Executive Summary

This report begins with a discussion of a number of formulations of uncertainty and the various ways in which uncertainty can arise. It introduce several alternative perspectives on uncertainty including both the classical frequentist view of probability and the subjectivist view in which probability is an indication of degree of belief, informed by all available evidence. A distinction is drawn between uncertainty about the value of specific quantities and uncertainty about the underlying functional relationships among key variables. The question of when it is and is not appropriate to represent uncertainty with a probability distribution is explored. Part 1 of the report closes with a discussion of "ignorance," and the fact that while research often reduces uncertainty, it need not always do so, and indeed in some cases may actually lead to greater uncertainty as new unanticipated complexities are discovered.

Part 2 argues that it is insufficient to describe uncertainty in terms of qualitative language, using words such as "likely" or "unlikely." Empirical evidence is presented that demonstrates that such words can mean very different things to different people, or indeed, different things to the same person in different contexts. Several simple strategies that have been employed to map words into probabilities in the climate literature are described.

In order to make judgments about, and in the presence of uncertainty, the human mind employs a variety of "cognitive heuristics." In many circumstances these serve well. However, in some settings they can lead to significant biases in the judgments that people make. Part 3 summarizes key findings from the experimental literature in behavioral decision making, and discusses a

number of the cognitive biases that can arise, including overconfidence, when reasoning and making decisions in the face of uncertainty.

Once uncertainty has been described in a quantitative form, a variety of analytical tools and models are available to perform analysis and support decision making. Part 4 provides a brief discussion of a number of statistical models used in atmospheric and climate science. This section also discusses methods for hypothesis and model testing as well as a variety of emerging methods and applications. While the treatment is general, the focus throughout is on climate-related applications. A boxed section provides an illustration of frequentist and Bayesian approaches applied to the prediction of rainfall.

Part 5 explores two broad methods for estimating uncertainty: model-based approaches and the use of expert judgment obtained through careful systematic "expert elicitation." In both cases illustrations are provided from the climate literature. Issues such as whether and when it is appropriate to combine uncertainty judgments from different experts, and strategies that have been used to help groups of experts develop probabilistic judgments about quantities and model forms, are discussed.

Part 6 explore the issues of how best to propagate uncertainty through models or other decision making aids, and more generally the issues of performing analysis of and with uncertainty. Again illustrative examples are drawn from the climate literature. Part 7 then explore a range of issues that arise in making decisions in the face of uncertainty, focusing both on classical decision analysis that seeks "optimal strategies," as well as

"resilient strategies" that work reasonably well across a range of possible outcomes, and "adaptive" strategies that can be modified to achieve better performance as the future unfolds. This section closes with a discussion of deep uncertainty, surprise, and some additional issues related to the discussion of behavioral decision theory building on ideas introduced in Part 3.

Part 8 addresses a number of issues that arise in communicating about uncertainty, again drawing on the empirical literature in psychology and decision science. Mental model methods for developing communications are outlined. One key finding is that there is no such thing as an expert in communication – in the sense of someone who can tell you ahead of time how a message should be framed, or what it should say. Empirical study is absolutely essential to the development of effective communication. The section closes with an exploration of the views of a number of leading scientists and journalists who have worked on the difficult problems that arise in the communicating about scientific uncertainty.

Finally Part 9 offers some summary advice. It argues that doing a good job of characterizing and dealing with uncertainty can never be reduced to a simple cookbook. One must always think critically and continually ask questions such as:

- Does what we are doing make sense?
- Are there other important factors which are, as or more important, than the factors we are considering?
- Are there key correlation structures in the problem that are being ignored?
- Are there normative assumptions and judgments about which we are not being explicit?

Then, based both on the finding in the empirical literature, as well as the diverse experience and collective judgment of the writing team, it goes on to provide some more specific advice on reporting uncertainty and on characterizing and analyzing uncertainty. That advice can be found on pages 142 through 148.