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Editorial

Improving information for managing an uncertain future climate

Public opinion increasingly supports action to mitigate greenhouse gas emissions to minimize the rate and magnitude of climate change. A majority of the public in many countries now believes that they will see the impacts of climate change in their lifetimes and that adaptation will be essential for limiting the damages. Even in the US, where public opinion is perceived as lagging behind many other regions of the world, the public now believes in the seriousness and urgency of addressing climate change. Surprisingly, this growing consensus in the public sphere is not supported by the public's perceptions of the degree of consensus about climate change in the scientific community. While a majority of Americans support action on global warming, many question whether there is a scientific consensus on this question or whether the quality of information about climate change and its impacts is sufficiently high to enable decision makers in their region to act on the problem. Continuing to improve how the scientific community assesses and communicates uncertainty to the public and decision makers is crucial to improving the utility of research on climate change both in perception and in reality.

Some examples of international and national surveys support these observations:

- In a poll of 33,237 people from all major regions of the world conducted by GlobeScan Incorporated between October 2005 and January 2006, an average 90% of respondents said that "climate change or global warming, due to the greenhouse effect" is a serious problem (see http://www.worldpublicopinion.org/pipa/articles/home_page/187.php?nid = &id = &p).
- In a June 2005 poll by the University of Maryland's Program on International Policy Attitudes, only 52% thought that there is a consensus among scientists that global warming exists and could do "significant damage," while 39% said that scientists are divided on the existence of global warming and its impact (see http://www.americans-world.org/digest/global_issues/global_warming/gw1.cfm).
- In the US during September 2005, the Oak Ridge Center for Advanced Study commissioned a Harris Interactive® survey of opinion on climate change and the quality of information available to decision makers. In that survey, six in ten American adults believed that they would feel climate change impacts during their lifetimes. Paradoxically, the same percentage said that they felt the quality of information available to support decision-making was only "fair" or "poor/terrible," with only two in five responding that the information was of sufficient quality for decisions makers in their region to act (see http://orcas.orau.org/news/releases/sepw.092805.pdf).

The public uncertainty about what the scientific community believes is in stark contrast to the actual evolution of views within the scientific community about what is really known, and with what level of confidence. The reports of the Intergovernmental Panel on Climate Change (IPCC) provide the best indicator of the evolution of the research community's self assessment of its knowledge (see http://www.ipcc.ch/). These reports document increasingly high confidence in the key areas of detection of change and attribution to human causes, and they document strong improvements in climate modeling and other specific areas of science. The reports also document much progress in the research community's understanding of the potential impacts of climate change under different scenarios, and of the factors that will set the stage for successful implementation of both adaptation and mitigation options. Indeed, many scientists believe that there is now sufficient knowledge to provide political decision makers with the information needed to determine what would constitute "dangerous" anthropogenic interference in the climate system. Many individuals and scientific groups have asserted that this threshold lies in the 2–2.5 °C range of global mean temperature increase (see, for example, the report of the UN Scientific Experts' Group, forthcoming link on http://www.unfoundation.org/). Improvements in the state of knowledge will become even clearer as the results of the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) come out during 2007.

Until recently, what seemed to receive disproportionate attention in the media is not the vast amount of information that we know with moderate to high confidence, but rather the perception that there is so much uncertainty that our information base is poor. There are of course persistent and crucial uncertainties that need to be

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addressed through additional research. But there is often confusion between what is uncertain but knowable, and what may actually be unknowable or unpredictable, for example the political or institutional evolution of countries or the rate of improvement in key energy technologies. This uncritical focus on uncertainty undoubtedly contributes to the public's misperceptions about the degree of consensus in the scientific community, or to their rating the quality of climate change information as only fair or poor.

A key component of a strategy for improving public perceptions of the quality of information to support climate change decision-making is continuing to improve how the scientific community assesses and communicates uncertainty to the public and decision makers.

