CLIMATE CHANGE:

Uncertainty and Climate Change Assessments

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Future emissions of greenhouse gases, their climatic effects, and the resulting environmental and economic consequences are subject to large uncertainties. The task facing the public and their policy-makers is to devise strategies of risk reduction, and they need a clear representation of these uncertainties to inform their choices. Absent this information, policy discussion threatens to deteriorate into a shouting match, where analysis results are used both to support calls for urgent action and to justify doing nothing while we wait for more information. The Intergovernmental Panel on Climate Change (IPCC), charged by governments to report on the state of knowledge, took on the issue of uncertainty in its Third Assessment Report (TAR) (1-3). We applaud the attempt to add this component to an already complex assessment process. However, we believe much remains to be done to adequately treat uncertainty in those conclusions that are most important for policy decision-making. Here, we highlight some of the shortcomings of the uncertainty analysis presented in the TAR in the hope of providing impetus to our research community, governments, and the IPCC to improve this aspect of future assessments.

The guidance given to authors in all three working groups of the TAR was to identify the most important uncertainties and characterize the distribution of values of key parameters, variables, or outcomes, where possible using formal probabilistic methods (4). Seeking consistency across the text, a set of terms was proposed to indicate specific likelihoods: virtually certain (99% or more), very likely (90 to 99%), likely (66 to 90%), medium likelihood (33 to 66%), unlikely (10 to 33%), very unlikely (1 to 10%), and exceptionally unlikely (1% or less). Whatever the application, methods for estimating such likelihoods fall into two categories. One applies an analytical model of the process under study and propagates uncertainty in inputs through the model to generate probability distributions of outcomes. In a second approach, probability distributions of key outputs are elicited directly from experts. Naturally, the two methods overlap. In the model-based approach, it is preferable to derive parameter uncertainty from observations, but the needed data often do not exist. Distributions of input parameters then must be selected by expert elicitation. Supplementing model-based uncertainty analysis with expert elicitation also can be useful because uncertainty may be inherent not just in the inputs (which can be analyzed using the model) but in the model structure (which cannot). Care must be taken in applying expert elicitation to compensate for well-known cognitive biases in human judgment (5), and protocols to reduce these biases have been developed (6 be repeated to gauge whether real changes in the scientific understanding of climate change have occurred, or if differences are simply an artifact of a different group of experts or variations in the protocol.

Expert judgment was widely used in preparing the TAR, but the organizers were not able to impose a consistent procedure across the various components. The likelihood terms above were variously assigned on the basis of "judgmental estimates" in the discussion of the science of climate (1) and on using "collective judgment" when discussing the effects of climate change (2). However, little or no documentation is provided for how judgments were reached or whose estimates were reflected. In discussion of mitigation measures (3), the TAR did not report any analysis using these concepts. The TAR states that many hundreds of scientists contributed to the report. In the absence of documentation, readers could easily conclude that reported likelihoods represent a consensus among them (7). This is not necessarily the case (8). Many of the scientists listed as contributors were never consulted about these probability judgments.

One of the difficulties facing the IPCC is its emphasis on consensus coupled with the range of disciplinary backgrounds and world views among its contributors. Where there are widely divergent views and a consensus cannot be reached, the alternative is to present the judgments of each expert independently (9, 10). Whereas a reader may choose to adopt one view or another from those given, this result is almost always preferable to an interpretation that corresponds to no particular expert's view.

Another feature of the TAR is that many less-important conclusions have attached likelihoods, whereas some crucial ones do not. Policy-makers need guidance on a small but important set of questions: how large will the climate change be; how damaging are its effects; and how expensive might it be to meet emissions goals? Likelihood statements about these important matters are too often poorly supported in the TAR or are missing altogether.

For example, a crucial conclusion of the TAR is the reported range of projected global mean temperature change over the next century, given as a rise of 1.4º to 5.8ºC. This finding is not accompanied by any quantification of the probability of those projections or the probability bounded by this range, and the reader is left to guess whether the likelihood of exceeding this range is 1 in 10 or 1 in 1000. An example of such an assessment is one carried out at the Massachusetts Institute of Technology by using formal uncertainty propagation techniques to assess a probability distribution for global mean temperature change. Applying an uncertainty analysis to a model of emissions (11) and a climate model (11), informed by estimates of the joint probability distribution of key climate variables conditioned by the historical data (12), we calculate a 95% confidence interval for temperature change by 2100, with no emissions control, of 0.9º to 5.3ºC (13). For comparison with the estimate by Wigley and Raper in this issue (14), our 90% confidence limits are 1.1º to 4.5ºC.

