chapter are clearly grounded in material that is fully discussed in the chapters.

3. *Certain versus debatable*: Similarly, there are instances within the main body of the material where matters are stated with certitude that the committee consider to be debatable. As an example, consider on Page 4, Lines 32-33, where the authors claim that "Barring [sic] a few exotic exceptions, uncertainty about model functional form is inherently epistemic." The committee suggests that model functional form is often epistemic, but this is not inherently true except in a few exotic circumstances.

4. *Policy prescription*: The authors of SAP 5.2 are charged with recommending ways to incorporate discussion of uncertainty into decision making, and this task is inherently policy prescriptive. However, the committee believes that the authors should recognize that in certain cases direct policy prescription should be avoided. For example, line 16 on Page 38 ("it is generally best to adopt robust strategies") could be interpreted as recommending a specific course of action for policymakers, in this case to address the middle range of uncertainties, when policymakers may be better served by addressing less probable but extremely negative impacts.

5. *Stylistic issues*: The committee notes several stylistic issues, which, if addressed, could significantly improve the overall accessibility of the document for a wider audience and improve the coherence of the document. Specific instances will be

noted in the sections of this report that provide reviews of individual chapters of the draft. Broadly, these issues are as follows:

5a. *Jargon and definitions*: The language suffers from excessive use of jargon, overly complex explanations for concepts that could have been stated more clearly, and a lack of definitions of terms that may have multiple meanings to multiple readers. Some of these issues are related to the question of the target audience for this Synthesis and Assessment Product (SAP). If the final product, or some portion of it, is intended to serve as a practical guide for decision makers and non-scientific users of uncertainty information, then the language should be appropriate for that audience. Notwithstanding this question of audience, the committee believes that even if the document is intended for the narrower subset of the Climate Change Science Program (CCSP) researchers and assessors, there is benefit in stating difficult concepts in straightforward language. The authors might also consider adding a glossary for less commonly understood terms and phrases.

5b. *Use of examples*: It would be very helpful if the authors would consider providing one or two "real-world" examples of a climate-decision making scenario, and then carrying those examples through the rest of the document as points of reference. In each chapter, relating the technical material in question to these examples would not only elucidate that material for the uninitiated reader, but would also help to shore up the framework of the document.

5c. *Use of quotes*: The committee believes that the authors make excessive use of long, direct quotes from the literature. In most cases the point the authors wish to make could be conveyed adequately by paraphrasing these quotes into simpler statements.

5d. *Content arrangement*: The committee recommends that the content arrangement of the chapters be reconsidered once the needed material has been incorporated into the document. One approach might begin with a framing of the issue, followed by discussion of the sources and types of uncertainty, followed by a synthesis of the various methods for estimating uncertainty (with a progression from conventional methods to expert elicitation), with later material providing information on methods of communicating uncertainty and concluding with recommendations for best practices. An enhanced emphasis on communication might also include material from both Chapters 2 and 6. The material in Chapter 7 could be placed earlier in the document and amended slightly to provide the recommended addition of contextual information early in the document. Arranging the discussion of techniques to begin with the outlining of objective and then more subjective methods could also enhance readability. In its current form, the discussion somewhat confusingly alternates between the two types of methodologies.

4

Review of Individual Chapters

This chapter provides specific comments on the eight individual chapters of draft Synthesis and Assessment Product (SAP) 5.2. In some cases, these specific comments relate to the overarching comments provided in the previous two chapters of this review. In the other cases, these specific comments are generally minor in nature. The review of each chapter includes a statement that summarizes the committee's overall thoughts. For some chapters, there are enumerated comments that follow this statement to provide suggested editorial changes or other details for the authors to consider during the revision process.

CHAPTER 1

Sources and Types of Uncertainty

As noted earlier, the committee recommends the addition of a full introduction section and a foreword to provide framing and context before the technical material in Chapter 1 is presented. The comments provided here pertain only to what is contained in the draft Chapter 1. Chapter 1 provides a good summary of the sources and types of uncertainty; the committee suggests that these concepts could be further elucidated with the use of real-world examples related to climate and decision making. In addition, the authors should acknowledge that some types of uncertainty cannot be defined or characterized because the existence of the subject in question, and all the sources and types of uncertainty associated with that subject, are completely unknown.

- Page 1, Line 19: Insert "in a timely fashion" in front of "before."
- Page 1, Line 29: "stationarity" is a relative concept.
- Page 1, Line 33: This is not true.
- Page 1, Line 35: Change "belief" to another word (e.g., "certainty")
- Page 4, Lines 5-10: Consider replacing this lengthy quote with a paraphrased version using common prose.

- Page 4, Line 31: Not sure this is entirely true in the case of this example. Please further elucidate the concepts of aleatory and epistemic. Consider using more accessible terms for the concepts.

- Page 4, Line 33: Replace "inherently" with "often."

- Page 5, Line 1: Is it not true that probabilities can only be assigned on empirical quantities.

- Page 5, lines 19-20: The terms "parametric analysis" and "switchover" could be made more accessible by using the phrase "sensitivity analysis," which is used commonly in the climate research community.

CHAPTER 2

The Importance of Quantifying Uncertainty

The committee suggests that the content of this chapter be merged with that of Chapter 6 under the rubric of communication and that this material be placed near the current location of Chapter 6 (after the discussion of the sources and types of uncertainty and the various methods for characterizing uncertainty). It would also be helpful if the authors provided some background information on the research process that led to the formulation of the terminology for numerical probabilities outlined in the figures and tables. This chapter could also be an appropriate place for further elaborating on the concept of risk, wherein probabilities are combined with consequences.

CHAPTER 3

Cognitive Challenges in Estimating Uncertainty

In this chapter the authors provide an excellent summary of the cognitive challenges that affect rational analysis of uncertainty by individuals. We normally consider decisions to be made cognitively, and the ideal decision is made "rationally," with a calculus of plusses and minuses, tradeoffs, and net gain or loss. This leads to an emphasis on cognitive elements in judgments and decisions and a relative under-emphasis on other factors influencing people's estimates of uncertainty. Two factors that ought to be discussed, at least briefly, are group processes of decision making and the role that emotions play.

People are often asked to make decisions about issues that are complex and involve uncertainty in terms of potential outcomes. These decisions are most often made in groups and in institutional settings. The context of decision making presents important constraints and opportunities on the processes and outcomes. One factor is the worldview of the group, for example as analyzed by Mary Douglas, Aaron Wildavsky,

and Michael Thompson under the concept of Cultural Theory. People's orientations to their groups and their adherence to the rules of the group determine important aspects of their attitudes toward risk and uncertainty. Even within cognitive analysis, decision making can (perhaps ought to) be modeled as social rationality (with non-optimizing choices), as assessed and discussed in Jaeger et al. (1998).

The role of emotion in decision making is increasingly the subject of research, principally by psychologists and social psychologists. Jennifer Lerner and Baruch Fischhoff of Carnegie Mellon University—along with Roxana Gonzalez and Deborah Small, graduate researchers at the time—examined how emotions affect our assessment of risk. Although we may like to think that our judgments about risk are entirely objective, these researchers have demonstrated that emotional responses to the September 11 terrorist attacks could affect not only a person's judgment of risk for future attacks, but also risk estimates for other types of hazards.

Participants exposed to media clips that induced fear held more pessimistic perceptions and were more risk-averse, while participants exposed to media clips that induced anger held more optimistic perceptions and were more risk-seeking. The same research found that respondents felt public health officials had failed to communicate easily understood (and desired) facts about terrorism.

Finally, people and organizations may make faulty judgments and erroneous decisions because they do not take into account all of the relevant information available to them. For example, the Challenger shuttle disaster in 1986 and the Columbia shuttle disaster in 2003 occurred despite the availability of information whose appropriate consideration may have averted the decisions that lead to tragic consequences. Information must be salient to potential users of it. If uncertainty information is not understandable or not seen a useful to decision making, it will be irrelevant to decisions. Some specific points to consider include:

- Figure 3.3 is interpreted as the availability heuristic, but may be the result of the distinctions people draw between very large and very small hazards, where consequences are orders of magnitude different.

- The factor "what gets your attention" is not adequately addressed. This factor does not involve the matter of use all available information in making rational decisions, but only what gets ones attention.

- References to consider: (Epstein 1994; Finucane et al. 2003; Kasperson et al. 2003; Jaeger et al. 1998; Lerner et al. 2006; Lerner and Tiedens 2006; Peters et al. 2003, 2006; Slovic 2004, 2006; Slovic and Slovic 2004, 2005; Slovic et al. 2004, 2005; Sunstein 2005; Thompson and Rayner 1998; Vaughn 1996; Wilson and Arvai 2006; Zajonc 1980)

CHAPTER 4

Methods for Estimating Uncertainty

As noted, the document focuses almost exclusively on expert elicitation for subjective Bayesian analysis. There is a need to review the full range of methods used to characterize uncertainty.

