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Statement on the processes that give rise to decadal forecast skill in the Euro-Atlantic sector

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1. Introduction

The evolution of climate on decadal timescales is governed by a combination of: a) internal variability, and b) the response to changing radiative forcings. Both these components are potentially predictable to some degree. In the first place, there are 'slow' components of the internal variability, particularly those that involve the ocean. Knowledge of the ocean state can potentially constrain the evolution of these slow components for some time ahead, and thereby provide a basis for predictions. In the second place, predicting the response to changing radiative forcings relies partly on knowledge of how these forcings will change in future. However, because the response of the climate system is sluggish, there is also important information in the ocean state that can help to predict this component of climate change.

This report focuses on the potential predictability that is associated with internal variability, and on the North Atlantic region. Previous work (see review by Latif et al, 2006 and ENSEMBLES Deliverable D4.4.1) has found clear evidence that the North Atlantic Ocean exhibits significant, and unusually high, potential predictability on decadal timescales. In particular, the Atlantic Meridional Overturning Circulation (MOC) has been shown to exhibit decadal predictability (e.g. Collins and Sinha, 2003). A key question, however, is: what are the mechanisms that give rise to this predictability? Understanding the mechanisms involved is essential if we are to evaluate the reliability of model results and develop prediction systems for the real world. This report describes analyses carried out on experiments with the HadCM3 climate model to address this question.

2. Mechanisms influencing predictability in the North Atlantic

The simplest mechanism that can give rise to predictability is "damped persistence": the ocean integrates the effects of fluctuations in the atmosphere (particularly in the air sea fluxes) and, as first described by Hasselmann (1976), the resulting time series resembles a "red noise" process, which is characterised by two parameters: a de-correlation timescale and a variance. Damped persistence can be the basis of useful predictions but involves no role for non-local ocean dynamics: each region of the ocean can be thought of as responding independently to variations in air-sea fluxes. However, previous work has shown that for some variables (e.g. the Atlantic MOC, Collins and Sinha, 2003) predictability greatly exceeds that expected for a red-noise process, thus suggesting that ocean dynamics do in fact play an important role. Furthermore, even where damped persistence is an adequate model, it is important to understand the processes that determine the de-correlation timescale.

The importance of convection

Fig 1 shows an analysis of error growth in one of the predictability experiments analysed by Collins and Sinha. In this experiment an ensemble of nine 20-year integrations was integrated from a particular initial condition taken from a long control run of the HadCM3 model (Gordon et al. 2000). The individual ensemble members differed in respect of small changes in the atmospheric initial conditions. The figure shows that error growth is initially fastest near the surface, as expected since this is the region directly forced by fluctuations in the atmosphere. However, after about 10 years there is very rapid growth extending down to ~1500m. This rapid growth is almost certainly caused by the onset of deep convection in some ensemble members (HadCM3 shows active but intermittent deep convection in this region). The importance of this behaviour is that it shows that the onset of convection is associated with a very rapid loss of predictability, as one might expect given that convection arises from an instability. Conversely, predictability is likely to be greatest when, and where, convective instability is weak or absent. Thus the nature of the stratification, and especially the degree of convective instability, will play a major role in determining the persistence and de-correlation time of oceanic anomalies.

