REVIEW: Decadal – Multidecadal Climate Predictability

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Abstract

Enhanced variability on decadal to multidecadal timescales occurs over a number of regions of the world (e.g., Tropical Pacific, North Pacific, and North Atlantic). Understanding the mechanisms for this variability and to what extent it is predictable are important, both because of the economic and socioeconomic consequences, and to improve detection and attribution of anthropogenic forcing of climate change. There have been a number of important developments in the last few years. Especially, the PREDICATE project has shown in a comparison of several coupled general circulation models that North Atlantic climate could be predicted at least a decade in advance. There is even research underway into the development of prediction systems. Here we review the recent progress in decadal and multidecadal climate predictability.

1. Introduction

Over the last twenty years we have seen major developments in seasonal forecasting, and now many centers around the world routinely make seasonal forecasts. The success of these efforts is based on the predictability of the El Niño Southern Oscillation (ENSO), and in our ability to capture it in our models and statistical schemes. In this processes observations and simple models have played a crucial role. Observational networks, such as the TOGA/TAO array in the tropical Pacific (McPhaden et al. 1998), also play an integral role in the monitoring and forecasting of this phenomenon.

In contrast to seasonal forecasting, decadal to multidecadal climate predictions are at an infant stage. None the less, there are many things that can be learned from seasonal forecasting experience. Paramount among these is the recognition that better understanding of the physical mechanisms involved and better monitoring systems are needed for advances to be made. In terms of understanding decadal variability, we are handicapped much more significantly by a lack of adequate data, and we will have to wait much longer to get it. Thus, in decadal variability studies there has been a heavy reliance on models. But models do not always agree with each other or with observations, and thus while models have been helpful in identifying possible mechanisms, the true mechanisms for decadal variability are still not known. However in this respect, observations can play a crucial role: They can be used to reduce model uncertainties, through improvements in model physics, especially those aspects believed important to decadal and multidecadal timescales, and on which models disagree.

As with seasonal forecasting, decadal to multidecadal climate prediction are of economic, political and public interest. Their value lies in planning the future in all fields that depend on climate to some degree. This includes for example the choice of agricultural species, insurance fees, plans of infrastructure, the energy sector, or simply the diameter of gutters. Unlike seasonal forecasting, the relevant periods are longer than a single political reign, and anthropogenic forcing of climate becomes an issue.

It is the aim of this review to summarize our current understanding on the level of decadal to multidecadal predictability of global climate, and to discuss some early steps toward the development of decadal to multidecadal prediction systems. Understanding the mechanism of decadal to multidecadal variability is an integral part of understanding the predictability. Thus, the potential mechanisms are also discussed, but not in detail; for greater detail see Latif (1998). Further, attention is restricted to four regions, the North Atlantic (NA), the North Pacific (NP), the Tropical Pacific (TP), and the Southern Oceans (SO). There is some consensus that these regions exhibit some degree of decadal to multidecadal predictability. As in the literature, the NA is paid the most attention and the SO the least. In addition to reviewing the literature, relevant recent, ongoing and future EU projects on variability and predictability are discussed.

This paper is organized as follows. In section 2, the global pattern of decadal predictability, and the mechanism and predictability of the NP and TP are reviewed. Section 3 goes on to describe in detail the mechanisms and predictability of NA decadal variability. Section 4 discusses ongoing work on the development of decadal prediction systems. The paper is concluded with a summary.

2. Global pattern of decadal to multidecadal predictability

In this section we examine the global pattern of decadal predictability as found in potential and classical predictability studies, which are two common methods for estimating decadal predictability. Decadal potential predictability is defined as the ratio of the variance on the decadal timescales to the total variance (Boer 2000). A value approaching one indicates an enhancement of variability on decadal timescales, and would argue for the presence of an oscillatory mode of variability and against the null hypothesis of the stochastic climate model (Hasselmann 1976; Frankignoul et al. 1997). Classical predictability studies consist of performing ensemble experiments with a single model perturbing only the initial conditions (Griffies and Bryan 1997a/b; Boer 2000). In these studies, the predictability of a variable is given by the ratio of the ensemble variance to the actual signal variance. These experiments provide an upper limit of predictability, since they assume a perfect model and near perfect initial conditions. Although potential 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, both these predictability estimates rely heavily on models.

