



**IFM-GEOMAR**

Leibniz-Institut für Meereswissenschaften  
an der Universität Kiel



# **IFM-GEOMAR Report 2002-2004**

**From the Seafloor to the Atmosphere**

**- Marine Sciences at IFM-GEOMAR Kiel -**



**June 2005**



## Preface

For the first time, the Leibniz Institute of

Marine Sciences (IFM-GEOMAR) presents a joint report of its research activities and developments in the years 2002-2004. In January 2004 the institute was founded through a merger of the former Institute for Marine Research (IfM) and the GEOMAR Research Center for Marine Geosciences. This report addresses friends and partners in science, politics and private enterprises. It gives an insight into the scientific achievements of IFM-GEOMAR and its predecessor institutes during the last three years.

### 3.2 Dynamics and Predictability of North Atlantic / European Climate Variability

The climate of northern Europe is strongly controlled by the North Atlantic thermohaline circulation (THC). The THC is a global belt of ocean currents and an important component of the global climate system. Its surface branch in the North Atlantic, the North Atlantic Current which is the northeastward extension of the Gulf Stream, warms northern European temperatures by several degrees in the annual mean (Fig. 1). Strong and rapid changes in the THC have been reported from paleo-climatic records, and it is currently discussed whether greenhouse warming may have a serious impact on the stability of THC.

The North Atlantic sea surface temperature (SST) varied on a wide range of timescales during the last century. It has been pointed out that the short-term interannual variations are driven primarily by the atmosphere, while the long-term multi-decadal changes are forced by variations in ocean dynamics, specifically variations in the THC. The latter is supported by simulations with global climate models which show that variations in the THC lead to characteristic large-scale North Atlantic SST anomalies which cause climate anomalies that extend into Europe.

We have explored the dynamics and predictability of the North Atlantic/European climate variability on multi-decadal timescales initially using an extended-range integration with a global climate model from the Max-Planck-Institute for Meteorology. The model simulates the present-day climate of the North Atlantic/European region realistically. The climate model's mean thermohaline circulation is consistent with observations, with a maximum strength of about 20 Sv (1 Sv (Sverdrup) =  $10^6 \text{ m}^3/\text{s}$ ) and a northward heat transport of about 1 PW (1 PW (Petawatt) =  $10^{15} \text{ W/m}^2$ ) at  $30^\circ\text{N}$ . The model simulates pronounced multi-decadal variability in North Atlantic SST. Its thermohaline circulation and North Atlantic SST are closely related to each other. Specifically, the strength of the meridional overturning at  $30^\circ\text{N}$ , an index of the North Atlantic THC, correlates almost perfectly with the North Atlantic SST at timescales beyond several years. This suggests indeed that the multi-decadal SST fluctuations are driven by ocean dynamics and not by the atmosphere through anomalous air-sea heat exchange.

The close connection between THC strength and SST can be used to either reconstruct past changes of the THC from SST observations or to monitor the state of the THC in the future.