In scientific work, as opposed to decision problems, the classical or frequentist approach remains dominant. Although the Bayesian approach is increasingly used in scientific work, the emphasis is on objective methods involving the use of non-informative prior distributions. In contrast, the Bayesian paradigm is dominant in decision problems. This is due to the nature of the probabilities needed, for example, to maximize expected net benefits or utility.

Like the frequentist approach, the Bayesian approach is typically based on a formal structure involving a parametric model and observations generated from it. Although standard methods assume that the model is specified up to a finite set of parameters, formal methods do exist for treating uncertainty about the form of the model (see suggested references). Considerable clarity could be gained by laying out this formulation and referring to it in reviewing different sources of uncertainty and alternative approaches for characterizing it.

The authors appear to justify the exclusive focus on the subjective Bayesian approach by appealing to the presence of 'deep uncertainty'. This term needs to be defined, its implications for alternative methods need to be explained, and the case must be made that such deep uncertainty is endemic to problems involving climate.

The committee also suggests that in revising this chapter, in tandem with Chapter 5, the revised document first present and discuss frequentist and more objective techniques, followed by Bayesian approaches (first objective, then subjective), and that the discussion then proceed to a discussion of eliciting subjective probabilities. Some specific points to consider include:

- The discussion of the model-based exercise and its relation to the larger questions in Chapter 4 is insufficient.

- Reference should be made to the large literature on assessing the value of information.

- Page 18, line 5. Need to further elaborate on the concept of "best" strategy (goes along with need for description of when expert elicitation is "best").

- Citations to the literature are heavily weighted toward the authors' own work. The authors should consider citing the recent review by Garthwaite et al. (2005) on elicitation, Genest and Zidek (1986) on combining subjective prior distributions from different experts, Mosteller and Yountz

(1990) on quantifying probabilistic expressions, and Berger (1994) on Bayesian robustness.

- The issue of 2nd order distributions is not worth raising if the purpose is only to dismiss it; if it is raised, something substantive should be said about it; otherwise, it should be deleted.

- "The caption of Figure 4.1 refers to the use of 'Bayes' Monte Carlo estimation'. This is not a term of art and should not be used without further explanation."

- The authors state that experts (for elicitation) have difficulty dealing with extremes. Please consider discussing *why* this is so. Some argue experts have the same problem as the general public. From where does this problem arise?

- When referring to climate sensitivity, if sensitivity to double CO_2 is explicitly meant, as opposed to the change in T per unit forcing (K/Wm^{-2}), please state this.

- The committee would like to see a discussion in this chapter about "surprise." One can argue this is associated with large uncertainty or particular types of uncertainty (but not always). What types of events are associated with surprise? Can surprises be anticipated (not what they will be, but that they will occur)? An example in this context is abrupt climate change.

CHAPTER 5

Analysis of, and with, Uncertainty

Chapter 5 in particular would benefit from the use of "real-world" examples that relate the content to climate decision making. Again, it appears that there is some redundancy of the material presented in this chapter with that presented in Chapter 4. This chapter would also be a good place to discuss the strengths and weaknesses of the use of scenario analysis, which is not addressed at all in the current document. Synthesis and Assessment Product (SAP) 2.1 provides relevant material on this topic.

Another concern of the committee regarding the content of this chapter involves the use of the concept of "robustness." The committee finds that this term is insufficiently defined. A plausible argument can be made that there is no meaningful distinction from usual optimality analysis and that the concept discussed in this report is a matter of a poorly defined utility function. If indeed there is a real technical distinction to be made, the authors should consider expanding and supporting the discussion of this

concept. Furthermore, the committee suggests that the authors address the concept of adaptive management in conjunction with discussions of robustness and in particular address how different sources of uncertainty affect different kinds of decisions. Finally, the committee would appreciate a further elucidation of what the author considers to constitute "deep uncertainty" (page 34 and other locations). The committee understands that there is overlap between this concept and the others defined in this section (e.g., "robust"), but nevertheless finds that it is not entirely clear when the author considers the situation inappropriate for use of conventional methods for characterizing uncertainty. Some specific comments include:

- Page 34, end of Line 3: Please elaborate on the concepts of "traceable accounts" and "multiple metrics aggregation."

- Figure 5.3 does not account for the issue of structural uncertainty. For example, consider the formulation of an ocean model (purely diffusive versus advective-diffusive).

CHAPTER 6

Communicating Uncertainty

The communications chapter constitutes 1.5 pages of a 44 page report. This is very brief in light of the complex issues involved. This chapter currently treats several methods or techniques, such as graphical displays and mental models. It would be helpful to have a discussion of the different target audiences for communication efforts and the issues or challenges that each poses in communicating uncertainty. The chapter appropriately emphasizes the importance of interactions with target audiences in the design of communication messages. This could be further extended to a treatment of communication as a two-way process and carried forward to the section on advice and guidance.

An extensive literature exists on empirical studies of the communication of risk and uncertainty, including a number of useful assessments of practice. Some extended work specifically addresses the communication of uncertainty, such as *Communicating Uncertainty* (Friedman et al. 1999). This literature could be more heavily drawn upon and extensively referenced in this chapter.

The social contexts and institutional settings in which communication activities occur have large implications for the types of communication processes that are appropriate and how substantive issues such as social trust and credibility may be addressed. The report would benefit if these issues were addressed.

Finally, many analysts have pointed to the need for ongoing evaluation of communication efforts, linked to midcourse corrections and assessment of what is working well (and what is not). This issue could also be mentioned in the revised report. Some specific comments include:

- Page 37, lines 5-29: Jumps too quickly from effective uncertainty communication methods to methods of risk communication. Please flesh out these links.

- Page 37, lines 8-73: Note there are also "translators" who are not spinners but "repackagers." These are scientists who give guidance and advice, not political spinners. This document does not speak to this audience. Consider expanding upon these lines to address this issue.

CHAPTER 7

Making Decisions in the Face of Uncertainty

Early in SAP 5.2, it would be very useful to have discussion of what particular challenges and problems are present that need to be addressed and considered in decisions under different levels of uncertainty. What is the decision problem that public and private sector managers confront in decisions made under high degrees of uncertainty? Chapter 7 is very brief for such a complex subject, although relevant material is presented in other chapters (e.g., in Chapter 5 on the discussions of robustness). Nevertheless, the draft does not identify and assess the different types of decision strategies that are available to decision makers, their relative strengths and weaknesses, and their situational appropriateness.

Notable is the lack of any significant discussion in this chapter of adaptive management, a decision approach that has been identified as particularly appropriate to situations of high uncertainty over long time frames with diffuse actors and interests, such as climate change. Please consider expanding the discussion of this concept beyond Figure 1. Other concepts that could use further discussion include the differences between distributed decision systems and unitary decision structures. Discussions of decision strategies often implicitly assume the latter, but the former is often what exists, particularly in the case of climate decision making. It would also be helpful to relate decision making to the treatment of deliberative processes as discussed in the NRC report *Understanding Risk* (NRC 1996). This may help to link assessments with the role of stakeholder participation in shaping effective decision strategies. Some specific suggestions include:

- A discussion of the work presented by Cash et al. (2002) could be useful in considering effective ways to link scientific assessments to decision making.

- A revised chapter on decision making could draw upon and reference the large amount of prescriptive and empirical literature that exists, little of which is included in the current draft.

- Page 37, first paragraph: What are these uncertainties? Are they non-scientific?

- Page 38, Line 8: Please choose a word other than "smart" (wise?). In this context, this adjective could be interpreted as condescending.

- Page 38, line 25: This may not be strictly true (the notion that research reduces uncertainty is not an assumption of classical decision analysis). Program managers may assume that research has an expected positive value, but in fact research does not necessarily reduce uncertainty. What about reversely identifying research needs via meta-analysis of existing problems?

- Page 38, Lines 35-36 Take this to its logical conclusion: When exactly should the data collection end and a decision be made? Consider that adaptive management may provide a sensible framework to answer this question.

- References to consider: (Gregory, et al. 2006; Arvai, et al. 2006)

CHAPTER 8

Some Simple Guidance for Researchers

This chapter contains a number of excellent suggestions from the authors about practical suggestions for dealing with uncertainty. The committee understands that following these suggestions would substantially improve the representation of uncertainty in the Climate Change Science Program (CCSP) product; however, as a final chapter for the document it does not provide the types of summing up and recommendations that would also be helpful for all the users of the document. In some cases, conclusions are drawn that may not be entirely supported or even discussed elsewhere in the document, and thus may not be entirely clear to users who are not well conversant in all types of uncertainty evaluations. The committee recommends that the authors ensure that all conclusions provided in the revision are supported by material discussed elsewhere in the SAP document, and that statements of opinion be clearly identified as such. In terms of providing a summary of "best practices," the chapter provides a brief summary of professional advice for those involved in writing assessments, but it does not elucidate a range of best practices for all of the audiences set forth in the document prospectus. As stated in the Summary of this review, the committee believes that this would require a significantly expanded SAP, or the production of a companion Product. Finally, the committee disagrees with the recommendation to adopt the terminology/ranges shown in the figure at the bottom of page 41. This disagreement is not based upon a specific objection to the assignment of particular qualitative words to a particular range of probabilities, but rather on the substantial amount of overlap and ambiguity among the categories. The committee suggests that in a revised version of this figure, the

assignment of a given qualitative word to a given range of probability should be less ambiguous, where possible.

