Commentary 7

Techniques for Estimating Uncertainty in Climate Change Scenarios and Impact Studies – Quantitative Techniques

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General remarks

The discussion paper by Katz (1999) advocates the use of a fully probabilistic uncertainty analysis in the context of climate change and climate impact studies. The author first gives an overview of the problems encountered and then discusses the available quantitative techniques for dealing with uncertainty. He argues that the simultaneous use of several approaches might give the most robust results.

To my knowledge, Katz's paper deals with all major problem areas and methods. The proposed strategy of working towards probabilistic climate studies using a range of approaches is certainly meaningful. However, in my opinion two important aspects did not receive appropriate attention. Firstly, little was said about which technique should be best used when. In view of the very diverse needs and objectives of climate related studies this certainly presents a very challenging task. Secondly, the limitations of the probabilistic/quantitative approach have not been sufficiently addressed. The aim of this commentary is therefore to discuss some of these limitations.

Dealing with "unknowable" knowledge

The climate's evolution depends on a range of lergely unknown factors, such as the future behaviour of man, or possible surprises in the climate system. In my opinion, one important property of "unknowable" knowledge is that it cannot be described in terms of *objectively testable probability distributions*. For instance, although different persons may be willing and able to assign probabilities to alternative future global socio-economic development paths, there is actually no means to prove that one specific development is more probable than another.

The transition from "unknowable" knowledge to objectively testable knowledge is probably a gradual one. Figure 1 presents an attempt to rank some of the uncertainties related to climate change scenarios and impacts within a spectrum that ranges from completely unknown factors (on the left-hand side in Figure 1), to sources of uncertainty with completely known probability distribution functions (right-hand side). The future socio-economic development is quite obviously an "unknowable". An example at the other end of the spectrum is the natural climate variability, where the associated uncertainties can be estimated at relatively good accuracy from measurements or simulations with climate models.

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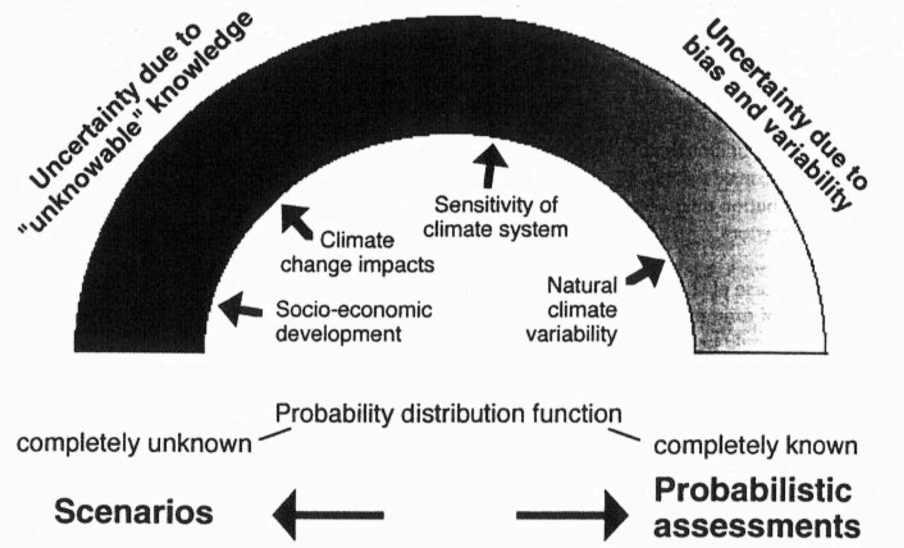

Figure 1: Spectrum of uncertainties related to climate change studies. Four selected uncertainties (small arrows) are shown to illustrate the gradual transition from statistically quantifiable uncertainty (right-hand side of the spectrum) to uncertainty due to "unknowable" knowledge. Large arrows mark two possible strategies to deal with the different types of uncertainty.

In my opinion, any attempt to assign probabilities to "unknownables" is misleading, unless these probabilities have been explicitly declared as subjective. For instance, one may assume that all socio-economic scenarios provided by the IPCC are equally likely (uniform distribution), and then perform a Monte Carlo analysis of climate change impacts by repeatedly sampling the various scenarios. This "fully probabilistic" procedure is highly subjective because there is actually an infinite number of alternative, equally plausible probability distributions (e.g. triangular, bimodal, trimodal etc.) on which one may want to base the analysis.

An alternative, which avoids making assumptions on the probability of "unknownable" developments is the use of "if-then" analysis. The first step in such an analysis is to define a range of possible developments for one or several "unknowables". Probabilistic statements may then be derived *for each set of assumptions individually*. For instance, in the above example one could select a few key socio-economic scenarios, and then assess the uncertainty of a given impact (e.g., due to model or parameter uncertainty) conditional on each individual scenario with the aid of quantitative probabilistic techniques (e.g., sensitivity studies, Monte Carlo analysis etc.).