Recent potential predictability (Boer 2001) and classical predictability studies (Pohlmann et al. 2003) indicate four regions where predictability may exist at decadal timescales: The North Atlantic (NA), the Southern Oceans (SO), the North Pacific (NP), and the Tropical Pacific (TP). These regions are shown to be largely model independent by Boer (2001), where the potential predictability of decadal means of surface air temperature (SAT) from an ensemble of eleven climate models was calculated (Figure 1). The most prominent regions are the NA and the SO, where greater than 50% of the variance exists in the decadal band. The NP and TP also show a significant fraction of variability at decadal timescales. For the NA and SO regions, the results of the Pohlmann et al. (2003) classical predictability study with the ECHAM5/MPI-OM coupled model are in good agreement with Boer's (2001) study, showing these regions are predictable out to 10 years or longer. For the NP and TP regions, the level of predictability weakens, but the patterns remain largely similar.

The NA has received the largest amount of attention, since it shows among the largest potential for decadal predictability and because of its potential influence on Western Europe and the Eastern United States. Discussion of this region is left to the next section. The SO has received the least amount of attention, no doubt since it has little or no social or socioeconomic impact. Hence, the mechanisms for decadal predictability in this region are not yet well understood, and further work is required in this region. The predictability of the SO will not be further discussed here. In the remainder of this section the TP and NP regions are discussed.

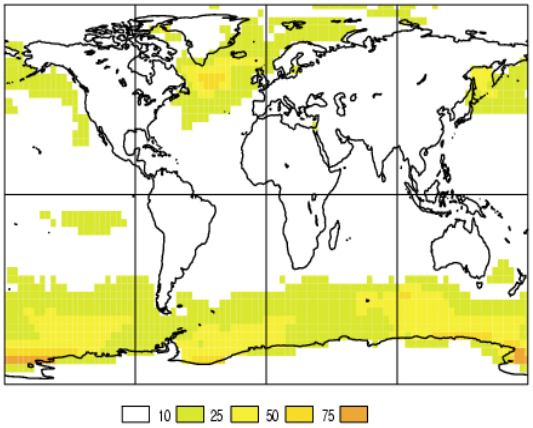

Figure 1 (Boer 2001): *Potential predictability for decadal mean surface air temperatures from a model ensemble of 11 coupled models.*

2.1 North Pacific Decadal predictability

It is well accepted that NP variability has a decadal to inter-decadal component (e.g., Tourre et al. 1999), however there is no consensus on the mechanisms for this variability (Latif 1998; Miller and Schneider 2000). There are two main schools of thought on this: The first is the gyre mode proposed by Latif and Barnett (1994), the second is the stochastic climate model, adapted by Frankignoul et al. (1997) to wind driven gyres. Both mechanisms are found in coupled climate models, with result very model dependent (Latif 1998). The key factor determining the different behaviour among the models is the atmospheric sensitivity to mid-latitude SST anomalies; those models with higher sensitivity simulate the Latif and Barnett (1994) mode. The true atmospheric sensitivity is not yet known, and hence this issue remains unresolved (Miller and Schneider 2000). While observations do contain some supporting evidence for the Latif and Barnett (1994) gyre mode (Tourre et al. 1999), observation records are comparatively short, and the null hypothesis of a stochastically forced response remains a very stringent test (Pierce 2001).

Little has been done in the way of predictability study specifically on NP variability. Venzke et al. (2000) show that there is a strong lead lag relationship between SST in the western NP and observed SST anomalies in the central NP, with anomalous heat content leading the SST changes by several years. This relation arises from the dynamics of gyre adjustment. This idea is supported by observations (Zhang and Levitus 1997) and other modeling studies (Schneider et al. 2002). Venzke et al. (2000) show, with a set of ocean only hindcasts, that this relation can be exploited in certain cases to predict central NP SST anomalies several years in advance. However, several coupled modeling studies indicate that decadal predictability of the NP is in fact weak (Grötzner et al. 1999; Collins 2002).