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Appendixes

A

CCSP Synthesis and Assessment Products

CCSP Synthesis and Assessment Products

According to the National Research Council, "an essential component of any research program is the periodic synthesis of cumulative knowledge and the evaluation of the implications of that knowledge for scientific research and policy formulation." The U.S. Climate Change Science Program (CCSP) will help meet that fundamental need through a series of 21 "synthesis and assessment" (S&A) products. A key component of the *CCSP Strategic Plan* (released July 2003), they will integrate research results focused on important science issues and questions frequently raised by decision makers.

The S&A products will support informed discussion and decisions by policymakers, resource managers stakeholders, the media, and the general public. They also will help define and set the future direction and priorities of the program. The products help meet the requirements of the Global Change Research Act of 1990. The law directs agencies to "produce information readily usable by policymakers attempting to formulate effective strategies for preventing, mitigating, and adapting to the effects of global change" and to undertake periodic scientific assessments.

Designated CCSP agencies or departments will take the lead in generating each S&A product. The CCSP also will continue to participate in the principal international science assessments, including the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report scheduled for completion in 2007, and the World Meteorological Organization (WMO)/United Nations Environment Programme (UNEP) assessments of stratospheric ozone depletion and associated environmental impacts.

The *CCSP Strategic Plan* sets forth general principles for the S&A products:

- Analyses structured around specific questions
- Early and continuing involvement of stakeholders
- Explicit treatment of uncertainties
- Transparent public review of analysis questions, methods, and draft results
- Flexible approach, building on lessons learned.

As the CCSP progresses with the S&A products, it will learn from experience and adjust its approach accordingly.

To help ensure adherence to those principles, the program has published guidelines for producing the S&A products. These guidelines establish a broadly standardized methodology that will facilitate involvement of the research community and the public; ensure focused and useful products; and meet the highest standards of scientific excellence. The guidelines also encourage transparency by providing public access to information about the status of the products through the *Federal Register*, the CCSP web site, and other means. The guidelines address three steps required to produce S&A products:

1) Developing a prospectus
2) Drafting and revising the document
3) Final approval and publication of each product.

The guidelines set forth the roles of participants and the steps in the process (see page 2).

The first S&A product—*Temperature Trends in the Lower Atmosphere: Steps for Understanding and Reconciling Differences*—will be issued by CCSP in early 2006. Others are in various stages of development. For more information on the products, process, and schedule, visit the Synthesis and Assessment products portion of the CCSP web site at <www.climatescience.gov/Library/sap/>.

INFORMATION QUALITY ACT (IQA) AND FEDERAL ADVISORY COMMITTEE ACT (FACA)

The S&A products are subject to the IQA and most also fall under FACA. Each product must meet the IQA guidelines of the lead agency responsible for the product. In particular, the lead agency must ensure compliance with peer review requirements established under IQA for "highly influential scientific assessments." This requires producing and implementing a peer review plan for each product. Where a product falls under FACA, the lead agency forms an advisory committee to which authors are appointed. The lead agency produces a draft charter outlining the committee's mission and specific duties. The charter is made available for public review, and subsequently a final charter is produced by the lead agency and approved by the CCSP Interagency Committee. Each FACA committee must adhere to its charter and must:

- Arrange meetings for reasonably accessible and convenient locations and times
- Publish adequate advance notice of meetings in the Federal Register
- Open advisory committee meetings to the public (with some exceptions)
- Make available for public inspection, subject to the Freedom of Information Act, papers and records, including detailed minutes of each meeting
- Maintain records of expenditures.

Steps of the Process[1]

Planning the Process and Preparing a Prospectus

1) The lead and supporting agencies solicit input from users and other stakeholders, plan preparation of the product, and summarize the proposed process in a draft prospectus.
2) The CCSP Interagency Committee reviews and approves the draft prospectus for public comment.
3) Expert reviewers and stakeholders review the draft prospectus over a period of at least 30 days.
4) Lead and supporting agencies revise the draft prospectus and finalize recommendations for individuals to serve as authors.
5) The CCSP Interagency Committee approves the revised prospectus.
6) The CCSP Office posts the draft prospectus comments and the final prospectus on the CCSP web site.

Additional Stakeholder Interactions, if Needed

7) Lead authors may solicit additional input from users and other stakeholders to assist in the development of the product. The process for soliciting additional input is open and is described in the prospectus. The results from additional stakeholder interactions are publicly available in summary or more extensive forms through publication on the CCSP web site.

Drafting/Reviewing the Products

8) Lead authors prepare the first draft, including a technical section and a summary for interested non-specialists.
9) The lead and supporting agencies organize and facilitate an expert peer review of the first draft. All comments submitted during the expert peer review are publicly available.
10) Lead authors prepare the second draft of the product.
11) The CCSP Office posts the second draft for public comment for not less than 45 days. All comments are publicly available.
12) The lead authors prepare a third draft of the product.

Approving, Producing, and Releasing the Products

13) Lead agencies certify that the product complies with the Information Quality Act, and submit the third draft and comments received to the CCSP Interagency Committee.
14) If the CCSP Interagency Committee review determines that no further action is needed, the product is submitted to the National Science and Technology Council (NSTC) for approval. Otherwise, the Committee's comments are sent to the lead and supporting agencies for consideration and resolution by lead authors.
15) If needed, the National Research Council (NRC) can be asked to provide additional scientific analysis.
16) Once any remaining concerns are addressed, the CCSP Interagency Committee submits the final draft to NSTC for review and approval. Approval requires the concurrence of all Committee on Environment and Natural Resources (CENR) members.
17) Once NSTC approval has been obtained and the product is finalized, the lead agencies produce and release the completed product.
18) The CCSP Office widely disseminates the product through its web site and other mechanisms.

[1] A more detailed description is available on the CCSP Web site at <http://www.climatescience.gov/Library/sap/sap-guidelines.htm>.

PARTICIPANTS AND THEIR ROLES

CCSP Interagency Committee
CCSP's Interagency Committee is chaired by the CCSP Director (DOC appointee) and includes representatives of 13 participating departments/agencies that have mission or funding responsibilities in climate and global change research:

- Department of Agriculture (USDA)
- Department of Commerce / National Oceanic and Atmospheric Administration (DOC/NOAA)
- Department of Defense (DOD)
- Department of Energy (DOE)
- Department of Health and Human Services (HHS)
- Department of the Interior / U.S. Geological Survey (DOI/USGS)
- Department of State (DOS)
- Department of Transportation (DOT)
- Agency for International Development (USAID)
- Environmental Protection Agency (EPA)
- National Aeronautics and Space Administration (NASA)
- National Science Foundation (NSF)
- Smithsonian Institution (SI).

The committee also includes liaisons from the Executive Office of the President (EOP). Membership on the CCSP Interagency Committee is joint with the Subcommittee on Global Change Research (SGCR) of the Committee on Environment and Natural Resources (CENR) of the President's National Science and Technology Council (NSTC).

Lead Agencies/Departments
A single CCSP agency or department will take the lead in producing each product. Among the lead agency's responsibilities is ensuring compliance with the Information Quality Act (PL 106-554, §515 (a)). Each S&A Product must meet the lead agency's Information Quality Guidelines. In so doing, lead agency must ensure compliance with peer review requirements. The lead agency also is responsible for ensuring that the report is produced in accordance with the Federal Advisory Committee Act.

Lead and Contributing Authors
Lead and contributing authors are individuals with appropriate technical expertise. They may be citizens of any country and be drawn from within or outside the Federal government. Lead authors are responsible for producing the S&A reports.

Federal Advisory Committee Act (FACA) Committees
If FACA is applicable to a particular product, a FACA committee is formed. In general, if non-Federal scientists serve as lead authors, the authors are constituted as an advisory committee under the Federal Advisory Committee Act. After substantive deliberations on the product, the committee submits the finished report to the lead agency.

Interagency Working Groups
The CCSP's research-oriented interagency working groups (IWGs) consist of agency program managers who have budget authority within their agencies to implement CCSP research programs. IWGs may help the lead agencies with any product-related task. Current IWGs focus on Atmospheric Composition, Climate Variability and Change, Global Water Cycle, Land-Use/Land-Cover Change, Global Carbon Cycle, Ecosystems, Human Contributions and Responses to Global Change, Decision Support, Modeling, Observations and Monitoring, International, and Data Management.