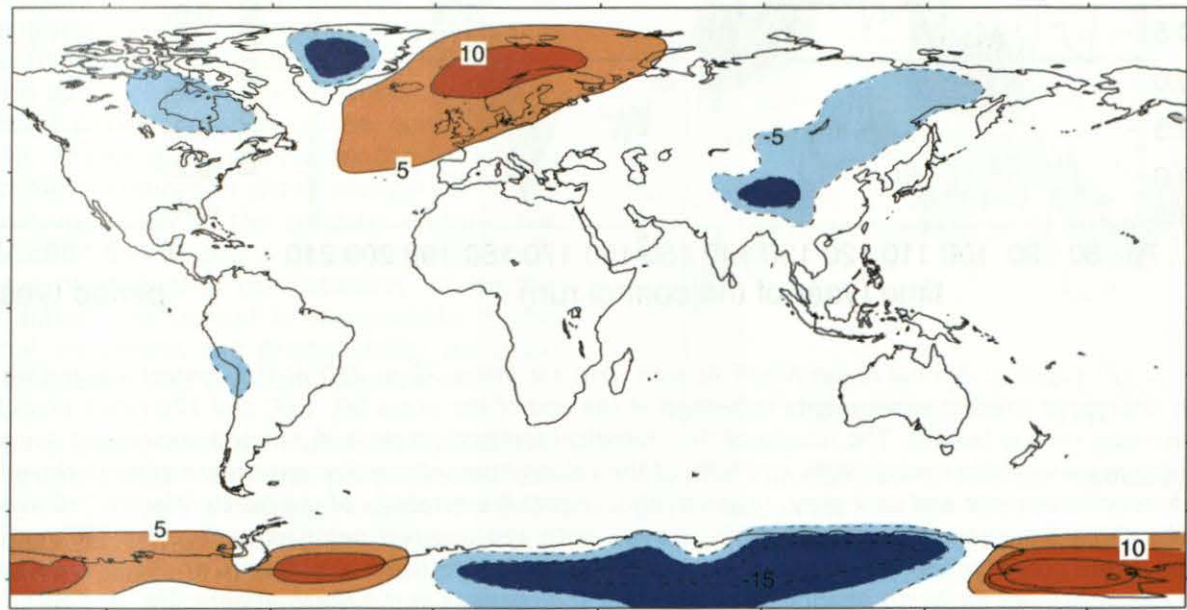


Figure 1: The deviation of annual mean surface air temperature from the latitudinal (zonal) average. Please note that northern Europe is much warmer relative to the zonal mean temperature, which demonstrates partly the impact of the THC on European climate.

### 3. Scientific Highlights

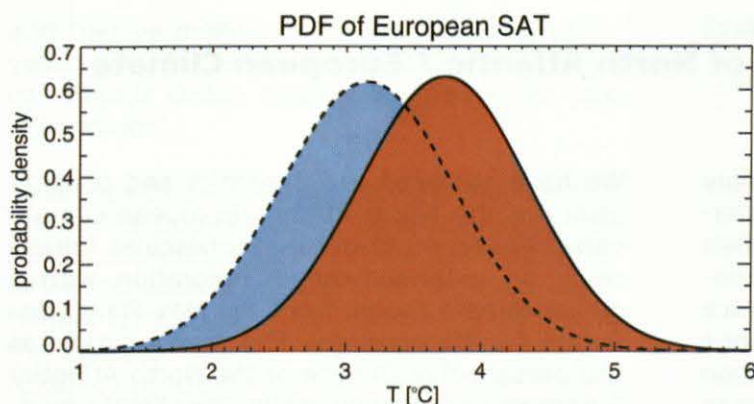


Figure 2: Fitted probability density functions (PDFs) of the European surface air temperature for years with strong (red/solid) and weak (blue/dashed) THC. A threshold value of  $\pm 0.44$  standard deviations has been used.

If the model mimics the real relationship between THC and SST correctly, the observed changes in North Atlantic SST during the last century can be interpreted as changes in the THC strength: Decade-long positive anomalies in the North Atlantic SST index can be regarded as indicators for an anomalously strong THC and vice versa. In particular, the strong cooling during the period 1960-1990 may just as well be related to an anomalously weak THC resulting from an internal oscillation rather than to anthropogenic factors.