2.2 Tropical Pacific Decadal predictability

Like NP variability, TP decadal variability and its modulation of ENSO are well accepted, but not well understood. Several potential mechanisms for TP variability have been proposed. The simplest explanation is again the stochastic climate model (Hasselmann 1976; Eckert and Latif 1997). A second possibility is that the variability is internal to the TP (e.g., Tziperman et al. 1995; Timmerman et al. 2003). Another idea, is that decadal variability originates in the NP and is teleconnected to the tropics via the atmosphere (e.g., Barnett et al. 1999) or ocean (e.g., McCreary and Lu 1994). A fourth idea, is that decadal variability arises from coupled variability involving extratropical-tropical interactions of the ocean and atmosphere (e.g., Gu and Philander 1997; Kleeman et al. 1999).

As far as we are aware there have been no decadal predictability studies focused on the TP. However, in similar way to the idea of circulation generated predictability (e.g., Venzke et al. 2000), variations in the strength of the upper branch of the sub-tropical cells have been suggested as means for predicting decadal tropical SST variations several years in advance (Klinger et al. 2002). Observations also support the idea that variations in the subtropical cells indeed affect tropical SST variability (McPhaden and Zhang 2002).

The TP among the four regions identified by recent decadal predictability studies (Boer 2000, Pohlmann et al. 2003) shows the weakest potential for decadal predictability. A straight forward conclusion may be that the TP has little predictability on these timescales. An alternative explanation may be that the decadal signal is masked by the dominance of ENSO, which explains the largest amount of variance. Although decadal variations may only directly explain a small portion of the total variance, it is likely they will modulate the ENSO signal (e.g., Kleeman et al. 1999) and its predictability (e.g., Power et al. 1999), through non-linear interactions with the slow variations in the mean state. Thus, the potential for decadal predictions of the TP has important implications for society.

3. Predictability of decadal fluctuations in North Atlantic-European climate

European climate exhibits substantial fluctuations on 5-20 year timescales. The NA Oscillation (NAO) index, which is the most important single index of climate fluctuations in the Atlantic-European sector, underwent major low frequency fluctuations during the last century, with high values predominating at the beginning and end of the century and low values in the 1950s-1970s. These fluctuations were associated with large anomalies in storminess, temperature and rainfall, with major impacts on the people and economies of Europe. Anomalies in the Atlantic Ocean, which occurred simultaneously with the atmospheric anomalies, severely affect European fisheries. For these reasons, NA decadal variability has received special attention. In this section we review the mechanisms and predictability of NA variability. First, work is discussed that demonstrate a significant impact of the NA ocean SST on the atmosphere on decadal timescales. This provides the motivation to study the mechanism and predictability of the NA ocean-atmosphere system, and these are discussed in the two following subsections.

3.1 Ocean forced atmospheric variability

Ensembles of uncoupled AGCM experiments forced by observed SSTs and sea ice distributions are used to identify atmospheric predictability under the assumption that the SSTs are themselves predictable. Potential predictability is estimated by comparing external (ocean) forced and total climate variance (e.g., Rowell 1998). Although these studies have been criticized, since they exclude any feedback of the atmosphere on the ocean (Barsugli and Battisti 1998; Bretherton and Battisti 2000), they provide a first estimate of how much of the atmospheric response may be predictable.

Rowell and Zwiers (1999) results indicate the tropics are generally more predictable than the extratropics. These results were further quantified in the PREDICATE project (Sutton et al. 2003), where the potential predictability of the NA - European region derived from four AGCMs forced by observed SST and sea ice distributions was systematically compared. The results showed that potential decadal predictability is highest in the summer season both for tropical and extra-tropical parts of the NA - European region. In summer (winter), roughly 60% (50%) and 30% (20%) of the variance is potentially predictable for the tropical and extra-tropical parts of the NA - European region respectively. There are, however, significant differences between estimates of potential predictability from different atmosphere models, particularly in spring and autumn.