Expert Reviewers
Expert reviewers are scientists or individuals selected by the lead agencies/departments based on expertise, balance, and independence criteria. In accrediting the experts, the lead agencies/departments ensure that there is no perceived conflict of interest. Reviewers may be citizens of any country and be drawn from within or outside the Federal government (e.g., universities or other public or private sector organizations).

Stakeholders
Stakeholders are individuals or groups whose interests (financial, cultural, value-based, or other) are affected by climate variability, climate change, or options for adapting to or mitigating these phenomena. Stakeholders participate during the "scoping" process by providing information that helps define the audience and potential uses of a product. In addition, stakeholders provide comments on the prospectus, and on the product during the public comment period.

National Research Council
The National Academy of Sciences/National Research Council will provide advice on an as-needed basis to the lead agencies. The NRC may be asked to provide additional scientific analyses to help bound the uncertainty associated with these issues.

National Science and Technology Council
The NSTC is responsible for final review and approval. Approval will require written concurrence from all members of the NSTC's Committee on Environment and Natural Resources, which consists of 15 agency and department representatives on the Assistant Secretary or Deputy Assistant Secretary level. The committee also includes liaisons from the Executive Office of the President, and other Executive organizations, departments, and agencies as the co-chairs may, from time to time, designate.

Summary of Synthesis and Assessment Products*

CCSP GOAL 1	Extend knowledge of the Earth's past and present climate and environment, including its natural variability, and improve understanding of the causes of observed changes	
Product 1.1	Temperature trends in the lower atmosphere: steps for understanding and reconciling differences	NOAA
Product 1.2	Past climate variability and change in the Arctic and at high latitudes	USGS
Product 1.3	Re-analyses of historical climate data for key atmospheric features: implications for attribution of causes of observed change	NOAA
CCSP GOAL 2	Improve quantification of the forces bringing about changes in the Earth's climate and related systems	
Product 2.1	Scenarios of greenhouse gas emissions and atmospheric concentrations and review of integrated scenario development and application	DOE
Product 2.2	North American carbon budget and implications for the global carbon cycle	NOAA
Product 2.3	Aerosol properties and their impacts on climate	NASA
Product 2.4	Trends in emissions of ozone-depleting substances, ozone layer recovery, and implications for ultraviolet radiation exposure and climate change	NOAA
CCSP GOAL 3	Reduce uncertainty in projections of how the Earth's climate and related systems may change in the future	
Product 3.1	Climate models: an assessment of strengths and limitations for user applications	DOE
Product 3.2	Climate projections for research and assessment based on emissions scenarios developed through the Climate Change Technology Program	NOAA
Product 3.3	Climate extremes including documentation of current extremes: prospects for improving projections	NOAA
Product 3.4	Risks of abrupt changes in global climate	USGS
CCSP GOAL 4	Understand the sensitivity and adaptability of different natural and managed ecosystems and human systems to climate and related global changes	
Product 4.1	Coastal elevation and sensitivity to sea-level rise	EPA
Product 4.2	State-of-knowledge of thresholds of change that could lead to discontinuities (sudden changes) in some ecosystems and climate-sensitive resources	USGS
Product 4.3	Analyses of the effects of global change on agriculture, biodiversity, land, and water resources	USDA
Product 4.4	Preliminary review of adaptation options for climate-sensitive ecosystems and resources	EPA
Product 4.5	Effects of global change on energy production and use	DOE
Product 4.6	Analyses of the effects of global change on human health and welfare and human systems	EPA
Product 4.7	Within the transportation sector, a summary of climate change and variability sensitivities, potential impacts, and response options	DOT
CCSP GOAL 5	Explore the uses and identify the limits of evolving knowledge to manage risks and opportunities related to climate variability and change	
Product 5.1	Uses and limitations of observations, data, forecasts, and other projections in decision support for selected sectors and regions	NASA
Product 5.2	Best-practice approaches for characterizing, communicating, and incorporating scientific uncertainty in decision making	TBD
Product 5.3	Decision support experiments and evaluations using seasonal-to-interannual forecasts and observational data	NOAA

* The righthand column provides the S&A product lead agency for IQA and FACA purposes.

This fact sheet was generated by the Climate Change Science Program Office in collaboration with an interagency working group composed of representatives of the 13 Federal agencies participating in the U.S. Climate Change Science Program.

For further information, see <www.climatescience.gov>.

B

Prospectus for Synthesis and Assessment Product 5.2

Prospectus for Synthesis and Assessment Product 5.2

Best Practice Approaches for Characterizing, Communicating and Incorporating Scientific Uncertainty in Climate Decision Making

Sponsoring Agency: National Oceanic and Atmospheric Administration
Supporting Federal Partners: Department of Energy
Department of Transportation
Environmental Protection Agency
National Aeronautics and Space Administration
National Science Foundation

1. OVERVIEW

1.1 Introduction

The U.S. Climate Change Science Program (CCSP) is an interagency endeavor designed to create an extensive body of scientific knowledge and associated decision support tools that can foster improved understanding and adaptation in the face of a dynamic climate system. In order to help bridge the gap between science and practical management challenges in sectors and regions that are sensitive to climate change and variability, the CCSP contributes to and participates in a range of regional and international assessment activities, including the Intergovernmental Panel on Climate Change (IPCC). In addition to participation in broader assessment activities, the CCSP is committed to developing a series of Synthesis and Assessment Products (SAPs) that summarize the current state of scientific understanding about key issues related to climate change, variability, ecosystems and human society[1]. Essentially, these products will communicate what is known, from a CCSP perspective, including degrees of uncertainty, about climate and its interactions with natural and socioeconomic systems in a context and format that may be useful for policymakers, resource managers, scientists and other stakeholders.

[1] A complete list of CCSP SAPs can be found at www.climatescience.gov.

In order for CCSP research outputs/findings (including, but not limited to the SAPs) to be both scientifically accurate and useful to decision makers, scientific uncertainties must be acknowledged and clearly defined. Given the importance of providing clear information concerning uncertainties associated with the application of climate science and information in decision making, the CCSP is developing a Synthesis and Assessment Product (5.2) that explicitly focuses on best practices for characterizing, communicating and incorporating scientific uncertainty. This prospectus outlines the plans for the development of SAP 5.2.

1.2 Topic and Content

Uncertainty factors into large and small decisions made by individuals every day throughout society. The choice to bring an umbrella to work, take a new job, or to move to a new neighborhood all involve some degree of uncertainty, with various levels of risk and opportunity that must also be considered. In most cases, the uncertainties inherent in personal decisions are not treated as explicitly and systematically as they might be. Unlike personal decision-making, building an understanding of potential climate change impacts requires a synthesis of science, practical resource management strategies and an anticipation of the requirements for the long-term health and welfare of human society and the environment. This complex analysis creates a demand and opportunity for examining the way scientific uncertainty is articulated, communicated, and considered in decision making.

The *Strategic Plan for the U.S. Climate Change Science Program* defines uncertainty as:

> *An expression of the degree to which a value (e.g., the future state of the climate system) is unknown.*

Uncertainty concerning the nature and impacts of climate change and variability is the inevitable consequence of the necessary synthesis of various types of data of varying degrees of quality with models possessing varying degrees of skill in simulating natural processes and human behavior. Scientists work to minimize uncertainty in their projections by identifying its nature and source and, then by undertaking focused research to reduce the margin between what is known and what is not known. Various factors can complicate the accurate formulation and communication of uncertainty in climate change projections including the definition of concepts, terminology, and scale (Moss and Schneider, 2000).

The level of certainty in the projections of climate change and its effects has emerged as a central issue in the public discourse, reinforcing the need to evaluate current methods and to define best practices for assessing uncertainty. The scientific community – which includes scientists from academia, government, and the private sector, as well as research and operational entities[2] - are looked to by policymakers, decision makers, and the media for "answers" (or insights) about trends, rates, impacts, and adaptation options related to climate change. Meeting these societal demands, and providing effective support for decisions in sectors and regions affected by climate change and variability, requires a better understanding and articulation of the nature and

[2] In the context of this discussion, operational entities are those which regularly provide science-based products for utilization by other technical entities and the general public.

implications of uncertainty to enable more informed policy and management decisions. Essentially, researchers, technical experts and decision makers must develop a functional degree of shared understanding and language regarding uncertainty in order to facilitate a constructive dialogue between those who produce, and those who would utilize scientific information.