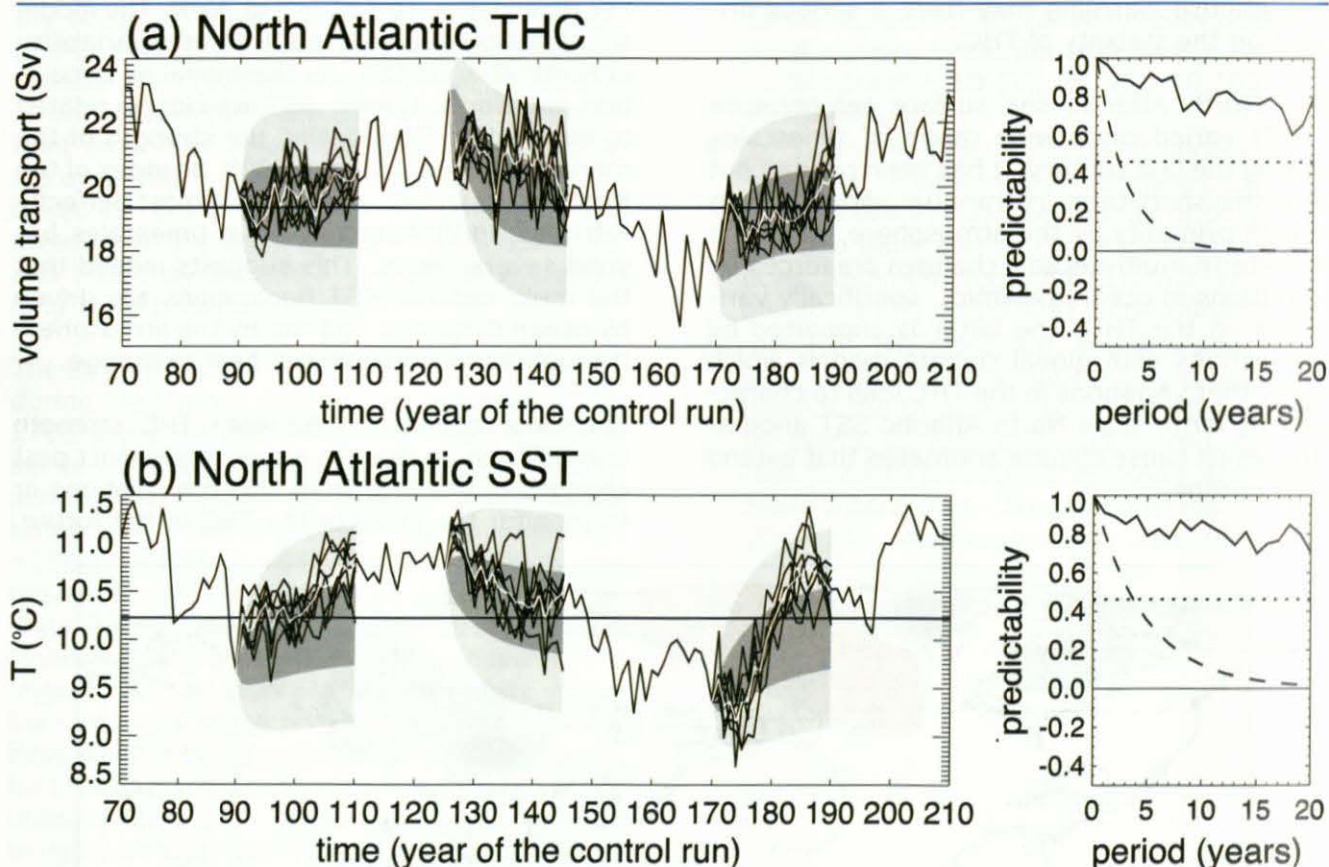


Figure 3: (a) (upper): Annual mean North Atlantic THC for years 70 to 210 of the control integration (thin black); ensemble forecast experiments initialised at the end of the years 90, 125, and 170 (thick black); and the ensemble means (white). The results of the statistical forecast method of damped persistence are shown as the range expected to contain 90% and 50% of the values from infinite size ensembles of noise driven AR-1 random processes (light and dark grey, respectively). (right) Predictability of the North Atlantic THC averaged over the three ensemble experiments (solid curve), with the damped persistence forecast (dashed) as a function of the prediction period. Additionally, the 95% significance level according to an F test is dotted. (b) (lower) As in (a), but for North Atlantic SST. Note that the changes in the North Atlantic THC and SST indices are predictable a few decades ahead.

The next question that was addressed is the impact of the multi-decadal THC variations on European climate. It is found that the probability density functions (PDFs) of surface air temperatures and precipitation over Europe are significantly affected by the multi-decadal variability of the North Atlantic THC (Fig. 2). An anomalously strong North Atlantic THC coincides with a strong northward heat transport in the North Atlantic. During such conditions the European surface air temperature is enhanced, which yields, for instance, fewer frost and more hot days. Thus some useful decadal climate predictability may exist in the Atlantic/European sector.

The close relationship between SST and THC implies that the SST variations may be predictable at decadal timescales. In order to explore the predictability of the SST, an ensemble of classical predictability experiments was conducted with the global climate model. Three states from the control integration were chosen, the atmospheric initial conditions perturbed and the model restarted. The oceanic initial conditions were not perturbed, so that the predictability estimates may be regarded as upper limits of the predictability. Each perturbation experiment has a duration of 20 years, and an ensemble of 6 perturbation experiments for each of the three initial states was conducted. This yields a total integration time of 360 years.

The results of the predictability experiments are summarised in Figure 3. A predictability measure  $P$  was defined as  $P = 1 - (E/C)$ . Here  $E$  is the variance between the ensemble members and  $C$  the variance of the control integration. If the spread between the individual ensemble members is small compared to the internal variability of the coupled system, the predictability measure is close to unity, indicating a high level of predictability. If, on the other hand, the spread is comparable to the internal variability, the predictability measure is close to zero and predictability is lost.