In the PREDICATE project (Sutton et al. 2003) experiments were also carried out with different AGCMs forced by idealized patterns of Atlantic SST anomalies. The SST anomalies were identified from observations using a lagged maximum covariance analysis as those most likely to induce a significant response. A key finding was that, contrary to expectations, the response to the SST forcing was very consistent among the different atmosphere models. In many cases, the uncertainty was significantly less than the signal strength. The magnitude of the response was generally smaller than the interannual variability, but sufficient to be of clear importance for understanding and predicting decadal variability.

Sutton and Hodson (2003) studied the influence of the ocean on atmospheric variability in the NA region, by applying an optimal detection method to ensemble simulations of an AGCM forced by observed SST. They found that SST variability had a significant influence on the climate of the NA region during the period 1871-1999. Furthermore, SST variability influenced both interannual variations and longer timescale, multidecadal, variations of NA climate.

3.2 Characteristics and mechanisms of decadal variability of the North Atlantic ocean

There are two leading mechanisms for NA variability. One idea is that this variability is part of a thermohaline driven coupled atmosphere-ocean mode. Timmermann et al. (1998) found such a mode of variability, with a 35-year period, in a multicentury integration of the ECHAM3/LSG climate model. The mechanism for this mode is as follow: Anomalous strong NA THC drives positive SST anomalies. The atmospheric response to these SST anomalies involves a strengthened NAO, which leads to anomalously weak evaporation and Ekman transport off Newfoundland and in the Greenland Sea, and the generation of negative sea surface salinity (SSS) anomalies. These SSS anomalies weaken the deep convection in the oceanic sinking regions and subsequently the strength of the THC. This leads to a reduced poleward heat transport and the formation of negative SST anomalies, which completes the phase reversal.

A second idea is that multidecadal THC variability is driven by the low-frequency portion of the spectrum of atmospheric flux forcing. Delworth and Greatbatch (2000) find such a mode in their analysis of a series of coupled and uncoupled GCM integrations. Further, they show that the multidecadal THC fluctuations are driven by a spatial pattern of surface heat flux variations that bear a strong resemblance to the NAO. No conclusive evidence is found that the THC variability is part of a dynamically coupled atmosphere-ocean mode. Saravanan et al. (2000) results with an idealized model (with ocean-atmosphere coupling in an Atlantic like basin) agree with this second idea. Saravanan et al. (2000) further conclude that midlatitude atmospheric predictability is modest compared to the predictability associated with tropical phenomena like El Niño, and that this predictability arises only from the atmospheric response to oceanic modes of variability, rather than from coupled modes.

Whether decadal NA THC variability is truly coupled or not, the close correspondence between the NA SST and THC variability in conjunction with the dynamical inertia of the THC should allow for the prediction of the slowly varying component of the NA climate system (Latif et al. 2003). The level of decadal predictability of NA variability found in climate models is discussed in the next section. There is another important point associated with the dynamical inertia of the THC that is relevant for climate change detection: The interia of THC also implies that anthropogenically forced changes in THC strength (and NA SST) may be masked for several decades by natural multidecadal variability. This is clearly illustrated in greenhouse gas simulations with the ECHAM5/MPI-OM coupled model. In Figure 2 four different greenhouse gas simulations (with an CO_2 increase of 1% per year) initialized from different states of a control integration are shown. While the global mean surface temperature exhibits a rather monotonic increase (Figure 2, left panel), THC evolution closely follows that of the control run for some decades (Figure 2, right panel).

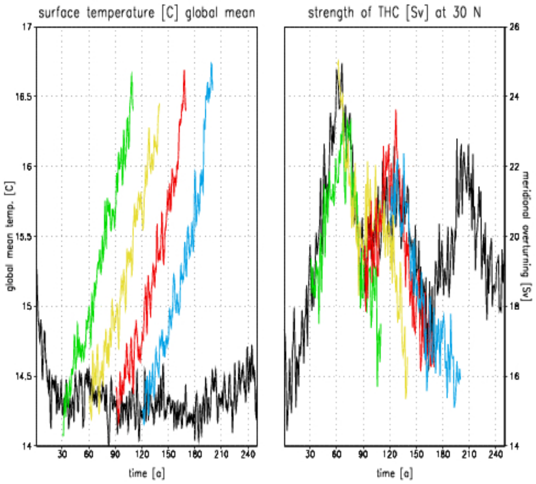

Figure 2 (Sutton et al. 2003): *Global mean surface air temperature (left panel) and meridional overturning index (right panel) from the control run (black) and four greenhouse gas experiments (colored lines) with the ECHAM5/MPI-OM climate model.*

