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**D5.12: Assessment of the climate predictability in perfect-model mode over the North Atlantic/European sector for seasonal to decadal timescales based on high resolution AGCM simulations**

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Abstract

An upper predictability limit of North Atlantic/European sector climate is estimated by the analysis of variance (ANOVA) of a five member ECHAM5 simulation forced with observed sea surface temperature (SST), and sea-ice cover for the period 1870 till 2003. Potential predictability of sea level pressure (SLP), precipitation, 2m-surface temperature, and zonal wind shear is estimated on seasonal, annual, and pentad time-scales.

On seasonal time-scales, predictability levels are high in the tropics, low north of 30ºN, and greater in boreal summer than in winter. In summer in the tropics, 70-80% of variance is potentially predictable. Predictability over Europe at levels greater than 10% is only found for boreal summer surface temperature, and only in the west.

For annual means, the pattern of predictability remains similar to the seasonal, but levels are overall higher. In particular, over significant regions of western Europe and North America more than 20% of the variance in surface temperature is potentially predictable. A significant portion of the predictability in annual means arises from variability with timescales longer than five years. Over western Europe and North America this variability explain up to 50% of the potentially predictable variance.

For pentad means, predictability levels increase further. In the tropics, areas are found where 90% of the variance is potentially predictable. Over western Europe and eastern and southern North America now 50-60% of variance in surface temperature is predictable. Pentad means however only explain 20-30% of the total variance. In terms of seasons, pentad means for boreal summer are more predictable than winter. Large predictability of summer time climate is greater than that of winter, because internal atmospheric variability is weaker in summer.

Introduction

There is currently much interest in decadal prediction. This stems largely from predictability studies, which show four regions where decadal variability exists and is potentially predictable: North Atlantic, North Pacific, Tropical Pacific, and the Southern Oceans. The mechanisms behind decadal variability in all four regions remain controversial. In the North Atlantic, however, it widely accepted that the Atlantic meridional overturning circulation (MOC) is the dominant forcing of low frequency variability in SST, and that low frequency variability in the MOC, simply through its inertia, provides a physical basis for decadal predictability. See Latif et al. 2006 for a review of North Atlantic decadal predictability.

The current interest has extended to the development and testing of experimental decadal forecast systems. The first two efforts, and the only ones to date, were both developed within the EU-ENSEMBLES projects. The first is the system based on the Hadley centre model (Smith et al. 2007), and the second is based on the Max-Planck-Institute for Meteorology’s model (Keenlyside et al. 2007). Smith et al. 2007 demonstrate that initialisation of the ocean leads to improved predictions, w.r.t. radiative forcing only simulations, of global mean surface temperature out to a decade in advance. They also demonstrate skill at some regional levels. In the North
Atlantic/European sector, however, skill improvements are marginal. In contrast, Keenlyside et al. 2007 demonstrate significant skill in predicting North Atlantic SST a decade in advance, with indications also of enhanced skill over North America and Europe. The skill is demonstrated to arise from initialisation of the Atlantic MOC. However, they demonstrate no improvement in predicting global mean temperature. The contrast between skill demonstrated by these two studies raises the question of what is actually expected. This motivates the main objective of this report: to provide an estimate for the upper limit in predictability on decadal timescales focused on the North Atlantic.

There are three common ways to estimate predictability: diagnostic potential predictability, prognostic classical predictability, and model simulations with reduced dynamics. A brief overview of these techniques follows; see Latif et al. 2006 for a more detailed review. All three techniques attempt to estimate the ratio between signal and noise. In this context, the internally generated natural variability, which is not predictable on long time scales, and so may be considered “noise” (Hasselmann 1976; Frankignoul et al. 1997). The signal is the long-term variability arises from processes operating in the physical system. If the signal exists and is appreciably greater than the noise then it is deemed potentially predictable.

Diagnostic potential predictability is closely related to ANOVA, and in the climate context was first formulated by Madden, 1976. Decadal potential predictability is defined as the ratio of the variance on the decadal time scales to the total variance (Boer 2000, Boer 2004). Classical predictability studies are essentially derived from the work of Lorenz, 1965 and consist of performing ensemble experiments with a single coupled model perturbing only the initial conditions (Griffies and Bryan 1997a,b; Grötzner et al. 1999; Boer 2000; Collins 2002; Collins and Sinha 2003; Pohlmann et al. 2004). In these studies, the predictability of a variable is given by the ratio of the actual signal variance to the ensemble variance. These experiments provide in most cases an upper limit of predictability in the models used since they assume a perfect model and near-perfect initial conditions. The third method compares the variability simulated with and without the inclusion of an active part of the climate system. In this context, ocean dynamics are probably the most relevant, and in which case this method identifies those regions in which ocean dynamics are important in generating the variability. It is likely that these regions are also the regions of high predictability potential (Park and Latif 2005).