The time series of North Atlantic THC of the control integration and the predictability experiments are shown together with the predictability in Figure 3a. The skill in predicting the North Atlantic THC is clearly better than that of the damped persistence forecast and exceeds the 95% significance level over the whole prediction period of 20 years. The skill in predicting the North Atlantic SST is also sig-

nificant at the 95% significance level over the whole prediction period of 20 years (Fig. 3b) and comparable to that of the North Atlantic THC. The predictability experiments indicate that the North Atlantic THC and SST are predictable even at multi-decadal timescales.

The SST anomaly pattern associated with the THC variability can also be used as a fingerprint to detect future changes in THC intensity. Many authors have reported a weakening of the THC in global warming simulations which may have strong impacts on the climate of the North Atlantic/European sector. However, it is unclear how such a change in THC intensity can be observed. The model results suggest that an easy means to monitor the THC strength is by observing Atlantic SSTs. However, in the presence of global warming, a differential SST index which measures the contrast between the North and South Atlantic has to be used. In order to test this hypothesis, an additional ensemble of three greenhouse warming simulations was conducted (Fig. 4). For this purpose the climate model was initialised from different states of the control integration that are 30 years apart from each other (years 30, 60 and 90), and the atmospheric  $\text{CO}_2$  content was increased by 1% per year (compound). The results are analysed for the longest integration (110 years), initialised in year 60 in which the

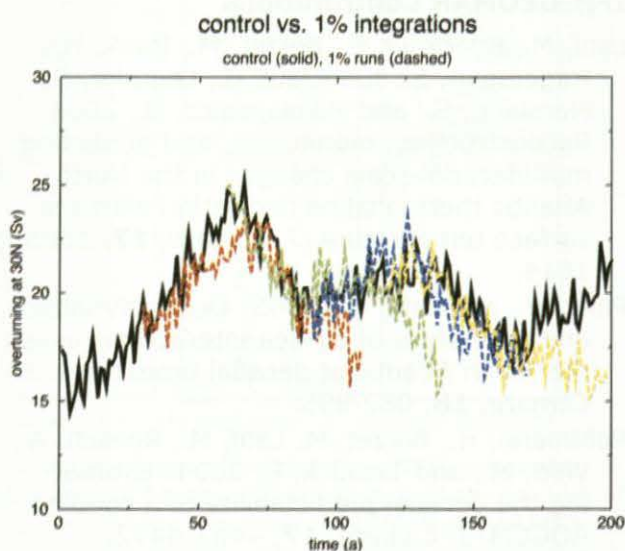


Figure 4: Time series of the annual mean anomalies of the maximum overturning (Sv) at 30°N in the control integration (black line) and in the greenhouse warming simulations (coloured lines). Note that the evolutions in the greenhouse warming simulations closely follow those of the control integration for several decades, indicating a very high level of THC predictability.

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CO<sub>2</sub> concentration triples, and they confirm the hypothesis that changes in THC strength can be seen in the differential Atlantic SST index.

The results also show that the THC evolution in the greenhouse warming simulations closely follows that of the control run for some decades before diverging from it (Fig. 4). This behavior is markedly different from that of global mean surface temperature which exhibits a rather monotonic increase in all members. This implies a strong sensitivity to initial conditions but also a great deal of predictability of the multi-decadal variability in the North Atlantic, provided the initial state is well known. These results are consistent with our classical predictability experiments discussed above. Furthermore, our results imply that anthropogenically forced changes in THC strength may be masked for quite a long time by the presence of the internal multidecadal variability. The next several decades may therefore be dominated by the internal multi-decadal variability, and we have to consider a joint initial/boundary value problem when assessing how the THC will evolve during this century. Greenhouse gas simulations should therefore be properly initialised using present-day ocean conditions and they should be conducted in ensemble mode to assess the uncertainty.

#### IFM-GEOMAR Contributions

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- Park, W., and Latif, M., 2005: Ocean dynamics and the nature of air-sea interactions over the North Atlantic at decadal timescales. *J. Climate*, **18**, 982-995.
- Pohlmann, H., Botzet, M., Latif, M., Roesch, A., Wild, M., and Tschuck, P., 2004: Estimating the decadal predictability of a coupled AOGCM. *J. Climate*, **17**, 4463-4472.
- Pohlmann, H., Sienz, F., and Latif, M., 2005: Influence of the multidecadal Atlantic meridional overturning circulation variability on European climate. *J. Climate*, in press.

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