3.3 Decadal climate predictability in the North Atlantic-European region

There have been several classical decadal predictability studies of NA variability. As discussed below, they all seem to indicate that NA THC variations are predictable out to a decade or more. However, there are major disagreements on the level and extent of predictability of SST and atmospheric quantities, such as SAT and SLP. But there are some positive indications of decadal predictability of SAT and SLP over Europe.

In the PREDICATE project (Sutton et al. 2003) a systematic comparison of the predictability of five state-of-the-art AOGCM (HadCM3, ECHAM5/MPI-OM, ARPEGE3/ORCA, BCM, ECHAM4/ORCA) is made. The results indicate that in general the strength of the Atlantic THC is potentially predictable at least a decade in advance and, in some situations, multidecadal predictions of the THC may be possible (Figure 3, left panel). In addition, THC-related variations in SST and SAT are potentially predictable one or two decades in advance (Figure 3, right panel). The exact level of predictability is dependent on the oceanic initial conditions and on the coupled model used.

The results of Griffies and Bryan (1997a/b) with the GFDL climate model also suggest that variations of NA SST are predictable on multidecadal timescales. Grötzner et al. (1999) used the ECHAM3/LSG climate model and found that the NA THC is predictable about one decade in advance, but NA SST only about one year. Boer (2000) analyzed simulations with the CCCma climate model and found that on multidecadal time scales predictability of SAT was mainly restricted to the SO. Collins (2002) used the HadCM3 climate model and found that SAT is predictable over the NA on decadal timescales. Collins and Sinha (2003) have shown that the multidecadal THC predictability in the HadCM3 model leads to some predictability of western European climate.

4. Development of a Decadal Climate Prediction System

To our knowledge there are no centers in the world making routine forecast on decadal-to-multidecadal timescales. In this section, the efforts of the Hadley Centre for Climate Prediction and Research (Smith et al. 2003) and the aims of the newly funded EU project ENSEMBLES to develop such a system are discussed. Unlike seasonal to

