Climate prediction in model land: On the roles of initial condition uncertainty and natural variability

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Predicting the details of future climate on multi-decadal timescales is a significant challenge. Complicated atmosphere/ocean general circulation models (AOGCMs), and even more complicated Earth System Models (ESMs), are widely interpreted as tools for climate prediction. It remains, however, a subject of scientific debate how the task might best be approached to provide reliable, robust information, and what role GCMs should play. Furthermore, the societal relevance of the topic provides an unusual urgency for a conceptual scientific question of this nature.

Given the inevitable further increase in atmospheric greenhouse gas concentrations it is clear that the challenge is one of extrapolation. The 21st century will only be experienced once so there is no possibility of probabilistic verification. Future changes might be expected to depend on the large-scale features of the current state which limits the relevance of testing any prediction system on historic/palaeo data. A consequence of these characteristics of the problem is that climate prediction must rely heavily on physical understanding. However, we know that many aspects of the system exhibit nonlinear behaviour and scale interactions which raises questions over how complex or simple a model needs to be to be informative; are reductionist models likely to be most useful or should there be greater emphasis on emergent behaviour[1] or simply exploratory physically-based storylines[2]?

Progress on these issues can perhaps be made by considering what we mean by and how we go about climate prediction. Here I will illustrate some of these issues with a low-dimensional nonlinear system[3]. The limited scope of the concept of climate change as a changing attractor will be illustrated, along with the differences between natural variability and initial condition uncertainty; two concepts which are often used interchangeably in the climate modelling community. The differing roles of micro-initial condition uncertainty and macro-initial condition uncertainty[4] will be illustrated with ensembles of an AOGCM[5]. The consequences for the design of future AOGCM ensembles and the interpretation of todays cutting-edge ensembles will be discussed. Finally, questions regarding the required level of model complexity for real-world climate prediction and the relevance of stochastic parameterisations will be raised and left for open discussion.

[l] Harrison and Stainforth, Eos **90(13)**, 111 (2009).

[2] Hazeleger et al., Nature Climate Chnge **5**, 107 (2015).

[3] Daron and Stainforth, ERL **8**, 1 (2013).

[4] Stainforth et al., Phil. Trans. A **365(1857)**, 2145 (2007).

[5] Hawkins et al., Climate Dynamics , 1 (2015).