Unlike the "fully probabilistic" approach, this procedure does not yield a single probability distribution for a given impact, but rather a set of probability distributions, one per set of assumptions. However, it has the advantage of being more transparent, and the end-users of the information are free to judge which story line they consider as the most likely.

Dealing with expert knowledge within a probabilistic framework

In the discussion paper it is suggested that expert knowledge could be included in climate-related studies via a fully Bayesian approach. According to this approach an expert's knowledge on a quantity of interest (e.g., the $2xCO_2$ sensitivity of the climate system) is first translated into some prior probability distribution, which is then combined with a statistical model (e.g., a time series model) and independent data (e.g. the historical records for global mean temperature and CO_2) to derive a posterior distribution for that particular quantity under consideration. The experts may agree well with each other, and in this case a "narrow" posterior distribution might result. Alternatively, one may be confronted with a wide range of priors and associated posteriors.

I think that the case of strong agreement among experts is still problematic. This is because the history of science is full of examples where new evidence or an unexpected breakthrough has lead to a paradigm change. What would be the implications for climate system modelling if one day the missing C-sink were understood, or accurate parameterizations for clouds were found? Moreover, the expert's opinion is seldom truly independent from the data used to make the inference (in the above example all experts certainly know about the global temperature record). Finally, our perception of the world, and even the most objective scientific models upon which experts may have based their judgement, are the result of a range of social, cultural, psychological etc. interactions which are again only poorly understood. Therefore I suggest that even in the case of strong expert agreement alternative posterior distributions should be considered as possible, and their implications be explored. In the case of strong disagreement among experts I think that it is more honest to work with a set of posteriors rather than "averaging" the posteriors into one single probability distribution. This is because a single posterior suggests detailed quantitative knowledge, whereas in fact it reflects but a limited range of opinions, which can not be tested.

In summary, I argue that trusting quantitative information that has been derived from qualitative expert knowledge will always be a matter of belief. This does not preclude the use of qualitative knowledge, but in my opinion the assumptions that lead to a specific probability distribution should always be clearly stated. Also, different beliefs should be explored in a scenario-type analysis, and even in the case of strong agreement among experts a range of quantitative scenarios which reflect the possibility that all experts together are wrong should be formulated.

Dealing with complex models within a probabilistic framework

Here a similar problem occurs as with expert knowledge: If several models are available (as this is the case with GCMs): Which model should one trust more? Is it appropriate to construct a single best guess by "averaging" the results of individual models?

In principle, the first question can be answered by testing the individual models against measurements. For example, if one wishes to use GCM output for regional impact studies, one could define a range of tests which measure the model's ability to reproduce the observed mean climate and its variability over the region of interest, the observed relationships between large-scale and regional climate variables etc. The test results could then be summarized into an overall performance index, which could then be used together with expert judgement to select the most trustworthy model(s). Although there exists quite some work on intercomparison and regional performance of GCMs I am not aware of any formally defined and generally applicable procedure to evaluate the quality of GCM output with regard to impact studies.

The second question (averaging of model results) is much more difficult to answer. Often there is but a relatively small number (say, five to ten) of models available. Constructing some "best guess" from all models can certainly be instructive – but why should this guess (or some "averaged" posterior distribution) be more probable than an individual model result? Moreover, the models are often not independent of

each other (e.g., common parameterizations). Accordingly, a single "best guess" suggests more congruence where in reality the possibility of stronger disagreement should be highlighted (for instance, somebody could come up with a new parameterization that could strongly affect the results of several models). Therefore I believe that it is more appropriate to explore and judge the projections obtained from each model individually, i.e. each model should again be treated as an individual "story line" for an if-then analysis.

Concluding remarks

The combination of scenario and probabilistic techniques appears to be an adequate means to deal with uncertainty in climate change studies. Scientists should aim at providing (i) a range of scenarios that reflect all currently conceivable developments, and (ii) the background knowledge needed to judge the consistency of the different scenarios. In some cases it may be possible to make statements on the likelihood of individual "stories" based on detailed analyses or expert judgement. However, uncertainties due to "unknowable" knowledge should not be hidden behind nicely looking quantitative probabilistic statements. In particular, the final decision which scenarios should be considered as the most probable and important ones should not be done in advance by the scientists. Rather, the responsibility for this decision should be left to the end-users of the information, i.e. the wider public, stakeholders, and policy and decision makers.

Reference

Katz (1999) Techniques for estimating uncertainty in climate change scenarios and impact studies, in Carter, T., Hulme, M. and Viner, D. (eds.), ECLAT-2 Workshop Report No. 1, Helsinki, Finland, 14-16 April 1999.

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