The TAR also reports that the projected range of temperature change has increased since the Second Assessment Report (SAR) in 1995, when the range was from 1.0º to 3.5ºC. Both the TAR (1) and other analyses (14) attribute this difference to various causes, including lower projected sulfur dioxide emissions in the IPCC Special Report on Emissions Scenarios (SRES) (15), which was a key input to the TAR. However, given that the probability of the emissions forecasts or of the climate forecasts was not quantified in either the SAR or the TAR, and absent a calibrated methodology for measuring the likelihoods of the ranges in the two assessments, the reader cannot know whether or not the shift in range reflects a new judgment about future climate change.

There are some well-documented statements in the TAR, e.g., to the effect that the rate of temperature increase over the next few decades is likely to be between 0.1º and 0.2ºC per decade and that the increase over the past century is likely to be larger than over the past 10,000 years. The difficulty in extending the analysis to longer periods was increased by the procedure for developing the new emissions scenarios. The SRES explicitly avoided assigning probabilities to its scenarios. The Wigley and Raper study has assumed that they were of equal probability (14), although most emissions analysts would agree that they have very different likelihoods. Emissions forecasting is, in fact, one area where there is a history of quantitative uncertainty forecasting (16-18) that could be consulted. The difficulty with refraining from giving any estimate of likelihood is that the public will substitute their own nonexpert judgment about the probability and may assume far more (or far less) likelihood than the scientists involved believe.

On the issue of climate-change effects, the TAR includes a chart describing reasons for concern, indicating generally minor risks from a temperature rise of less than 2ºC over the century and gradually increasing risks up to 6ºC (2). However, no significant global impacts assessments have been completed using transient climate simulations forced with SRES emissions scenarios published in the TAR (1). Most published impacts work uses older and unrealistic equilibrium climate scenarios for doubled CO_2 levels without the effect of aerosols, or simple sensitivity analyses where temperature or precipitation is varied by an arbitrary amount unrelated to any particular climate projection. The TAR shows clearly that the detailed regional projections needed to confidently assess impacts are unreliable (1). The experts summarizing impacts studies can, of course, form judgments about climate effects at different global temperature changes and their likelihood without the aid of impact analyses, much less quantified uncertainty studies for these impacts. In this event, however, it would seem especially important to explain the procedure followed and to make clear that judgments were made absent quantitative studies using transient scenarios from state-of-the-art coupled ocean-atmosphere general circulation models. A broader knowledge of the weak analytical base for assessment of impacts, as compared with climate science, might encourage badly needed research on climate-change impacts.

In the TAR assessment of mitigation measures, statements are made [Table SPM-1 in (3)] about the amount of emissions reductions that may be achieved by 2010 and 2020 with direct benefits exceeding direct costs. These results condition expectations about the possible cost of emissions control measures and the economic risks associated with firm reduction targets. Far from a consensus, these findings remain the subject of active and sometimes rancorous disagreement. Although the TAR presents data from a range of studies, the text does not convey the uncertainty that attends them, an unfortunate omission given the substantial background of work on which to draw (10, 16-18).

The IPCC provides a useful service to nations that are trying to understand and respond to climate change, and its leaders and authors deserve credit for their attempt in the TAR to be more explicit about uncertainties. However, given their importance to policy, climate-change assessments must strive to establish standards of scientific evidence no less rigorous in their uncertainty analysis than in their presentation of the underlying natural and social science. If statements of likelihood are to be taken seriously, they need to be grounded in a documented procedure that can be repeated and calibrated. Careful analysis of uncertainty is difficult, so any future assessment must choose outcomes of interest judiciously, focusing on those that are most important. Finally, uncertainty analysis should not be pasted on to the end of an assessment, but needs to be implemented from the beginning, with guidance from experts in the field.

References and Notes

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