1. The importance of assessing and communicating uncertainty in science for decision-making

Uncertainty is not unique to the issue of climate change but pervades all areas of human activity. Sometimes uncertainty results from a lack of information, and on other occasions it results from inherent unpredictability. Some categories of uncertainty are amenable to quantification, while other kinds cannot be sensibly expressed in terms of probabilities, which are generally considered the best "language" for describing uncertainty with precision. Various typologies of uncertainty and factors that contribute to it have been proposed (a simple but elegant typology is contained in an IPCC guidance document for lead authors—see http://www.ipcc.ch/activity/uncertaintyguidancenote.pdf). In climate research, as in other areas such as seismic hazard prediction, ozone depletion, and hazardous wastes, some characteristics make assessment of uncertainty particularly challenging. These include global scale, systems complexity, long time lags between forcing and response, the impossibility of experimental controls, and the large number of research disciplines involved.

Moreover, because climate change is not just a scientific topic but also a matter of high policy, good data and thoughtful analysis may be insufficient to overcome confusion that masquerades as uncertainty caused by the clash of different interests, standards of evidence, or degrees of risk aversion/acceptance. Given the high economic stakes, careful characterization and communication of uncertainty will not necessarily overcome incentives for some parties to "spin the facts" by citing only a portion of the range of uncertainty to support their particular policy positions. But it can still help improve communication and comprehension by those individuals who are willing to let the evidence guide their opinions and decision-making.

Improving characterization of uncertainty in policy settings requires acknowledgement of the difference between discovery-driven basic research and "science for decision-making." The former is oriented towards hypothesis testing to high standards of statistical confidence while the latter seeks to characterize and apply the best information that is available to improve a specific decision being made in a particular location and point in time. Decision makers often do not have the luxury of waiting for information to improve but will, if they are creative and capable, design decisions that are robust to the range of uncertainty with which they must contend. They are also well advised to structure decision making processes that enable them to review and adjust their strategies over time, as new and improved information becomes available.

I will focus the remainder of this editorial in briefly providing my own perspective on improvements in characterizing and communicating uncertainty in deliberative assessments such as the IPCC. I will also point to developments in comparatively new areas of application of climate science that seek to support adaptation and analysis of uncertainty in setting mitigation targets and strategy. This special issue of *Global Environmental Change* includes articles related to improving deliberative assessments, supporting adaptation, and informing mitigation decision making. (See also US Climate Change Science Program, Strategic Plan, Chapter 11, "Decision Support Resources Development" http://www.climatescience.gov/Library/stratplan2003/final/ccspstratplan2003-chap11.htm for a more detailed description of these three applications of climate science).

2. Characterizing and communicating uncertainty in deliberative assessments

Assessment bodies such as the IPCC have as their main function to assess the state of our understanding and to judge the confidence with which we can make projections of climate change, its impacts, and costs and efficacy of mitigation options. IPCC works through a consensus process in which teams of lead authors evaluate the state of knowledge in different components of the problem and prepare technical chapters summarizing their findings. The process is driven by reviews of the literature, but subjective factors including the interpersonal dynamics among the authors can affect the conclusions. Once findings have been agreed at a chapter level, the most important conclusions are included in summaries for policy makers, which seek to convey a clear snapshot of information on climate change, potential impacts, and response options in a policy relevant but not prescriptive fashion.

In the first and second IPCC assessments, little attention was given to systematizing the process of reaching collective judgments about uncertainties and levels of confidence, or standardizing the terms used to convey uncertainties and levels of confidence to the decision-maker audience. Standardizing terminology was thought to be a particularly important gap, since much research indicated that different individuals assigned different implicit probabilities to key terms such as "almost certain," "probable," "likely," "possible," "unlikely," "improbable," and "doubtful." In the early assessments, these terms were not quantitatively or qualitatively calibrated across chapters and reports, and this led to very different interpretations of the findings in the media and among user groups.