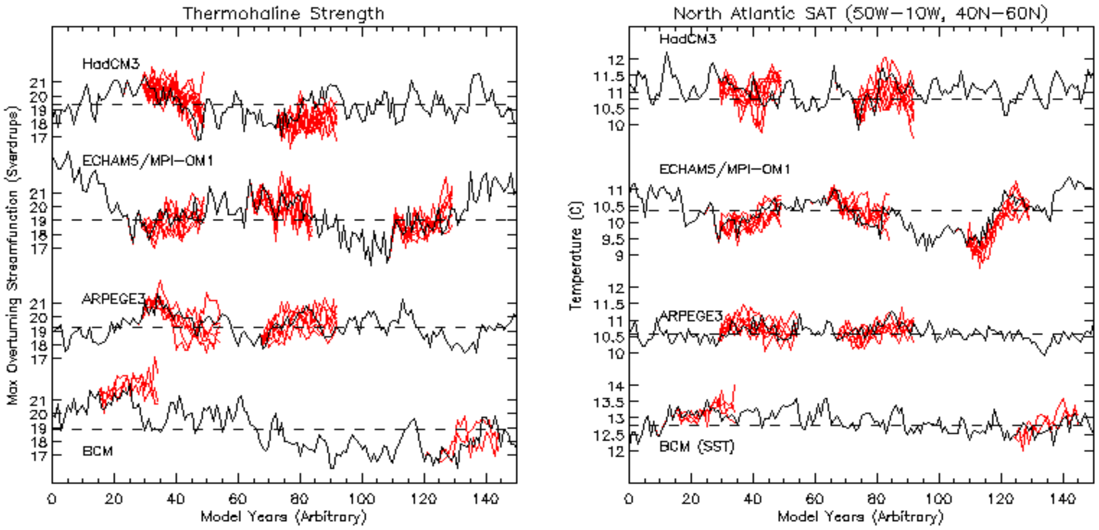

Figure 3 (Sutton et al. 2003): *Time series of THC strength (left panel) and surface air temperature over the North Atlantic ocean (50°W-10°W, 40°N-60°N, right panel) from four coupled models. The black lines show 150-year sections of time series taken from the control experiments of HadCM3, ECHAM5/MPI-OM, ARPEG3/ORCA and BCM. The dashed line is the mean of the time series over the whole control experiment. The red lines show ensemble experiments initialized from the control experiment where the oceanic initial conditions are identical, but small perturbations are made to the atmospheric initial conditions. Low ensemble spread and large displacements from the mean indicate high potential predictability.*

interannual forecasting, the effects of anthropogenic climate forcing needs to be considered when making predictions on longer timescales. Thus, the large uncertainties in making climate projections are discussed.

4.1 Decadal Prediction System (DePreSys)

The "Hadley Centre for Climate Prediction and Research" in the UK is developing a "decadal prediction system" (DePreSys) (Smith et al. 2003). A set of 60 hindcasts has been performed with the HadCM3. Initial conditions were created for the period 1979 to 1993, from which 10-year forecasts were initiated from the 1st March, June, September and December in each year. Ensemble forecasts of 4 members were generated in order to sample the range of predictions consistent with observational uncertainty. Each ensemble member was initialized from consecutive days immediately preceding the forecast period.

A multivariate optimal interpolation of temperature and salinity observations is employed to generate a three-dimensional dataset of monthly mean ocean temperature and salinity anomalies. The oceanic component of HadCM3 is initialized by relaxing the temperature and salinity fields to the optimally interpolated dataset. In addition, the atmospheric component of HadCM3 is initialized by relaxing the horizontal winds, potential temperature and surface pressure to ERA-15 data. The model is initialized with observed anomalies added to the model climate, rather than with observed values.

Compared with state-of-the-art seasonal forecasting models, DePreSys performs well on seasonal timescales. There are encouraging signs of predictability on multiannual timescales. The correlation between observed and predicted annual mean global near surface air temperature over land is almost 0.6 at one year lead time. Furthermore, there are a number of regions for which the temperature over the next few years could be sufficiently predictable to be of use to industry and commerce.

4.2 Ensemble-based Predictions of Climate Changes and their Impacts (ENSEMBLES)

ENSEMBLES is a large EU funded project, commencing April 2004, that aims to develop and test an end-to-end seasonal to decadal and longer timescales forecast system, which also accounts for anthropogenic climate change. The project will build on three previously funded EU projects: PREDICATE (Sutton et al. 2003; discussed above); DEMETER, Development of an European Multi-model Ensemble System for Seasonal to Interannual Prediction (Palmer et al. 2003; described below); and ENACT, Enhanced Ocean Assimilation and Climate Prediction (Davey et al. 2002). ENACT will contribute comprehensive ocean data assimilation schemes for initializing multidecadal hindcasts.

The DEMETER project (Palmer et al. 2003; http://www.ecmwf.int/research/demeter) addressed the issue of sampling model uncertainty in making predictions. In this project a multi-model ensemble for seasonal forecasting was constructed and tested: Seven comprehensive coupled ocean atmosphere models from research centers around Europe were used to make six-month long hindcasts over an extended period (of at least 29 years). An important outcome of the project is the demonstration of the superiority of the multi-model ensemble over any single model. The ranked probability skill score (RPSS) for precipitation over the tropics calculated for various combinations of models and of a single model clearly demonstrates this point (Figure 4), with the multi-model consistently outperforming the single model. This feature is quite universal and not restricted to any particular region or variable (Palmer et al. 2003). An important outcome from DEMETER is the demonstration that a multi-model ensemble is an effective method for sampling model uncertainties and for making more reliable forecasts, a result that should carry over to decadal-to-multidecadal predictions.