The climate research community has recognized the need to improve the treatment of uncertainty in assessment efforts. The Intergovernmental Panel on Climate Change (IPCC), the largest international climate assessment effort, recognized the need for a more formal, decision analysis based treatment of uncertainty in Chapter 11 of its report on *Climate Change 1995: The Science of Climate Change* (McBean et al., 1995). In response to this need, recommendations for reporting uncertainty were developed for the authors of the IPCC Third Assessment Report (TAR) and the ongoing Fourth Assessment Report (AR4). SAP 5.2 is intended to further develop this topic through the synthesis, assessment, and communication of what is known about the character of uncertainty (as it applies to climate), and to address some potential approaches to decision making under uncertainty. The report will address uncertainty dimensions that are inherent to the full spectrum of decision support activities, ranging from the conduct and communication of research to the actual consideration and use of scientific knowledge and information products in decision making.

1.3. Audience and Intended Use

SAP 5.2 is designed to address two distinct purposes and audiences. One purpose of the report is to synthesize and communicate the current state of understanding about the characteristics and implications of uncertainty related to climate change and variability to an audience of policymakers, decision makers, and members of the media and general public with an interest in developing a fundamental understanding of the issue. Such an understanding could contribute sound scientific underpinnings to an informed discourse about the nature and implications of climate variability and change. SAP 5.2 will contribute insight about the nature of uncertainty that is fundamental to a priority issue identified in the CCSP Strategic Plan: *an understanding of how the methods and capabilities for societal decision making under conditions of complexity and uncertainty about global environmental variability and change can be enhanced*. An increased awareness and understanding of the characteristics of scientific uncertainty as applied to climate is a critical step in this effort.

The second purpose is to provide recommendations for best practices for characterizing, analyzing and communicating uncertainty for scientists, science managers, and technical operational entities involved in conducting research and assessments, and producing climate information in the context of decision support, based on a thorough, state-of-the-art assessment of the current state of understanding. This latter audience includes, but is not limited to, future CCSP assessment efforts.

The potential stakeholders of the CCSP synthesis and assessment product effort are broad and diverse, consisting of resource managers and planners across various geographical and institutional scales, policymakers, and the national and international scientific and operational communities. Two segments of this broader stakeholder community are intended as the primary audience for SAP 5.2: a) policymakers, decision makers, and members of the media and general

public with a desire to better understand the complex nature of uncertainty as a foundation for interpreting scientific information regarding climate change and variability, and to apply this knowledge in considering adaptation needs and options; and b) the scientific and operational communities involved in producing and disseminating scientific information and products.

Given the intended audiences, it is anticipated that SAP 5.2 may be used as a) a relatively sophisticated summary and assessment of the state-of-the-art understanding of the characteristics of uncertainty and the illumination of some potential approaches to decision making under such uncertainty; b) decision analysis and social science-based guidelines for future CCSP, assessment and decision support activities and for researchers participating in broader assessment activities, such as the IPCC.

1.4 Key Questions

SAP 5.2 will address the following questions in the context of climate science:

- How is uncertainty estimated and measured?
- What are the sources and types of uncertainty that influence the way scientific information is communicated and understood by non-scientists?
- Why is an enhanced understanding of uncertainty important for communicating and utilizing climate information?
- What are some of the cognitive challenges in estimating uncertainty (e.g., the role of human judgment) and the relevance of these challenges to addressing climate?
- How is uncertainty analyzed, and how can it be applied in analyses of adaptation options?
- What are some effective methods for communicating uncertainty?
- How can decision makers consider and incorporate uncertainty?
- What are considered to be the best practices for the incorporation and communication of uncertainty in scientific assessments?

2. AGENCY CONTACT INFORMATION

The National Oceanic and Atmospheric Administration (NOAA) is the lead agency for SAP 5.2, supported by the Department of Energy (DOE), the Department of Transportation (DOT), the Environmental Protection Agency (EPA), the National Aeronautics and Space Administration (NASA), and the National Science Foundation (NSF). Together, these agencies constitute the interagency working group (IWG) responsible for overseeing the production of SAP 5.2[3]. Contact information for the agency personnel involved in this product is listed below.

Agency	Key IWG Personnel and Contact Information
NOAA	Tom Karl (Thomas.R.Karl@noaa.gov) Margaret McCalla (Margaret.R.McCalla@noaa.gov) Lisa Vaughan (Lisa.Vaughan@noaa.gov), Lead Agency Coordinator

[3] The respective roles of the Lead Agency and the IWG are outlined in the *Guidelines for CCSP Synthesis and Assessment Products*, available at www.climatescience.gov.

DOE	John Houghton (John.Houghton@science.doe.gov)
DOT	Richard Corley (Richard.Corley@dot.gov) Mike Savonis (Michael.Savonis@fhwa.dot.gov)
EPA	Brooke Hemming (Hemming.Brooke@epamail.epa.gov) Mike Slimak (Slimak.Michael@epa.gov)
NASA	DeWayne Cecil (LCecil@hq.nasa.gov)
NSF	Robert O'Connor (RoConnor@nsf.gov)

3. SAP 5.2 LEAD AND CONTRIBUTING AUTHORS

As articulated in the *Guidelines for Producing CCSP Synthesis and Assessment Products*, lead and contributing authors of SAPs are expected to be individuals with recognized technical expertise in a field relevant to the specific question(s) addressed by the SAPs, as evidenced by publication record and/or pertinent achievements and contributions to their field. Authors can be drawn from the international community of experts.

The authors of SAP 5.2 are well-respected scientific experts, who are solely responsible for the content of the report that will be submitted to the CCSP for review. He is responsible for selecting the contributing authors for the report. They are all considered to be experts in the characterization and treatment of uncertainty, and represent various perspectives from throughout the community; biographical information is included in this document as an appendix.

The CCSP research portfolio includes a suite of interdisciplinary centers dedicated to Decision Making Under Uncertainty (DMUU) in the context of climate change and variability. The DMUU centers are explicitly designed to conduct research and develop tools that can be utilized to increase understanding and adaptation options associated with the risks and uncertainties presented by climate change and variability. Five DMUU centers were established in 2004 through a highly competitive peer review process managed by the National Science Foundation (NSF). Given this substantial investment in decision support oriented studies of uncertainty, SAP 5.2 will capitalize on the work and expertise of the DMUU centers. The lead author identified for SAP 5.2 is associated with one of these centers, the DMUU Climate Decision Making Center. The National Science Foundation is supporting the lead and contributing authors for SAP 5.2 through a cooperative agreement with this DMUU Center.

Lead Author

Dr. Granger Morgan, Department of Engineering and Public Policy, Carnegie Mellon University, and leader of the DMUU Climate Decision Making Center

Contributing Authors

Dr. Hadi Dowlatabadi, Institute for Resources, Environment and Sustainability, University of British Columbia
Dr. Max Henrion, Lumina Decision Systems
Dr. David Keith, Department of Chemical and Petroleum Engineering and Department of Economics, University of Calgary
Dr. Robert Lempert, The RAND Corporation
Dr. Thomas Wilbanks, Environmental Science Division, Oak Ridge National Laboratory

4. STAKEHOLDER INTERACTIONS

CCSP synthesis and assessment products will be developed in consultation with a diverse group of stakeholders. The team of individuals identified as SAP 5.2 authors is composed of highly active members of the scientific community who are engaged in the current discourse related to uncertainty in the context of climate change and variability. They interact frequently on this topic with their scientific colleagues at workshops, conferences and advisory panels as well as decision makers, seeking and receiving feedback on specific theories, approaches and conclusions. The team will continue to do so, and will seek specific opportunities to vet this material by participating in conferences, workshops and other forums that present an opportunity for obtaining feedback from members of the broader stakeholder community, including but not limited to, the lead authors of other CCSP SAPs. In addition, decision makers will be invited to participate in one of the review meetings of the National Research Council and will have the opportunity to interact directly with the authors in this context. Finally, the interagency working group charged with overseeing the development of SAP 5.2 will make a concerted effort to inform the broader scientific and decision making communities of the opportunity for input presented by the public review of this prospectus and the actual product (see below for information regarding the review process).

5. DRAFTING PROCESS, INCLUDING MATERIALS TO BE USED IN PREPARING THE PRODUCT

Support for SAP 5.2 is provided by an NSF award to the lead author, Dr. Granger Morgan of the Carnegie Mellon Climate Decision Making Center. The SAP 5.2 interagency working group (members identified in section 2 above) will determine through the creation of this prospectus (including the consideration of comments received during the public review period) the overall scope, focus, and balance of the product. The IWG will not participate in the drafting of the actual report; public review and expert review comments will be handled by the lead author and his team. The lead author is responsible for the initial draft as a basis for further development by the team of contributing authors. The content and focus of this report will be discussed by the lead author with members of the scientific and decision making communities throughout the drafting process; this feedback will be incorporated in the progressive drafts, along with input provided through the formal public and expert review phases described below. Authors will draw upon peer-reviewed scientific literature in the drafting process.