Although potential decadal predictability can be estimated from observations, in practice data records are rather short and tend to be less reliable for earlier periods and, hence, it is often estimated from model simulations. Thus, all three methods for estimating decadal predictability rely heavily on coupled models. A disadvantage of this is that models are indeed not perfect. A second problem in the case of decadal prediction, is that as we know from seasonal prediction (Tang et al., 2005), forecast skill is heavily depend on the level of the (predictive) signal, and hence strongly depends on the period considered. This is particularly relevant when it comes to verification of decadal prediction systems through performing retrospective forecasts, for which the forecast period is clearly short: Instrumental data only exists over the last 130 years or so, and it is not clear over how much of this may forecasts realistically be initialised. A third complication is that external radiative forcing is important on decadal timescales and has had a clearly influence on variability in the
late 20th century (IPCC 4th assessment report) that also gives rise to predictive skill, even on regional levels (Lee et al. 2006). These three issues motivate the second aspect of this work: to quantify the amount of decadal predictability that existed during the instrumental period.

To assess the potential predictability (diagnostically) for the North Atlantic/European sector during the instrumental period we perform ANOVA on a five-member ECHAM5 simulation forced with observed sea surface temperature (SST), and sea-ice cover for the period 1870 till 2003. ANOVA has previously been applied mainly to assess potential predictability on seasonal timescales (Zwiers, 1996, Rowell 1998), but has also been applied to decadal variability (Chen and Van den Dool, 1997). In the latter, however, only a 45 year long simulation was considered at T42 resolution. Here, a 134 year long period is considered and the simulations are performed at considerably higher horizontal resolution (T106); this may be important, for example, for simulating El Niño Southern Oscillation (ENSO) teleconnections (Merkel and Latif, 2002).

The experimental design follows that of the Atmospheric Model Intercomparison Project (AMIP; Gates, 1992). Such experiments have been used to argue for a role of SST/SIC boundary conditions in forcing mid-latitude atmospheric variability on decadal timescales (e.g., Rodwell et al. 1999). However, it has been argued that this experimental setup is inappropriate, because in mid-latitudes SST variability is primarily atmospheric forced, and may lead to an incorrect interpretation (Bretherton and Battisti, 2000). While this is indeed true for seasonal-to-interannual variability, the picture may be different on longer timescales: On these timescales North Atlantic SST are likely forced by the large scale ocean circulation (e.g., Bjerkness 1964, Desser and Blackmon, 1993, Kushnir 1994, Latif et al. 2004). Also more recently, a number of studies have demonstrated the atmospheric response over North America and Western Europe, and Northern Africa and Brazil to low frequency changes in Atlantic SST is reproducible, particularly in summer (Sutton and Hodson, 2005, Zhang and Delworth, 2006). Thus, although the experimental design is not ideal and hence may not provide a true upper limit for decadal predictability, we feel the analysis is justified and the results useful. Furthermore, no better approach has been proposed.

The remainder of report follows with a brief description of the model, experiments, and analysis techniques. This followed by the results, and then discussions and future outlooks are given.

**Method and Experiments**

All experiments were performed with the ECHAM5 atmospheric general circulation model (AGCM). ECHAM5 is the latest version of the ECHAM model developed at the Max Planck Institute for Meteorology (MPI). It is a spectral model employing state-of-the-art physics. A detailed description of the model is given in Roeckner et al. (2003); a more concise summary of the model can be found in Roeckner et al. (2006), where the sensitivity of results to resolution is described. The model (as part of the MPI climate model) was used to carry out scenario simulations for the IPCC 2007 fourth assessment report (AR4).
Five simulations were performed with the model at T106 horizontal resolution (approximately 1 degree) with 31 vertical levels. All simulations were forced with identical monthly varying SST and sea-ice cover (SIC) boundary conditions from the HadISST 1.1 dataset (Rayner et al. 2003) for the period 1870-2003. The different ensemble members differ only in their initial conditions. The first member was started from the default January 1978 conditions and run with SST and SIC from 1870 for the first two years; the first year was discarded. The second member was generated by applying the 1870 boundary conditions for three years, and discarding the first two years. Subsequent members were similarly generated. External radiative forcing is maintained constant at 20\textsuperscript{th} century values throughout the simulation. There impact is assumed to be included in the SST boundary conditions.

ANOVA is designed to quantify the impact of different treatments in a series of controlled experiments. In our configuration, the treatment effect is the time varying SST and SIC. ANOVA is applied as in von Storch and Zwiers (1999; eq. 9.7, pg. 176). It is applied to boreal summer (JJA) and winter (DJF) means, annual means, and pentad running means. The component of variance explained in the annual means and seasonal means by the slowly varying component (here the 5 year running mean smoothed data) is estimated by computing the variance of the low and high-frequency variance separately. Note the sum of the squared variances of the low and high-frequency components equals the total squared variance. We confine our analysis to SLP, surface temperature over land, precipitation, vertical zonal wind-shear. The latter is of particular relevance to hurricane development.