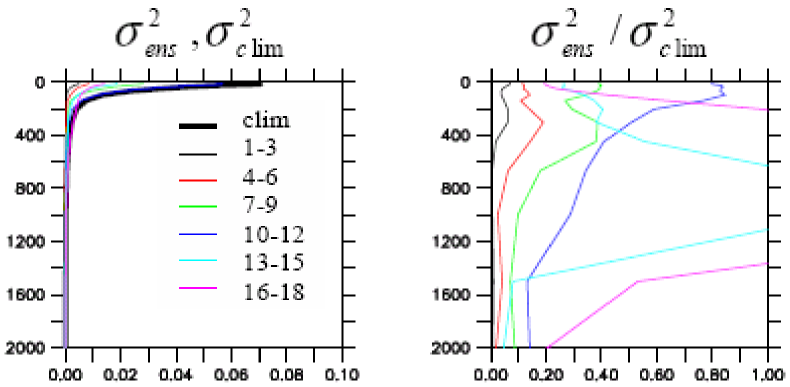

Fig 1: Growth of ensemble spread (variance, σ^2) in ocean density as a function of depth and time in the Nordic Seas region (20W-10E, 67.5-82.5N) in Experiment 3 of Collins and Sinha (2003). The left panel shows the absolute variances. "clim", shown in black, refers to the climatological variance computed from the control run. Other colours are for 3-year means (with the years indicated) computed from the ensemble. The right panel shows the ratio of the within ensemble variance for each 3-year mean to the climatological variance.

The importance of ocean dynamics

The fact that the Atlantic MOC shows high predictability, greatly exceeding that expected on the basis of damped persistence, is already evidence that ocean dynamics do play an important role in determining decadal predictability in the North Atlantic region. Fig 2 provides further evidence of the importance of ocean dynamics, and some insight into the mechanisms involved in the HadCM3 model. Coherent propagation of density anomalies is seen from the Irminger Sea to the Labrador Sea and then into the North Atlantic Current region. There is an associated propagation of salinity anomalies (not shown), and these anomalies appear to be similar to the “Great Salinity Anomalies” found in HadCM3 by Wadley and Bigg (2006). These authors show that salinity anomalies exhibit a characteristic timescale of 10-15 years to propagate around the subpolar gyre, and that the mechanism of propagation is not purely advective. Rather, the processes are quite complex, involving an interplay of temperature and salinity anomalies and their effects on density and anomalous ocean currents.

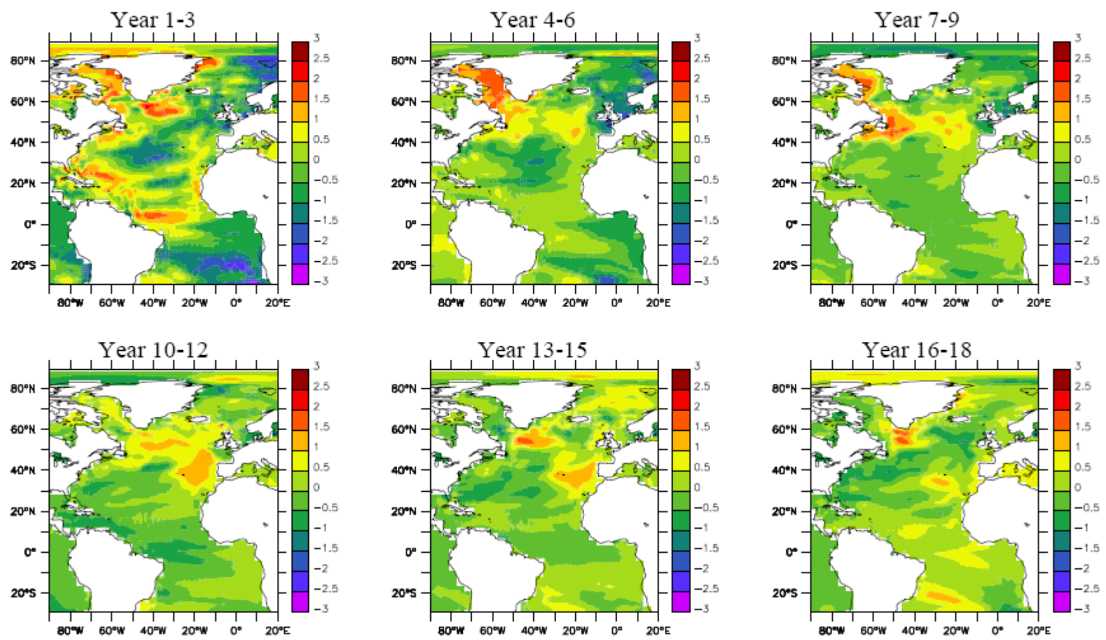

Fig 2: Time evolution of vertically integrated (0-800m) ensemble mean density anomalies, normalized by the climatological standard deviation, in Experiment 3 of Collins and Sinha (2003).