6. REVIEW

As the lead agency, NOAA will develop and oversee a review process that satisfies the SAP guidance issued by the CCSP, and is consistent with the Information Quality Act and the Office of Management and Budget's (OMB's) Final Information Quality Bulletin for Peer Review (December 2004). The *Guidelines for Producing CCSP Synthesis and Assessment Products* essentially requires three levels of review for each SAP: a) technical expert review; b) a 45 day public review; and c) a CCSP and National Science and Technology Council (NSTC) review prior to release of the final document. The review process outlined below is consistent with the requirements identified above.

As the lead agency for this project, NOAA will submit a draft of SAP 5.2 to the National Academies' National Research Council (NRC) for expert scientific review. The following questions are likely to be addressed in the review:

1) Are the goals, objectives, terminology and intended audience of the product clearly described in the document? Does the product address all questions outlined in the prospectus?
2) Are any findings and/or recommendations adequately supported by evidence and analysis? In cases where recommendations might be based on expert value judgments or the collective opinions of the authors, is this acknowledged and supported by sound reasoning?
3) Are the data and analyses handled in a competent manner? Are statistical methods applied appropriately?
4) Are the document's presentation, level of technicality, and organization effective? Are the questions outlined in the prospectus addressed and communicated in a manner that is appropriate and accessible for the intended audience?
5) Is the document scientific objective and policy neutral? Is it consistent with the scientific literature? How do the conclusions and general approaches for addressing uncertainty compare with those embraced by other treatments of the topic (e.g., IPCC, NRC activities)? If not, are differences supported by explicit and sound reasoning?
6) Is there a summary that effectively, concisely and accurately describes the key findings and recommendations? Is it consistent with other sections of the document?
7) What other significant improvements, if any, might be made in the document?

The findings of the NRC review will be available following completion. The lead author, assisted by his team, will consider and incorporate the findings of the NRC review as they deem appropriate.

NOAA will post the revised draft for a public review period of 45 days. Comments will be considered by the lead author and the contributing team of authors, and incorporated based on their scientific judgment. The author's comments to the NRC review will be posted on the CCSP website.

NOAA will submit the revised draft to the CCSP Interagency Committee for approval. If the CCSP Interagency Committee concludes that further revision is necessary, their comments will

be provided to the lead author, who will then consider and address these comments according to their scientific judgment. If the CCSP approves the draft product, they will submit it to the NSTC for review. Clearance will require the concurrence of all members of the Committee on Environment and Natural Resources. The sequence and potential timing of the review process is outlined in Section 9 of this prospectus.

7. RELATED ACTIVITIES

Several key activities with an explicit or implicit focus on the characterization and communication of uncertainty in the context of climate change and variability are currently underway. The SAP 5.2 effort is aware of, and in some cases, connected to these efforts through the participation of the lead and contributing authors. Relevant activities include the following:

- IPCC Fourth Assessment Report (AR4)[4], and associated activities, including the IPCC Workshop on Describing Scientific Uncertainties in Climate Change to Support Analysis of Risk and Options (Co. Kildare, Ireland; May 2004), and the development of *Guidance Notes for Lead Authors of the IPCC Fourth Assessment Report on Addressing Uncertainties*.

- NRC Board on Atmospheric Sciences and Climate (BASC) Study on Estimating and Communicating Uncertainty in Weather and Climate Forecasts.

- NRC BASC Analysis of Global Change Assessments.

- Ongoing and future CCSP synthesis and assessment activities.

8. COMMUNICATIONS

Throughout the process, the agency representatives are available to answer questions regarding the development and production of SAP 5.2.

As the lead agency, NOAA will manage the production and release of the completed product, utilizing a standard format established by the CCSP. The final report will be available in a PDF version, as well as in a hardcopy. The electronic information, and information about obtaining a hardcopy of the document, will be available on the CCSP web site (www.climatescience.gov).

9. TIMELINE

2006

June	Public review of SAP 5.2 draft prospectus (30 days)
September	Establishment of NRC Committee for the review of SAP 5.2, and draft report #1 submitted to the NRC for expert review
October	Final SAP 5.2 prospectus posted on CCSP web site

[4] IPCC AR4 is scheduled for completion in 2007.

November/ December	NRC review of draft #1, including stakeholder session

2007

January	NRC review of draft report #1 delivered to CCSP
February	Author team considers NRC review and develops draft #2
March	Public review of draft report #2 begins (45 day period)
April	Author team considers public review and develops draft #3
April	Draft report #3 submitted to CCSP Interagency Committee and NSTC for review and approval
May	Final product posted on CCSP web site

APPENDIX A: Author Biographical Information

Lead Author

Dr. M. Granger Morgan

Dr. Morgan is Professor and Head of the Department of Engineering and Public Policy at Carnegie Mellon University where he is also University and Lord Chair Professor in Engineering. In addition he is a Professor in the Department of Electrical and Computer Engineering and in The H. John Heinz III School of Public Policy and Management. His research addresses problems in science, technology and public policy, much of it involving the development and demonstration of methods to characterize and treat uncertainty in quantitative policy analysis. At Carnegie Mellon, Morgan directs the NSF Climate Decision Making Center and co-directs, together with Lester Lave, the Carnegie Mellon Electricity Industry Center. Morgan serves as Chair of the EPA Science Advisory Board, Chair of the EPRI Advisory Council, and Chair of the Scientific and Technical Council for the International Risk Governance Council (based in Geneva, Switzerland). He is a Fellow of the AAAS, the IEEE, and the Society for Risk Analysis. He holds a BA from Harvard College (1963) where he concentrated in Physics, an MS in Astronomy and Space Science from Cornell (1965) and a Ph.D. from the Department of Applied Physics and Information Sciences at the University of California at San Diego (1969).

Contributing Authors

Dr. Hadi Dowlatabadi

Dr. Dowlatabadi is Canada Research Chair & Prof in Applied Mathamatics and Global Change, University of British Columbia. He is Associate Director of the Institute for Resources Environment and Sustainability and the Bridge Scholarship Program. He is a University Fellow at Resources for the Future and an Adjunct Faculty at Carnegie Mellon University. He is co-founder and Editor of the Integrated Assessment Journal and serves on the boards of four other periodical. He is co-founder of Offsetters and Cooldrivepass, and a Director of Canadian Bioenergy Corporation. His research has focused on the interface between humans and the environment and systems approaches to decision making under uncertainty. He studies problems in technology choice, acid rain, air quality, infectious and vector-borne diseases, energy policy, equity, ethics and climate change. He received his BSc in physics from Edinburgh University (1980) and his PhD in Physics from Cambridge University (1984).

Dr. Max Henrion

Dr. Max Henrion has 25 years of experience as a researcher, educator, software designer, consultant, and entrepreneur, specializing in the creation and effective use of decision technologies. He is the Founder and CEO of Lumina Decision Systems, which publishes

decision software and provides consulting in decision analysis to corporate and government clients. He was the lead designer of Lumina's flagship product line, *Analytica* -- the software about which *PC Week* said *"Everything that's wrong with the common spreadsheet is fixed in Analytica"*. He was Vice President for Decision Technology at Ask Jeeves, Inc, where he led the division that created the Jeeves Advisor, offering online consumer advice. He has led consulting teams offering decision and risk analysis in environment and energy, telecommunications, aerospace, healthcare, and consumer choice. He was the founding President of the Association for Uncertainty and Artificial Intelligence. He has (co)authored three books, including *Uncertainty: A Guide to dealing with Uncertainty in Policy and Risk Analysis* (Cambridge University Press, 1990), and over 60 peer-reviewed articles. He was Consulting Professor at Stanford University in Medical Informatics. He is now Adjunct Professor, and previously Associate Professor, at Carnegie Mellon University, where he taught in the Departments of Engineering and Public Policy, and Social and Decision Science. He has an MA in Natural Sciences from Cambridge University, Master of Design from the Royal College of Art, London, and a PhD from the School of Urban and Public Affairs at Carnegie Mellon University.

Dr. David Keith

Dr. David Keith is Canada Research Chair in Energy and the Environment; Professor Department of Chemical and Petroleum Engineering and Department of Economics, University of Calgary, and Adjunct Professor Department of Engineering and Public Policy Carnegie Mellon. Professor Keith works near the interface between climate science, energy technology and public policy. Roughly half of his technical and policy work addresses the capture and storage of CO_2, including work managing the risks of geologic storage and services as chair of a crosscutting group for the IPCC special report on CO_2 storage. Keith serves as a member of several advisory boards and panels including Canada's 'blue ribbon' *Panel on Sustainable Energy Technology*, and the InterAcademy Council study on *Transitions to a Sustainable Energy Systems*, and as member of U.S. National Academy committees. Keith's broader climate and energy related research addresses the economics and climatic impacts of large-scale wind power, the use of hydrogen as a transportation fuel, and the technology and implications of geoengineering. Keith's has addressed technical audiences with articles in *Science* and *Nature*. He as consulted for national governments, industry and environmental groups and has reached the public through U.S. and Canadian radio and television. Keith is trained as a physicist. As a graduate student at MIT, he built the first interferometer for atoms work which was the "hottest topic" in physics according to ISI's citation index. As an atmospheric scientist he worked at NCAR and Harvard, where he served as lead scientist for a new Fourier-transform spectrometer with high radiometric accuracy that flies on the NASA ER-2 high-altitude aircraft. Keith returned to Canada in 2004 taking a position at the University of Calgary where he leads a research group on energy and environmental systems.