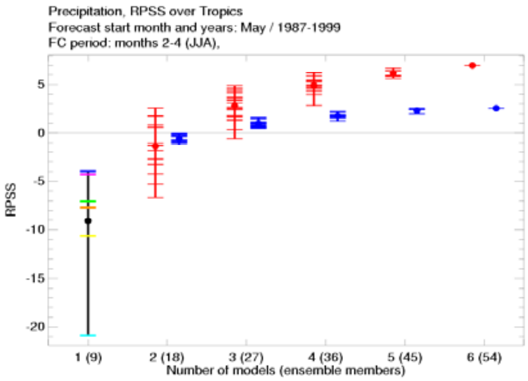

Figure 4 (DEMETER): *Ranked Probability Skill Score for precipitation over the tropics (30°S to 30°N) is shown for a single model ensemble (blue) and for multi-model ensembles (red). The number of models and total number of ensemble members (in brackets) is shown along the lower axis. Each horizontal dash indicates an arbitrary combination, with all distinct permutations shown. The multi-model combination is clearly superior to a single model setup.*

4.3. Predicting global change

The "Intergovernmental Panel on Climate Change" (IPCC; Houghton et al. 2001) has been established to assess scientific, technical and socioeconomic information relevant for the understanding of climate change, its potential impacts and options for adaptation and mitigation. The results of this report show a wide range in both, projections of atmospheric concentrations of greenhouse gases / aerosols and model dependence of global and local response on the forcing. The reason global change scenarios are discussed here is two fold. First, anthropogenic changes in greenhouse gases / aerosols are an important forcing for climate on longer timescales and thus need to be taken into account when making multidecadal forecasts. Second, natural climate variability, since it can mask anthropogenic climate change, is an important consideration in predicting global climate change, particular at a regional level. The main point we wish to convey is the large uncertainties involved.

The IPCC Special Report on Emission Scenarios (SRES; Nakićenović et al. 2000) specifies the evolution of emissions. Four different storylines were developed to describe consistently the relationships between emission driving forces and their evolution: A1, A2, B1, and B2. Each storyline represents different demographic, social, economic, technological, and environmental developments. For each storyline several different scenarios were developed using different modeling approaches to examine the range of outcomes arising from a range of models that use similar assumptions about driving forces. Altogether 40 SRES scenarios have been developed. All are equally valid with no assigned probabilities of occurrence. The set of scenarios consists of six scenario groups drawn from the four families: one group each in A2, B1, B2, and three groups within the A1 family, characterizing alternative developments of energy technologies: A1FI (fossil fuel intensive), A1B (balanced), and A1T (predominantly non-fossil fuel). To reduce the number of scenarios to a manageable size, a single scenario within a family is selected as a representative case. These scenarios are named marker scenarios. The projected CO_2 concentrations of these SRES scenarios are shown in Figure 5 (left), along with the IS92a scenario (IPCC 1992).

Global average temperature is projected to rise under all IPCC SRES scenarios. In order to make projections of future climate, models incorporate past, as well as future emissions of greenhouse gases and aerosols. Hence, they include estimates of warming to date and the commitment to future warming from past emissions. The globally averaged surface temperature is projected to increase by 1.4 to 5.8°C (Figure 5, right) over the period 1990 to 2100. These results are for the full range of SRES scenarios, based on a number of climate models. The projected rate of warming is much larger than the observed changes during the 20th century and is very likely to be without precedent during at least the last 10,000 years, based on palaeo-climate data. By 2100, the range in the surface temperature response across the group of climate models run with a given scenario is comparable to the range obtained from a single model run with the different SRES scenarios.

5. Summary

Predictability studies identify four regions where decadal predictability may exist: The NA, SO, NP, and TP. The NA and SO regions show the most potential decadal predictability, while the NP and TP are less predictable. In the NA region there are indications that the THC, SST, and SAT variations may be predictable out to a decade and longer. SST and SAT variations in the SO also exhibit a similar amount of predictability. In the NP, variations in heat content and SST appear only predictable several years in advance. In the TP there are signs that regions of the southern and northern subtropics are predictable several years in advance, but it is unclear whether this predictability is part of a larger mode of variability that covers the tropics. The possible connection to ENSO decadal modulation makes this region of significant interest.

