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**Difficulties in Deriving Forecast Probabilities From General Circulation Models and Efforts to  
Estimate Uncertainty in Future Climate projections**

David Stainforth, Grantham Research Institute, London School of Economics, Houghton Street,  
London. WC2A 2AE

**Abstract**

Many decisions taken today will have long term consequences on time scales ranging from one or two decades to 50 or 100 years or beyond. Building design, flood protection measures and water resource planning often involve substantial investment in assets which we hope will be suitable for these very long periods. Over such time periods we know that the earth’s climate will undergo substantial further changes as a result of anthropogenic emissions of greenhouse gases. It is therefore sensible to make such decisions in the context of these changes. This is widely described as climate change adaptation and is in contrast to climate change mitigation where the focus is to limit the extent of changes in the physical climate rather than prepare for expected or inevitable changes ahead.

Usually climate change is only one of the drivers in such long terms decisions. Financing, population shifts and changes in demand characteristics are examples of others. Nevertheless, to the extent that climate change is a driver in such decisions it will be valuable for society to consider this driver appropriately. A common response is to view the challenge as one in which we should optimise our decisions over predictions which take the form of probability distributions; the “predict and optimise” approach. Here I will argue that the science of climate physics and modelling faces very significant barriers in providing information, particularly probability information, which can be used in such an approach. Through appropriate study of these barriers we can hope to provide more relevant and reliable information today while improving the design of our models, and our modelling experiments, in ways which will enable us to provide better information in the future. However, ignoring or overlooking these barriers leads to misrepresentation of what our models are telling us and has a high risk of leading to mal-adaptation. It also has the possibility of undermining the credibility of climate science. This latter point has profound risks in terms of undermining the robust science which underlies the need for significant climate change mitigation measures.

Climate is a highly complex system involving not just complex dynamics but also interactions of the dynamics with radiative processes, phase change processes, chemical interactions, land surface processes etc. Parts of the system can be studied mathematically with either analytical or numerical solutions. However, the interactions of many aspects of the system can only be studied using complex climate models. These models have components representing many aspects of the system and are powerful research tools and impressive research achievements in themselves. They are also the only tools which provide information on regional or even local

scales; scales which begin to appear relevant for practical adaptation decision making. It is not surprising therefore, that in recent years they have begun to be used not just for research and process understanding but also for climate prediction on these scales. It is in this context that it is useful to consider the challenges in using these models to support water resource management.

The first and overarching barrier is the fact that climate change prediction is a problem of extrapolation. Unlike weather, and many other types of, forecasting the aim is to predict a state of the system which we have never before observed and which we will not observe before the forecasting system is of only historical interest. There is therefore no hope of verification of the method. The onus is therefore on the scientists to question as comprehensively as possible how the forecasting system could fail. This burden is far more substantial than in systems where verification is possible.

The second barrier is simply the quality of the models. Global Climate Models can, and are, at the same time fantastic achievements, tremendously powerful research tools, and significantly deficient as representations of the real world. There are model inadequacies in the sense that significant aspects of the system are not included e.g. the stratosphere, ice sheet dynamics, atmospheric chemistry etc. There are also model uncertainties in the sense that processes which are included can be poorly represented e.g. ENSO, the diurnal cycle of tropical precipitation etc. These deficiencies are not surprising but must be recognised if the models are to be used to predict the real world system.

Major efforts have been made in recent years to explore model uncertainties either through multi-model ensembles such as CMIPIII or perturbed physics ensembles such as climate prediction.net. Attempts have been made to relate model diversity in such ensembles to real world probabilities. Unfortunately the lack of independence between complex climate models, and between model versions in perturbed physics ensembles, fundamentally undermines such approaches. In addition it undermines the use of most traditional statistical approaches to the analysis of such datasets. This lack of independence is the third barrier.

As an aside it is worth noting that statistical emulators have been used to “fill-in” parameter space in an effort to overcome the subjectivity in selecting parameter values in the perturbed physics ensembles. This method adds complexity to the analysis but does not overcome the lack of independence problem because even the shape of model parameter space is the result of ad hoc decisions in the model formulation process. Equally valid alternative decisions can change the shape of model parameter space and completely change the resulting probability distributions. This problem can be discussed in terms of both the importance and the arbitrariness of the prior sampling in a Bayesian formulation of the problem. Although not solving the problem the added complexity does create a barrier to informed discussion and interpretation of the results.

Given the lack of independence the best current approach to the interpretation of multi-model and perturbed physics ensembles is that they provide a domain of possibility; a non-discountable envelope which should be considered plausible in the decision making process. The fourth and final barrier relates to whether such envelopes can be reduced in size using metrics of model quality. The non-linear

nature of the system and the “distance” between the models and reality create new challenges here. Challenges which have not yet been addressed but which may well provide fruitful areas for further research.

These four barriers to the generation of probabilities of future climate on regional and local scales from General Circulation Models undermine several current approaches. But they do not undermine the fact that these models contain valuable information which can be useful in guiding societal decisions. By considering such barriers we can work more effectively towards better using the models, and associated scientific understanding, to guide climate change adaptation. Perturbed-physics ensembles should be designed to push out the bounds of the plausible. Integrating process understanding from climate physics and palaeo-climate observations are likely to improve societal guidance. Designing robust metrics to judge when models have reached various stages of reliability will be crucial as we move forward. Integrating global climate understanding with local hydrological understanding could reap significant benefits. The opportunities to use complex climate models to guide societal decisions are substantial but the risk of their mis-use is also substantial. The onus is on the scientific community to fully and openly discuss the challenges in this important field.