Dr. Robert Lempert

Dr. Robert Lempert is a senior scientist at RAND and an expert in science and technology policy, with a special focus in climate change, energy, and the environment. An internationally-known scholar in the field of decision making under conditions of deep uncertainty, Dr. Lempert is a Fellow of the American Physical Society, a member of the National Academy of Science's Climate Research Committee, and a member of the Council on Foreign Relations. Dr. Lempert has led studies on climate change policy, the environment, energy, national security strategies, and on science and technology investment strategies for clients that include the White House Office of Science and Technology Policy, the U.S. Department of Energy, the National Science Foundation, and several multinational firms. He holds a bachelor of arts and science degree in physics and political science from Stanford University and a doctorate in applied physics from Harvard University. A Professor of Policy Analysis in the RAND Graduate School, Dr. Lempert is an author of the recent book *Shaping the Next One Hundred Years: New Methods for Quantitative, Longer-Term Policy Analysis*.

Dr. Thomas J. Wilbanks

Dr. Thomas Wilbanks is a Corporate Research Fellow at the Oak Ridge National Laboratory and leads the Laboratory's Global Change and Developing Country Programs. He conducts research on such issues as sustainable development, energy and environmental technology and policy, responses to global climate change, and the role of geographical scale in all of these regards. Wilbanks is a member of the Board on Earth Sciences and Resources of the U.S. National Research Council (NRC) and Chair of NRC's Committee on Human Dimensions of Global Change. He is Coordinating Lead Author for the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Working Group II, Chapter 7: Industry, Settlement, and Society. He is a past President of the Association of American Geographers and a Fellow of the AAAS. He holds a BA from Trinity University (1960) and MA and PhD degrees in geography from Syracuse University (1967, 1969).

APPENDIX B: References

CCSP, 2004: *Guidelines for Producing CCSP Synthesis and Assessment Products*. Available at http://www.climatescience.gov/Library/sap/sap-guidelines.htm.

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Office of Management and Budget (OMB). 2004. Final Information Quality Bulletin for Peer Review. December 16.

C

Committee and Staff Biographies

Carol Anne Clayson (*Chair*) is Associate Professor in the Department of Meteorology at Florida State University and is Director for the Geophysical Fluid Dynamics Institute. From 1995-2001, she was an assistant and associate professor in the Department of Earth and Atmospheric Sciences at Purdue University. Dr. Clayson's research interests are in air-sea interaction, ocean and atmosphere boundary layers, numerical ocean and coupled ocean-atmosphere modeling, and remote sensing of air-sea surface fluxes. She was the recipient in 2000 of a Presidential Early Career Award for Scientists and Engineers (PECASE) and an Office of Naval Research Young Investigator Award. She was also the recipient in 1996 of an National Science Foundation (NSF) career award. Her professional service activities include: program chair for the 12th American Meteorological Society (AMS) Conference on Air-Sea Interactions (2003); membership on a number of committees and working groups including AMS Committee on Interaction of the Sea and Atmosphere; AMS Board of Meteorological and Oceanographic Education in Universities; and NASA TRMM Science Team. Dr. Clayson has been the chair of the GEWEX SEAFLUX project dedicated to producing climatologies of air-sea heat, moisture, and momentum fluxes since 2005. She is a member of the AMS, the American Geophysical Union (AGU), and the Oceanography Society. Dr. Clayson is a member of the Board on Atmospheric Sciences and Climate and several NRC committees, including the Committee on Earth Studies, the Committee on the Future of the Tropical Rainfall Measuring Mission, and the Committee to Review the NASA Earth Science Enterprise Strategic Plan (2003).

Tom Buschatzke, Water Resource Management Advisor to the City of Phoenix, is responsible for policy development for management of the City's water resources and works with City executive staff, the City Manager, the Mayor, and with members of City Council on a variety of water issues. He was recently appointed by Arizona Governor Napolitano to the Arizona Water Banking Authority, a state entity responsible for storing water supplies underground in central Arizona. Mr. Buschatzke also serves as the City's liaison with the Salt River Project, the Central Arizona Project, and the Arizona Department of Water Resources. Presently, Mr. Buschatzke is on the Governor's Colorado River Advisory Council; the Statewide Water Advisory Group; and the Board of Director's of the Western Urban Water Coalition where he serves as Chair of their

Endangered Species Act Committee. Tom holds a Bachelor of Science in Geology from the State University of New York and has in Geology at Arizona State University. He has extensive knowledge of the City's water rights and has worked on negotiations for the Gila River Indian Community Water Rights Settlement; Plan 6 modifications to Roosevelt Dam; Endangered Species Act impacts on the City's water supply; the Arizona Groundwater Management Act; water delivery contracts with SRP; Colorado River issues and a variety of other water resources issues, contracts, and planning activities with local and regional implications.

Radford Byerly, Jr. is a research scientist at the Center for Science and Technology Policy Research, University of Colorado. He formerly worked at the National Institute of Standards and Technology (then the National Bureau of Standards) in the environmental measurement and fire research programs; he served as chief of staff of the U.S. House of Representatives Committee on Science and Technology; and he was director of the University of Colorado's Center for Space and Geosciences Policy. He served as a member of NASA's Space Science and Space Station Advisory Committees and served on NSF site visit committees and review panels. Dr. Byerly was a member of the NRC Space Studies Board and served on the Committee on the Scientific Context for Space Exploration (2004-2005), the Committee on Principles and Operational Strategies for Staged Repository Systems (2001-2003), the Committee on Building a Long-Term Environmental Quality Research and Development Program in the U.S. Department of Energy (2000-2001), and the Board on Assessment of National Institute of Standards and Technology Programs (1995-2000).

Heidi Cullen is the climate expert at The Weather Channel and has the key responsibility of adding explanation, depth and perspective to climate stories for The Weather Channel network and other platforms. Dr. Cullen most recently was a scientist at the National Center for Atmospheric Research (NCAR) in Boulder, CO. She has done research in the U.S. Southwest and the Middle East, publishing on domestic and international climate topics. As a post-doc, she received a NOAA Climate & Global Change Fellowship and spent two years working at the International Research Institute for Climate Prediction. She received a B.S. in Engineering/Operations Research from Columbia University in NYC and went on to receive a Ph.D. in climatology and ocean-atmosphere dynamics at the Lamont-Doherty Earth Observatory of Columbia University. Her dissertation focused on trying to understand the impacts and dynamics of the North Atlantic Oscillation.

Ann-Margaret Esnard joined Florida Atlantic University's Department of Urban and Regional Planning in August 2005 as an Associate Professor and Director of the Visual Planning Technology Lab (VPTLAB). Dr. Esnard's expertise encompasses GIS/spatial analysis, coastal vulnerability assessment, land use planning, and disaster planning. Dr. Esnard is the co-author of the Hypothetical City Workbook (with Edward Kaiser, Dave Godschalk, and Philip Berke) and has written on other topics that include quality of life and holistic disaster recovery, spatial analysis of New York metropolitan urban

expansion, vulnerability assessments of coastal and flood hazards), public participation GIS, environmental justice, GIS education, and ethics. Dr. Esnard served on the NRC's Disaster Roundtable Steering Committee from 2002 - 2004. Her multidisciplinary background in Regional Planning (Ph.D.), Agronomy and Soils (M.S.) and Agricultural Engineering (B.Sc.) is tied together by a computer applications theme and a fundamental belief in appropriate technologies and techniques, as well as a holistic approach to improving natural, physical and social conditions in both urban and rural communities.

Roger E. Kasperson (*NAS*) is a research professor and distinguished scientist at Clark University. While at Clark University, he also directed the Stockholm Research Institute from 1999 to 2002. He holds a Ph.D. in geography from the University of Chicago. He has written widely on issues connected with risk analysis and communication, global environmental change, and environmental policy. Dr. Kasperson has served as a consultant or advisor to federal agencies and private entities on energy and environmental issues. Notable committee appointments include the Potsdam Institute of Climate Change Research Science Advisory Board, the U.K. Tyndall Institute for Climate Change Scientific Advisory Committee, and the NRC Committee on the Human Dimension of Global Change. He has been honored for his hazards research by the Association of American Geographers, and made a fellow of the American Association for the Advancement of Science and the Society for Risk Analysis for his contributions to the field of risk analysis. He is a member of the National Academy of Sciences.