Quasi-periodic variations such as those described by Wadley and Bigg can clearly have a major influence on predictability. Another example of quasi-periodic variability in the North Atlantic region in HadCM3 has been described in detail by Gamiz-Fortis and Sutton (2007). They identify a variation with a period of ~ 7 years, whose centre of action lies in the Nordic Seas. The mechanism involves a competition between convection and advection. Advection carries cold, fresh, Arctic Water over warm, salty, Atlantic Water, while convection periodically mixes these two water masses vertically, raising both temperature and salinity at the sea surface. Convection can raise SST because of the presence of a subsurface temperature maximum. In this region, the convection in HadCM3 is forced by wind stress curl anomalies related to the North Atlantic Oscillation. The consequent SST anomalies feed back positively to force the atmosphere, resulting in a weak spectral peak (at ~7 years) in local sea level pressure. Thus this appears to be an example of weakly coupled ocean-atmosphere mode of variability. Although there is no evidence of a similar oscillation in reality, Gamiz-Fortis and Sutton argue that key aspects of the simulated mechanism may be relevant to understanding variability in the real Nordic Seas.

3. Predictability of rapid changes in the Atlantic Meridional Overturning Circulation and its effects on climate.

Further insight into the mechanisms that govern the predictability of the MOC in HadCM3 has come from a study of spontaneous large, rapid, MOC changes which are found in a multicentury control run of the model (Hawkins and Sutton, 2008, submitted to GRL). Rapid changes in temperature and salinity in the Nordic Seas, and the flow of water through Denmark Strait are found to be precursors of rapid changes in the MOC, with a lead time of around 10 years. The mechanism proposed to explain this predictability involves variations in convection in the Nordic Seas which create density anomalies which propagate through Denmark Strait and along the deep western boundary current, affecting the overturning. Fig 3 shows, for one particular event, how positive density anomalies emerge from Denmark Strait, and propagate down the western boundary at depth. Fig 4 shows that these rapid changes in the MOC have significant and widespread climate impacts, which are potentially predictable a few years ahead. In particular, a rapid increase in the Atlantic MOC leads to large-scale warming of the Northern Hemisphere. The mean warming is around 0.5K over Europe and ~1K over Russia. These features are consistent with previous work on the climate impacts of MOC changes in HadCM3 (Knight et al, 2005).

