Do we need more precise and accurate predictions in order to adapt to a changing climate?

Many scientists have called for a substantial new investment in climate modelling in order to increase the accuracy, precision and reliability of climate predictions. Such investments are often justified by assertions that any lack of improved predictions will prevent society from adapting successfully to a changing climate. This contribution aims to question these claims, suggest limits to predictability, and argue that society can (and indeed must) make successful adaptation decisions in the absence of accurate and precise climate predictions.

Climate prediction for decision-making

There is no doubt that climate science has proved vital in detecting and attributing past and current changes in the climate system and in projecting potential long-term future changes based on scenarios of greenhouse gas emissions and other forcings. Climate models' ability to reproduce the time-evolution of observed global mean temperature has given them much credibility. Advances in scientific understanding and in computational resources have increased the credibility of model projections of future climates.

Many climate scientists, science funding agencies and decision makers now argue that further quantification of prediction uncertainties and providing more accuracy and precision in assessments of future climate change are necessary to develop effective adaptation strategies. The World Modelling Summit for Climate Prediction (http://wcrp.ipsl.jussieu.fr/Workshops/ModellingSummit/index.html) argues that "*climate models will, as in the past, play an important, and perhaps central, role in guiding the trillion dollar decisions that the peoples, governments and industries of the world will be making to cope with the consequences of changing climate*". The Summit called for a revolution in climate prediction because society needs it and because it is possible. They argue "*it is necessary because adaptation strategies require more accurate and reliable predictions of regional weather and climate extreme* ...". It is possible, they argue, because of advances in scientific understanding and computational power.

If true, such claims place a high premium on accurate and precise climate predictions at a range of geographical and temporal scales as a key element of decision-making related to climate adaptation. Under this line of reasoning, such predictions become indispensable to, and indeed a prerequisite for, effective adaptation decision-making. Until such investments come to fruition, according to these views, adaptation will be fundamentally limited by the uncertainties and imprecision that characterise current climate predictions.

The limits of climate prediction

The accuracy of climate predictions is limited by fundamental, irreducible uncertainties. For climate prediction, uncertainties can arise from limitations in knowledge (e.g., cloud physics), from randomness (e.g., due to the chaotic nature of the climate system), and also from human actions (e.g., future greenhouse gas emissions). Some of these uncertainties can be quantified, but many simply cannot, leaving some level of irreducible ignorance in our understandings of future climate uncertainty.

A 'cascade' or 'explosion' of uncertainty arises when climate change impact assessments aim to inform national and local adaptation decisions, because uncertainties from the various levels of the assessment accumulate. Studies propagating these various uncertainties for the purposes of adaptation assessments (sometimes called end-to-end analyses) generate large uncertainty ranges in climate impacts. They also find that the impacts are highly conditional on assumptions made in the assessment, for example with respect to weightings of GCMs (according to some criteria, such as performance against past observations) or to the combination of GCMs used.

Future prospects for reducing these large uncertainties remain limited for several reasons. Computational restrictions have thus far limited the uncertainty space explored in model simulations, so uncertainty in predictions may well increase even as computational power increases. The search for 'objective' constraints with which to reduce the uncertainty in regional predictions has proved elusive. The problem of equifinality (sometimes also called the problem of 'model identifiability') – that many different model structures and many different parameter sets of a model can produce similar observed behaviour of the system under study – has rarely been addressed. Furthermore, current projections suggest that the Earth's climate may soon enter a regime dissimilar to any seen for millions of years and one for which paleoclimate evidence is sparse. Thus the model projections of future climate represent extrapolations into never before experienced states of the system, making it impossible to either calibrate the model for the forecast regime of interest or confirm the usefulness of the forecasting process.

In addition, climate is only one of many important processes that will influence the success of any future adaptation efforts, and often it is not the most important factor. Society's current ability to predict many of these other processes – such as the future course of globalisation, economic priorities, regulation, technology, demographics, cultural preferences, and so on – remain (much) less amenable to prediction than is future climate. This raises the question of why improved climate predictions ought to be given such a high priority in designing adaptation policies.

Alternatives to prediction

Individuals and organizations commonly take actions without accurate predictions of the future to support them. They manage the uncertainty by making decisions or establishing robust decision processes that produce satisfactory results in the absence of accurate predictions. In recent years, a number of researchers have begun to use climate models to provide information that can help evaluate alternative responses to climate change, without necessarily relying on accurate predictions as a key step in the assessment process. The basic concept rests on an exploratory modelling approach where analysts use multiple runs of one or more simulation models to systematically explore the implications of a wide range of assumptions and to make policy arguments whose likelihood of achieving desired ends is only weakly affected by the irreducible uncertainties.

As one key step, such analyses use climate models to identify potential vulnerabilities of proposed adaptation strategies. These analyses do not require accurate predictions of future climate change from cutting edge models. Rather they only require a range of plausible representations of future climate that can be used to help organisations, such as water resources agencies, better understand where their climate-change-related vulnerabilities may lie and how they can be addressed. Even without accurate probability distributions over the range of future climate impacts, such information can prove very useful to decision makers.

Such approaches generally fall under the heading of "robust decision-making". Robust strategies perform well compared to the alternatives over a wide range of assumptions about the future. In this sense, robust strategies are "insensitive" to the resolution of the uncertainties. A variety of analytic approaches have been proposed to identify and assess robust strategies.

Climate and science policy implications

Given the deep uncertainties involved in the prediction of future climate and even more so of future climate impacts, and given that climate is usually only one factor driving the success of adaptation decisions, we believe that the 'predict and provide' approach to science in support of climate change adaptation is significantly flawed. Efforts to justify renewed investments in climate models based on promises of guiding decisions are misplaced.

This does not imply that continued climate model development cannot provide useful information for adaptation. For instance, such development could further inform the plausible range of impacts considered when crafting a robust adaptation strategy. However, further scientific effort will never eliminate uncertainty completely; it may in fact increase uncertainty. Thus, the lack of climate predictability should not be interpreted as a limit to adaptation. By avoiding an approach that places climate prediction at its heart, successful adaptation strategies can be developed in the face of this deep uncertainty. Decision makers should systematically examine the performance of their adaptation strategies over a wide range of plausible futures driven by uncertainty about the future state of climate and many other economic, political and cultural factors. They should choose a strategy that they find sufficiently robust across these alternative futures. Such an approach can identify successful adaptation strategies without accurate and precise predictions of future climate.

These findings have significant implications for science policy. At a time when government expects decisions to be based on the best possible science (e.g., evidence based policy-making), we suggest that climate science is unlikely to support prediction-based decisions. Over-precise climate predictions can also lead to mal-adaptation if misinterpreted or used incorrectly. From a science policy perspective it is worth reflecting on where investments by science funding agencies can best increase the societal benefit of science.

The World Modelling Summit for Climate Prediction called for a substantial increase in computing power (an increase by a factor of 1000 at the cost of more than a billion dollars) in order to provide better information at the local level. We believe, however, that more than any plausible and foreseeable increase in the accuracy and precision of climate forecasts, society will benefit from a greater understanding of the vulnerability of climate-influenced decisions to large irreducible uncertainties and the alternative means to reduce such vulnerabilities.

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