Elizabeth L. Malone is a senior research scientist at the Joint Global Change Research Institute in College Park, MD. The institute is a partnership between the Pacific Northwest National Laboratory (PNNL) and the University of Maryland. Dr. Malone's interests focus on policy-relevant social science research in global change issues, developing studies that integrate disparate worldviews, data sources, and scientific approaches. Her work has contributed to linkages among global environmental change, globalization, economic development, equity, and sustainability. She is the co-editor of Human Choice and Climate Change, a four-volume assessment of social science research relevant to global climate change, and co-author, with Steve Rayner, of the summary volume and an invited paper for Nature on the conclusions. She has published papers on globalization and climate change, vulnerability to climate change, scenario development, and the role of science in developing global environmental policy. In June 2005. Dr. Malone received the NSF Director's Award for Collaborative Integration for her work on the Human and Social Dynamics Priority Area Team while she was on an Intergovernmental Personnel Act assignment to NSF.

Franklin W. Nutter has been president of the Reinsurance Association of America (RAA) since May of 1991. Mr. Nutter currently serves on the Board of Trustees of the Bermuda Biological Station for Research; the Board of the International Hurricane Research Center; the Advisory Board of the Center for Health and the Global Environment, an adjunct to the Harvard University Medical School; and the Board of the University Center for Atmospheric Research. Mr. Nutter has a Juris Doctorate from the

Georgetown University Law Center and a bachelor's degree in economics from the University of Cincinnati. He was also a member of the NRC's Panel on Human Dimensions of Seasonal-to-Interannual Climate Variability.

Jennifer Phillips obtained her Ph.D. in Environmental Biophysics and plant/water relations in the Department of Soil, Crop and Atmospheric Sciences at Cornell University in 1994. She is an Assistant Professor at the Bard Center for Environmental Policy, Bard College. Formerly, she worked at the International Research Institute for Climate and Society, Columbia University, and at NASA Goddard Institute for Space Studies. Her research interests include the impact of climate change and variability on farming systems, communication and perception of climate information for farm management, individual and group process in decision making, and sustainable farming systems. After eight years of research in eastern and southern Africa, she is now working with farmers in eastern New York State on climate risk management, adaptation to climate change and sustainability in the face of extreme climate events in collaboration with scientists from Columbia University. Dr. Phillips' publications include articles in Agricultural Systems, Agricultural and Forest Meteorology, Climatology, and International Journal of Climatology.

Henry N. Pollack has been a Professor of Geophysics at the University of Michigan for more than 40 years. In the scientific community, he has earned a reputation as an expert on the temperature of the Earth, both today and in the geological past. An award-winning teacher with a gift for explaining science to non-scientists, Dr. Pollack has taken a special interest in helping leaders in government, business, and the general public understand the scientific developments associated with global climate change. Over the course of his career, he has educated generations of students, published widely in scientific journals, led his department as chairman, served as an advisor to NSF, testified before Congress, and launched the first international efforts to coordinate research into geothermal evidence of global climate change. He is a Fellow of the American Association for the Advancement of Science, the American Geophysical Union and the Geological Society of America, and was a member of the NRC's U.S. Geodynamics Committee. He is the author of "Uncertain Science… Uncertain World" (Cambridge University Press, 2003).

Stephen H. Schneider (*NAS*), the Melvin and Joan Lane Professor for Interdisciplinary Environmental Studies, has been a professor of Biological Sciences and Professor by Courtesy in the Department of Civil Engineering at Stanford University since September, 1992. He is a Senior Fellow and Co-Director of the Center for Environmental Science and Policy in the Woods Institute for the Environment. Dr. Schneider received his Ph.D. in Mechanical Engineering and Plasma Physics from Columbia University in 1971. In 1975, he founded the interdisciplinary journal, Climatic Change and continues to serve as its Editor. Dr. Schneider was elected to membership in the U.S. National Academy of Sciences in April 2002. He has served on numerous NRC committees, including Section 63: Environmental Sciences and Ecology and Committee on the Human Dimensions of Global Change. He is a Coordinating Lead Author in Working Group II of the

Intergovernmental Panel on Climate Change (IPCC) (under the auspices of the World Meteorological Organization and the United Nations Environment Program) from 1997 to the present (including AR4, the Fourth Assessment Report currently in preparation for 2007) and was a Lead Author in Working Group I from 1994-1996. He was also a lead author of the IPCC guidance paper on uncertainties. He is a member of the CEC California Climate Change Advisory Committee to advise the Governor and state agencies on climate change policy. Dr. Schneider received both the National Conservation Achievement Award from the National Wildlife Federation and the Edward T. Law Roe Award of the Society of Conservation Biology in 2003, and he and his spouse-collaborator, Terry Root, jointly received the Banksia Foundation's International Environmental Award in 2006 in Australia. Dr. Schneider's current global change research interests include: climatic change; climatic modeling; global warming; ecological and economic implications of climatic change; integrated assessment of global change policy; uncertainties; dangerous anthropogenic interference (DAI) with the climate system, and abrupt climate change.

Andrew R. Solow is a Senior Scientist at the Woods Hole Oceanographic Institution where he also directs the Marine Policy Center. Solow is a statistician, specializing in environmental and ecological statistics. His recent work in the area of climate has focused on reconstructions based on proxy records and characterizing ENSO variability. Solow is a former member of the NRC Commission on Geosciences, Environment, and Resources and has served on a number of NRC committees including one reviewing the U.S. Climate Change Science Program Strategic Plan.

STAFF

Chris Elfring is director of the Polar Research Board (PRB) and the Board on Atmospheric Sciences and Climate (BASC). She is responsible for all aspects of strategic planning, project development and oversight, financial management, and personnel for both units. Since joining the PRB in 1996, Ms. Elfring has overseen or directed studies that produced the following reports: *Frontiers in Polar Biology in the Genomics Era* (2003), *Cumulative Environmental Impacts of Oil and Gas Activities on Alaska's North Slope* (2003), *A Century of Ecosystem Science: Planning Long-term Research in the Gulf of Alaska* (2002), and *Enhancing NASA's Contributions to Polar Science* (2001). In addition, she is responsible for the Board's activities as the U.S. National Committee to the Scientific Committee on Antarctic Research.

Curtis H. Marshall is a Program Officer with the Board on Atmospheric Sciences and Climate. He received B.S. (1995) and M.S. (1998) degrees in meteorology from the University of Oklahoma, and a Ph.D. (2004) in Atmospheric Science from Colorado State University. His Doctoral research examined the impact of anthropogenic land-use change on the mesoscale climate of the Florida peninsula. Prior to joining the staff of BASC in 2006, he was employed as a research scientist in the National Oceanic and

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Katherine Weller is a Senior Program Assistant for the Board on Atmospheric Sciences and Climate (BASC) and the Polar Research Board (PRB). In 2004, she received her B.S. from the University of Michigan in Biopsychology. She is currently working toward a master's degree in Environmental Science and Policy from Johns Hopkins University. Since her start at the National Academies in June 2006, Ms. Weller has been working on a study involving the scientific accomplishments of satellite observations, a review of the U.S. CCSP's SAP 3.3, and the Climate Research Committee.

D

Committee to Review the U.S. Climate Change Science Program's Synthesis and Assessment Product 5.2 STATEMENT OF TASK

This committee will review the U.S. CCSP's draft Synthesis and Assessment Product 5.2 entitled "Best-Practice Approaches for Characterizing, Communicating, and Incorporating Scientific Uncertainty in Decision Making." The purpose of SAP 5.2 is to synthesize the current state of understanding about the characteristics and implications of uncertainty related to climate change and variability, and provide recommendations for best practices for characterizing, analyzing and communicating that uncertainty. The role of the National Academies committee will be to provide a peer review of CCSP SAP 5.2. The committee will address the following issues:

1. Are the goals, objectives, terminology, and intended audience of the product clearly described in the document? Does the product address all questions outlined in the prospectus?
2. Are any findings and/or recommendations adequately supported by evidence and analysis? In cases where recommendations might be based on expert value judgments or the collective opinions of the authors, is this acknowledged and supported by sound reasoning?
3. Are the data and analyses handled in a competent manner? Are statistical methods applied appropriately?
4. Are the document's presentation, level of technicality, and organization effective? Are the questions outlined in the prospectus addressed and communicated in a manner that is appropriate and accessible for the intended audience?
5. Is the document scientifically objective and policy neutral? Is it consistent with the scientific literature? How do the conclusions and general approaches for addressing uncertainty compare with those embraced by other treatments of the topic (e.g., IPCC, NRC activities)? Are differences supported by explicit and sound reasoning?
6. Is there a summary that effectively, concisely and accurately describes the key findings and recommendations? Is it consistent with other sections of the document?
7. What other significant improvements, if any, might be made in the document?