**Results**

Consistent with previous studies (Zwiers, 1996; Rowell 1998) the tropics show the highest levels of potential predictability. In boreal summer, in the Atlantic between the equator and 30\textdegree N, 50-70\% of the variability in SLP is explained by the boundary conditions (Fig. 1a). Precipitation in the vicinity of the Intertropical Convergence Zone (ITCZ) is also highly predictable (Fig. 1b), so are vertical wind-shear (Fig. 1c), and surface temperature over Northern Brazil and Africa (Fig. 1d). In all cases predictability exceeding 70\% are found. North of 30\textdegree N significant predictability is also found in SLP over North America. Surface temperature over North America and Western Europe show significant predictability, but levels are only around 10\%. In winter, predictability levels drop significantly, and levels contract towards the equator (Fig. 2). A simple explanation for this result is that the level of internal atmospheric variability is less in summer than in winter. This is discussed further below.
Figure 1: Variance explained by the prescribed SST and SIC in simulated (a) SLP, (b) precipitation, (c) 2m-temperature, and zonal wind shear for boreal summer. Calculated from analysis of variance (ANOVA) of five ECHAM5 simulations from 1870-2003 at T106L31 resolution.

Figure 2: as figure 1, except for computed for boreal winter.
For annual means, the pattern of predictability remains similar to the seasonal ones, with high values in the tropics and low values in the extra-tropics (Fig. 3). Predictability levels are, however, overall higher. In particular, over significant regions of Western Europe and North America more than 20% of the variance in surface temperature is potentially predictable. Over tropical South America and Western and Central Africa, surface temperature is around 70-80% predictable (Fig. 3c). Separation of the variability into a component with timescales longer than five and a component shorter than five years shows that a significant portion of the predictability in annual means arises from variability longer than five years (Fig. 4). This is particularly the case for surface temperature over western Europe and North America, and Tropical Africa and South America, where this variability explains up to 50% of the potentially predictable variance.

For pentad means, predictability levels increase further (Fig. 5). In the tropics, areas are found where 90% of the variance is potentially predictable. Particularly high values are found for SAT in the tropics (Fig. 5c). This implies that if the SST could be perfectly known, then the five-year mean SAT anomalies over Northern South America and Western and Central Africa would be almost perfectly known. The strong predictability (Fig. 5d) in vertical wind shear means a large part of anomalous hurricane activity could be potentially predictable. Over Western Europe and Eastern and Southern North America now 50-60% of variance in surface temperature is predictable (Fig 5c). Of note are also significant levels in predictability of precipitation over the Gulf Stream extension (Fig. 5b), which may have implications for predictability in extra-tropical storms. However, notable minimums in the predictability in SLP occur South of Greenland and over Central Europe (Fig. 5a).

Although pentad mean exhibit considerable predictability, the amount of total variability they explain is quite small, and is generally in the 20-30% range (Fig. 6). Not surprisingly, a close correspondence is seen between regions with high potential pentad predictability and regions with comparatively high variance in pentad means (e.g. in the tropics, and over Western Europe). In terms of seasons, pentad means for boreal summer (Fig. 7) are more predictable than winter (Fig. 8). Large predictability of summer time climate is greater than that of winter, because internal atmospheric variability is weaker in summer (not shown).

**Discussions**

ANOVA was performed on SLP, precipitation, surface temperature, and vertical zonal wind shear from a five member ensemble of high resolution ECHAM5 simulations forced with observed SST and SIC for the period 1870-2003. On the seasonal and annual timescales, results were consistent with previous studies, indicating high predictability in the tropics and in boreal summer. For pentad means, it was shown that almost all the variance in surface temperature over tropical Africa and South America is potentially predictable. This would indicate a high socio-economic value for successful decadal forecasts. Vertical wind shear also showed high predictability in the tropical Atlantic, which may have large implications for decadal forecast of hurricane activity. High levels (50-60%) were also found in SAT over Western Europe, which may also be of economic value. The results of this study thus provide strong motivation for the development of decadal forecast systems.
Figure 3: same as figure 1, except computed using annual mean values.

Figure 4: Component due to variability five years and longer of total variance explained in the simulated annual means shown in figure 3.
Figure 5: As in figure 3, except computed on data smoothed with a five year running mean.

Figure 6: Ratio of variance of the five year running mean smoothed data to the variance of the unsmoothed data.
Figure 7: As in figure 1, except a five year running mean was applied to boreal summer data before ANOVA was performed.

Figure 8: As in figure 7, except computed for boreal winter.
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