Geophysical Research Abstracts
Vol. 16, EGU2014-**PREVIEW**, 2014
EGU General Assembly 2014

How big should a climate model ensemble be? Lessons from a low dimensional system

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The description of this session highlights that low frequency variability (LFV) on seasonal to decadal timescales “is governed by low-order nonlinear dynamics”. This creates a significant challenge for probabilistic multi-decadal climate predictions with high dimensional atmosphere/ocean global circulation models. Transient changes in forcing due to increasing atmospheric greenhouse gas concentrations might be expected to change such low frequency variability. That is to say, anthropogenic climate change could potentially drive the system into a state of larger or smaller amplitude LFV. In this context, the purpose of multi-decadal climate simulations is to study the transient, non-autonomous behaviour of the system as it moves between these two states. We present results which evaluate how the size of initial condition ensemble limits the probabilistic accuracy of a climate model prediction in this climate change like situation.

We present results from large ensembles of a low dimensional nonlinear system. The system consists of the Lorenz 84 system with a seasonal cycle of forcing, coupled to a Stommel ocean [1,2,3]. This is a five variable system with three “fast” variables (which parallel atmospheric behaviour) and two “slow” variables (which parallel ocean behaviour). We apply a transient change in one parameter (representing the latitudinal temperature gradient) to drive the system from one attractor (with low amplitude LFV) to another (with high amplitude LFV). Using ten thousand member ensembles we explore the time dependent probability distributions of the ocean variables.

We take these distributions as representing the time-dependent “climate” within the model, and study the implications of using smaller ensembles to evaluate the transient behaviour. Multi-decadal simulations of global climate models (GCMs) often have very few initial condition ensemble members; only three were required in the design of CMIP5. In such experiments it is common to construct “climatic” distributions, or simply the mean and low order moments, from single realisations or small ensembles using data covering a number of years – typically 30 years (the period used to calculate “Climate Normals”). Though often implicit, an assumption is being made that climatic distributions derived in this way are representative of time instantaneous distributions from a large ensemble – we call this the kairodic assumption. We present results demonstrating how this assumption and the size of the ensemble, together and individually, limit the probabilistic accuracy of a prediction.

Our results highlight how small initial condition ensembles limit the interpretation of GCMs. They illustrate a means of evaluating an upper limit on the probabilistic accuracy which can be expected from model-based multi-decadal climate predictions.

[1] Lorenz E 1984 Irregularity: a fundamental property of the atmosphere Tellus A 36 98–110

[2] Lorenz E 1990 Can chaos and intransitivity lead to interannual variability Tellus A 42 378–89

[3] Van Veen L, Opsteegh T and Verhulst F 2001 Active and passive ocean regimes in a low-order climate model Tellus A 53 616–28