Although there is some consensus that predictability on decadal timescales exists in these four ocean regions, to what extent does this predictability carry over to the atmosphere, especially over the regions of most interest--land--is unclear. It is also uncertain whether the strength of the atmospheric response relative to internal atmospheric variability is significant enough to be of practical use. Most of the effort in understanding these issues has focused on the NA European region. The more recent studies would tend to indicate that the climate of Western Europe does exhibit useful decadal predictability (Sutton et al. 2003; Collins and Sinha 2003; Pohlmann et al. 2003). Results from ensembles of AGCM forced by observed SST experiments also suggest reasonable agreement between atmospheric model responses (Sutton et al. 2003).

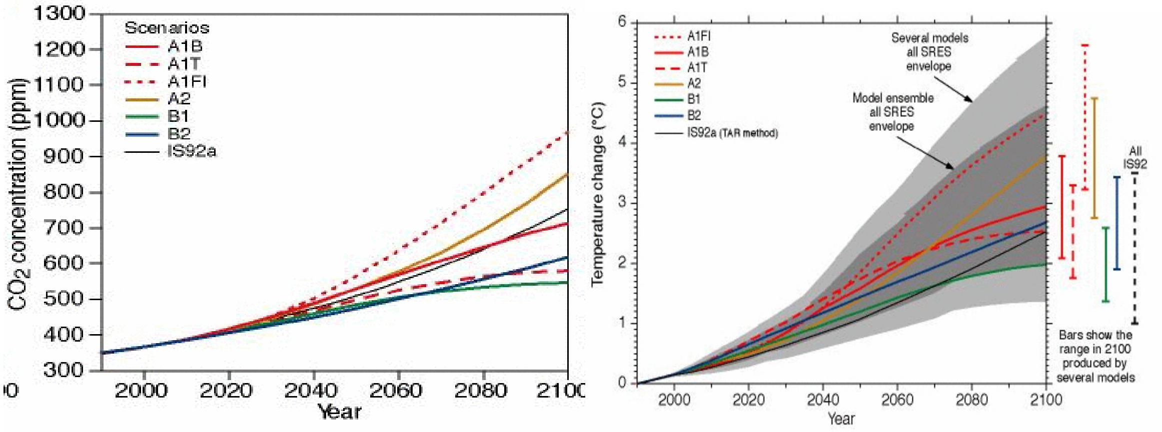

Figure 5 (Houghton et al. 2001): *Projected CO_2 concentrations (left panel) and temperatures (right panel) of six marker scenarios (Nakićenović et al. 2000) summarized in the text, along with the IS92a scenario (IPCC 1992). The "several models all SRES envelope" shows the average from a number of complex models and all SRES scenarios. The "model ensemble all SRES envelope" shows the temperature for a simple model when tuned to a number of complex models with a range of climate sensitivities.*

There is no consensus on the mechanisms responsible for decadal variability in these four regions. In general the models fall into two camps, either the decadal variability is the response of the ocean to stochastic forcing or it is part of a coupled ocean-atmosphere mode of variability. Clearly the latter has the most potential for predictability. However, where the ocean response to stochastic forcing has an oscillatory character, the inertia of these variations still offers the potential for decadal predictability. Nonetheless, understanding the true mechanisms for decadal variability is important with respect to developing decadal predictions systems. But the lack of data and the timescales involved makes this a challenge.

Early steps toward the development of decadal predictions systems were also reviewed. In this respect the importance of adequately sampling uncertainties was stressed. Perhaps the two largest uncertainties in making decadal-to-multidecadal climate predictions are in the models and in anthropogenic climate forcing. Results were discussed from the DEMETER project (Palmer et al. 2003) that indicate a mulit-model approach may be an effective way of sampling model uncertainties. Dealing with the uncertainties of anthropogenic climate forcing seems a bigger problem. But as 20 years ago people may have wondered if seasonal forecasting would ever be possible, in 20 years from now routine decadal-to-mutlidecadal predictions may have become accepted.

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