During the preparation of the Third Assessment Report (TAR), I was privileged to work with my colleague Steve Schneider in preparing guidelines for IPCC lead authors that proposed a more systematic approach for assessing uncertainty within the lead author teams, and that also provided an agreed standard set of ''uncertainty terms'' calibrated to a quantitative scale (see http://stephenschneider.stanford.edu/Publications/PDF_Papers/UncertaintiesGuidanceFinal2.pdf). These recommendations were developed over a span of about half a year in consultation with over 40 lead authors from across the three broad areas of the assessment: climate science, impacts/adaptation/vulnerability, and mitigation of emissions. Initial ideas for the guidelines were based on an evaluation of prior experience in the IPCC developed during a summer study involving IPCC lead authors and additional experts in analysis and communication of uncertainty hosted by the Aspen Global Change Institute (http://www.agci.org/publications/eoc96/AGCIEOC96TOC.html#SSSIITOC). While the guidelines provided suggestions for the process of reviewing the literature and developing collective judgments, as well as proposed terminology for more precise communication, they did not prescribe statistical or other estimation methods for chapters to use in analyzing data. This was because of the wide range of substance treated and hence methods required.

Two different sets of uncertainty terms were proposed: a five-point quantitatively calibrated scale, and a set of four qualitative uncertainty terms defined by two key characteristics: the amount/quality of information and the degree of consensus among knowledgeable experts (see Fig. 1). A key aspect of the process recommendations was inclusion of a ''traceable account'' for how judgments and levels of confidence were established for the primary findings. Authors were urged to include careful descriptions of important lines of evidence used, standards of evidence applied, approaches to combining/reconciling multiple lines of evidence, explicit explanations of methods for aggregation, and critical uncertainties, and to explain whether uncertainty originated in lack of information, lack of consensus, or some combination of factors (see Patt, 2007 in this issue, for further discussion of the importance of uncertainty assessment, and clear science communication).

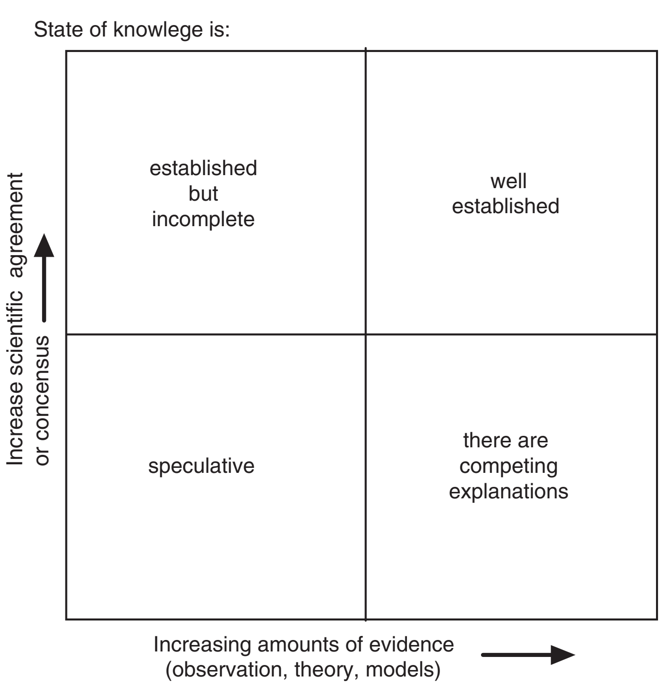

Fig. 1. Conceptual framework for qualitative uncertainty terms.

Experience with the uncertainty guidelines during the TAR was mixed. A key problem was the limited number of experts willing to work with authors in interpreting and implementing the guidelines. These individuals were dubbed ''the uncertainty cops'' and were informally responsible for reviewing chapters and providing suggestions for improvements in uncertainty statements. Working Group II (impacts/adaptation/vulnerability) adopted the proposed scales, and some chapters even structured their conclusions around the qualitative uncertainty terms and/or followed recommendations for graphical approaches for communicating uncertainty (see, for example, Chapter 7, ''Human Settlements, Energy and Industry, http://www.grida.no/climate/ipcc_tar/wg2/305.htm). Working Group I (climate system science) followed some of the process recommendations but adopted its own modified seven-point quantitative scale of uncertainty terms. Working Group III (mitigation) did not follow the uncertainty guidance to any significant degree.

