## North Atlantic Decadal Predictability

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### Introduction

There is increasing evidence (from both observations (e.g. Koltermann et al., 1999) and models (e.g. Dong and Sutton, 2001)) of decadal time-scale fluctuations in the circulation of the Atlantic Ocean. Variations in the meridional overturning circulation (MOC) may impact on the surface climate of both the ocean and the atmosphere through changes in the northward transport of heat by the ocean. Predictions of such decadal variations could bring considerable benefit to society, yet these remain unrealised partly because previous studies of predictability have revealed low levels of potential skill (Griffies and Bryan, 1997; Grötzner et al., 1999). This study represents an assessment of the potential predictability of variations in MOC and associated Sea Surface Temperature (SST) anomalies in a range of recent coupled atmosphere-ocean-sea ice models. It is found that, while different models do produce different estimates of predictability, some models show high levels of potential skill on time-scales of decades and longer that may, one day, be exploited by forecasters.

### Experimental Design

The coupled model experiments are of the form of "perfect ensemble" experiments, in which ocean initial conditions are fixed and the ensemble is generated by taking different atmospheric initial states. Thus the ensemble spread represents that which would be obtained in a hypothetical operational forecast system in which the ocean state is exactly known and the model is perfect (Collins, 2002). Thus it provides an upper limit on the estimate of predictability. Five models were used to perform experiments (HadCM3 (Gordon et al., 2000), ECHAM5/MPI-OM1 (Latif et al., 2003), ARPEGE3 (Jouzeau et al., 2003), BCM (Furevik et al., 2003) and INGV (Frankignoul et al., 2003)) initiated from unforced control integrations, with ensemble sizes varying from 3 to 9 and the length of the experiments varying from 20-30 years. An attempt was made to initiate experiments from high, low and (in the case of 2 models) intermediate values of the strength of the MOC. The experiments were performed as part of the European Union Framework 5 project PREDICATE (Sutton et al., 2003) and represent 1340 coupled model years of ensemble experiments, together with 3100 years of control experiments used to assess levels of natural variability. None of the models used employ flux corrections.

### Results

The coupled models all have very different magnitudes of natural internal decadal variability in their respective control integrations (Figure 1, page 16). The ECHAM5/MPI-OM1 model shows the largest variability, with peak-to-peak variations of up to 6 Sverdrups in the MOC and 2K for SSTs averaged in a region of the North Atlantic. The HadCM3 model shows slightly weaker variability than does ECHAM5/MPI-OM1 and the ARPEGE3 and BCM models (which share a common atmosphere) show the weakest. Output from the INGV model is also shown, although it is difficult to assess levels of variability as in this model the ocean component is not in equilibrium resulting in a drift in MOC strength and SST.

We identify potential predictability in the ensemble experiments when either the ensemble spread is small with respect to the background levels of natural variability, or when the ensemble mean is shifted with respect to the climatological average value indicating a bias in the probability of greater or less than average conditions. Without resorting to quantitative measures of ensemble "skill" or predictability (there is no universal measure) it can be clearly seen that there is some potential skill in the ensemble experiments on decadal time scales (Figure 1). The ECHAM5/MPI-OM1 model shows the highest level of decadal predictability: for each ensemble member the spread in both MOC and SST is significantly smaller than the background level of variability and the ensemble mean is displaced with respect to the long term climatological mean (Pohlmann et al., 2003). The HadCM3 model also has some decadal predictability (Collins and Sinha, 2003, give quantitative measures) but less than that seen in ECHAM5/MPI-OM1. For both these models there is also some indication of weak but significant potential predictability of surface temperatures over land areas in Europe (Collins and Sinha, 2003). The ARPEGE3 and BCM models perhaps show the lowest levels of predictability with the ensemble spread saturating after only a few years. While the INGV model appears to show significant levels of decadal predictability, this may be related to the model drift. Care should be taken in assessing levels of predictability in models that are not in equilibrium.

**Summary**

These new model experiments indicate that there may be some potential for initial-value decadal predictions of climate. In general, models that show the highest levels of decadal variability also show the highest levels of decadal predictability: so which model is right? Quantitative validation of the levels of decadal variability in the models is hampered by the short observational record and sparse palaeo-proxy record, and by the fact that these are records of not only the natural internal variability but also forced natural and anthropogenic variations (Collins et al., 2002). Hence it is not possible, at present, to say which model has the more realistic decadal variability and hence more realistic decadal predictability.

Studies of this type, which identify predictable signals, are the first step towards any future operational forecasting system. In any such system the most pressing problem would be in producing an adequate ocean analysis from which to initiate the forecast from sparse subsurface ocean observations. However ocean-only model experiments carried out during the PREDICATE project (Sutton et al., 2003), forced with the same time-history of surface fluxes of heat, moisture and momentum show that this alone may be adequate to constrain the trajectory of the ocean model, at least in terms of the decadal component of the variability of the MOC. Hence a *balanced* set of fluxes from, e.g., a re-analysis product would be a high priority. Further work should also concentrate on why the models shown here produce such a wide range of decadal variability and predictability.

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