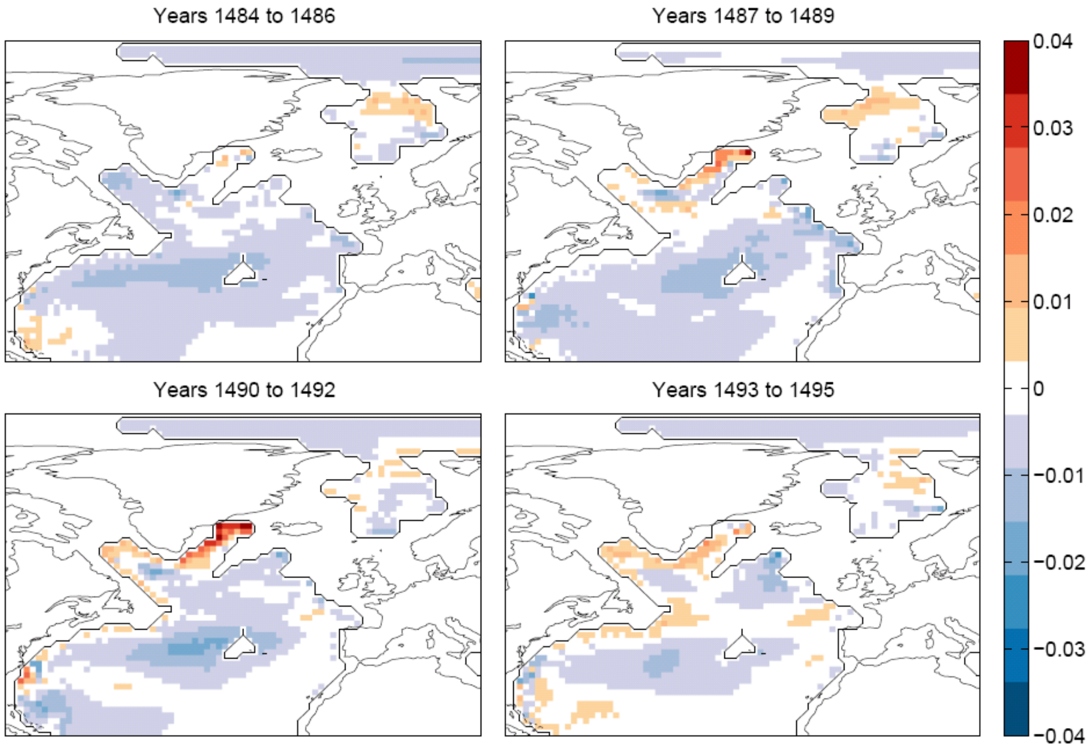

Fig 3: Vertically integrated density anomalies from 800m-3000m, relative to the control run mean, for averaged 3 year periods. The thin black line shows the 3000m isobath in HadCM3.

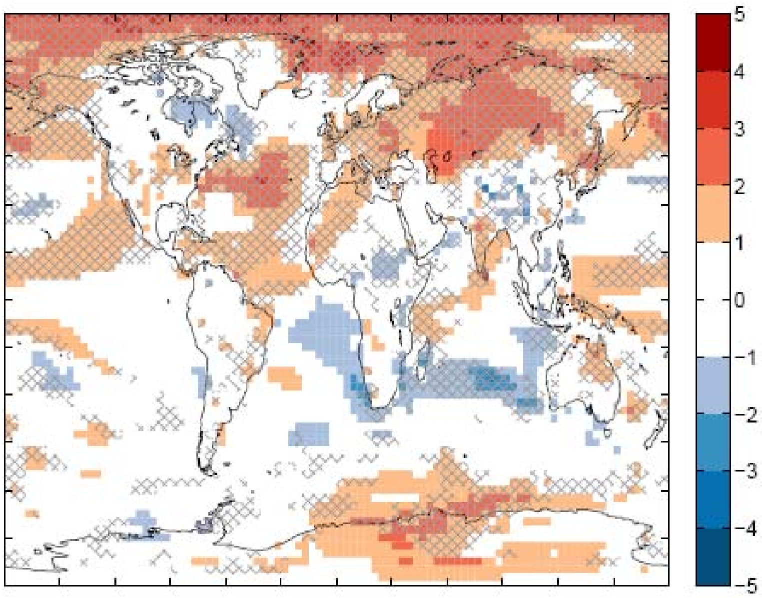

Fig 4: Composite of surface air temperature differences for decadal means before and after each rapid event, scaled by local decadal standard deviation. The hatched regions show where the signs of the changes are consistent between each of the 3 rapid events considered.

4. Conclusions

This report provides insights into the mechanisms that give rise to decadal forecast skill in the North Atlantic region in the HadCM3 climate model. Previous work has shown that, at least for some ocean variables, predictability in the North Atlantic significantly exceeds that which would be expected on the basis of a simple "damped persistence" model. It has also been shown that the degree of predictability depends on the initial conditions. In this report it has been argued that the onset of convection plays a key role in loss of predictability. Thus the nature of the stratification, and especially the degree of convective instability, is expected to play a major role in determining the predictability timescale associated with a given initial condition.

In addition, it has been shown that non-local ocean dynamics have a major influence on the North Atlantic predictability in HadCM3. Quasi-periodic fluctuations play an important role in the subpolar gyre, and rapid changes in the Atlantic MOC are caused by deep density anomalies propagating from Denmark Strait southwards along the western boundary of the Atlantic basin.

To build confidence in the understanding of decadal predictability there is clearly a need to investigate the extent to which the findings based on the HadCM3 model also carry over to other models. The new EU THOR programme aims to make a major contribution to this and other related issues concerning the predictability of the MOC in particular.

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