In preparation for the AR4, IPCC convened a workshop on uncertainty that sought to evaluate the experience of the TAR and set the stage for a revised set of guidelines for the next assessment. Several improvements in terminology and a simplification of the steps were proposed and are reflected in the revised guidance for authors (http://www.ipcc.ch/activity/uncertaintyguidancenote.pdf). A promising development was the active engagement of a broader group of lead authors, especially from Working Group III. The jury is still out, however, regarding whether the evolution in approach will lead to more widespread adoption of the basic guidelines.

Further work in assessing the experience of the IPCC and other similar assessment activities, such as those of the US Climate Change Science Program (CCSP), is required. CCSP is developing its own set of uncertainty guidelines, building on the approach adopted in IPCC and other assessments (see http://climatescience.gov/Library/sap/sap5-2/default.php). Unfortunately, delays associated with the process of preparing and approving the CCSP reports has meant that several of the first CCSP products will be prepared without the benefit of these uncertainty guidelines.

A key area for further improving the IPCC's treatment of uncertainty is to increase the linkage between users and producers of these assessments. IPCC is beginning to experiment with developing a better-informed understanding of user information needs, for example in the area of scenario design. Several workshops incorporating user perspectives in scenario development have already been held (see http://arch.rivm.nl/env/int/ipcc/pages_media/meeting_report_workshop_new_emission_scenarios.pdf), and an additional expert meeting on the topic of scenarios will be held in September 2007.

3. Characterizing uncertainty in support of adaptive management and mitigation

In addition to providing information in deliberative assessments, climate science for decision support has evolved in important ways that enable it to provide information relevant to local/regional adaptation decision-making, and to the setting of mitigation targets and policies. This work is exemplified by articles in this special edition (see, Dessai et al., 2007 and Groves and Lempert, 2007 in this issue). This work focuses on establishing a strong link between the information provided and the decision that the information is intended to inform. An improved understanding of the decision-making context drives not only the type of information that is provided, but also the schedule and format of delivery. The dimension of close involvement of users is seen as particularly important in establishing a clear understanding to the uses and limits of the information provided, and trust between the users and producers of the information that improves the efficacy of the decision support effort.

Key examples at a programmatic level of this sort of work include the US National Assessment of the Consequences of Climate Variability and Change (http://www.usgcrp.gov/usgcrp/nacc/default.htm), the US National Oceanic and Atmospheric Administration (NOAA) Regional Integrated Sciences and Assessments (RISA: http://www.climate.noaa.gov/cpo_pa/risa/) Program, and the UK Climate Impacts Programme (UKCIP: http://www.ukcip.org.uk/). Another Aspen Global Change Institute session co-chaired by Schneider and Moss was held during March 2004 to explore issues related to this area of work, focusing on support for adaptation and mitigation decision-making in the state of California (see the workshop report compiled by Susanne C. Moser of the National Center for Atmospheric Research at http://www.agci.org/KUU_report.html). The workshop explored improvements in general circulation models and emissions scenarios to enhance their utility for regional modeling and impacts assessment efforts. It concluded that promising scientific progress over the next few years is likely to produce more relevant, higher-resolution climate information that will provide an increasingly sound foundation for adaptive management. The workshop also examined barriers and opportunities for improved statistical downscaling and regional climate models, and approaches for integrating climate and socio-economic information in the assessment of adaptive capacity (see Vincent, 2007 in this issue) and vulnerability. Both users (for example in the area of water resources management) and producers of climate scenarios discussed approaches for improving communication of uncertain climate information that enables the users to identify potential strategies for adaptive management that consider the full range of potential outcomes.

4. Uncertainty and informed decision-making

There is cause for much optimism that the research community can meet the information needs of the public and decision makers. In part, this is because research is progressing and we are learning more. But it also in part because of improvements in approaches to exploring and communicating the implications of uncertainty for decision-making about managing the risks of climate change. As this work continues, it is crucial that analysis of uncertainty and levels of confidence are not seen as absolute judgments, but rather are placed in the context of specific decisions that they are intended to inform. Scientific projections about climate change and potential impacts are certain enough to support the decision that humankind must rapidly transition to a low- and eventually zero-carbon energy future, even if they are not be certain enough to enable policy-makers to precisely identify a stabilization target.

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