

**Influence of the multidecadal Atlantic meridional overturning circulation variability
on European climate**

Holger Pohlmann¹, Frank Sienz¹, and Mojib Latif²

¹ Max-Planck-Institut für Meteorologie, Hamburg, Germany

² Leibniz-Institut für Meereswissenschaften, Kiel, Germany

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Corresponding author:

Holger Pohlmann

Max-Planck-Institut für Meteorologie

Bundesstr. 53

D-20146 Hamburg

Germany

email: holger.pohlmann@dkrz.de

Abstract

The influence of the natural multidecadal variability of the Atlantic meridional overturning circulation (MOC) on European climate is investigated using a simulation with the coupled atmosphere-ocean general circulation model ECHAM5/MPI-OM. The results show that Atlantic MOC fluctuations, which go along with changes in the northward heat transport, in turn effect European climate. Additionally, ensemble predictability experiments with ECHAM5/MPI-OM show that the probability density functions of surface air temperatures in the North Atlantic/European region are affected by the multidecadal variability of the large-scale oceanic circulation. Thus, some useful decadal predictability may exist in the Atlantic/European sector.

1. Introduction

One important role of the large-scale oceanic circulation for climate is the transport of heat. The meridional overturning circulation (MOC) describes the zonally averaged oceanic circulation. The Atlantic MOC consists on a wind driven part and the thermohaline circulation (THC). Although both the Pacific and Atlantic have strong northward-flowing surface currents at their western margins (Kuroshio in the Pacific and Gulf Stream in the Atlantic) only in the Atlantic, which is much saltier than the Pacific, the oceanic water gets dense enough in high latitudes to initiate deep convection. This drives the Atlantic THC, a part of the great conveyor belt (Broecker 1991). Trenberth and Solomon (1994) regard the meridional heat transport of the atmosphere and ocean of unique importance. The recent estimation of Trenberth and Caron (2001) attributes the

atmosphere having a much greater dominance. In their study the atmospheric transport accounts at 35°N for 78% of the total meridional heat transport on the Northern Hemisphere. Seager et al. (2002) take the occasion to criticize the responsibility of the Gulf Stream for European's mild winters at all. However, sea surface temperature (SST) in the northern North Atlantic is warmer than in the northern North Pacific at the same latitudes (Manabe and Stouffer 1999a). One way of estimating the effect of the THC on climate is to switch it off in coupled atmosphere-ocean general circulation models (AOGCMs). The results show a cooling over the Nordic Seas (e.g., Schiller et al. 1997, Manabe and Stouffer 1999b, Vellinga and Wood 2002), but the magnitude depends on the AOGCM considered. In most models the temperatures over northern Europe decrease by several degrees. Furthermore, a collapse of the Atlantic THC in response to global warming is discussed (Broecker 1987, Manabe and Stouffer 1993, 1994, Weaver and Hillaire-Marcel 2004). The abrupt climate change associated with the collapse of the Atlantic THC might even be irreversible (Alley et al. 2003). More likely than a breakdown of the THC seems to be a weakening as simulated by many coupled climate models (e.g., Rahmstorf 1999, Wood et al. 1999, Latif et al. 2000). This study, however, focuses on the influence of the internally generated multidecadal Atlantic MOC variability on European climate. Observational data of the Atlantic MOC are rare. The existing observations give an estimate of the current strength of the MOC (Ganachaud and Wunsch 2000) but not of its past evolution. Climate model simulations provide a measure to estimate the MOC variability, its predictability and influence on climate.

2. Model and experiments

The coupled AOGCM used in this study is the European Centre Hamburg version 5 / Max Planck Institute Ocean Model (ECHAM5/MPI-OM) (Latif et al. 2004). The atmospheric component, ECHAM5 (Roeckner et al. 2003), is run at a spectral T42 resolution with 19 vertical layers. The oceanic component, MPI-OM (Marsland et al. 2003), is run on a bipolar orthogonal spherical coordinate system with equatorial refinement and 23 vertical levels. A dynamic/thermodynamic sea ice model and a river runoff scheme are included in this model. The components are coupled without the use of flux adjustments. A 500 year long control integration with greenhouse gases fixed to values of the 1990s is used to investigate the influence of the Atlantic MOC on European climate. Additionally, ensemble experiments are used to estimate the predictability of European climate. Started from the control integration, three different years (90, 125 and 170) corresponding to intermediate, strong, and weak Atlantic MOC conditions, are selected and used as initial conditions for three ensemble predictability experiments. Each ensemble consists on six ensemble members realized with slightly perturbed atmospheric initial conditions. The ensemble predictability experiments are integrated over a period of 20 years.

3. Results

The Atlantic MOC is strongest at 30°N in the ECHAM5/MPI-OM control integration. Figure 1 shows the anomalies of the maximum of the Atlantic MOC together with the anomalies of the oceanic heat transport (OHT) at this latitude. The first period (80 years) of the integration is characterized by the spin-up of the coupled system and therefore not

considered. However, rather strong MOC fluctuations with a period of 70-100 years (Pohlmann et al. 2004) are also apparent in the following centuries. The strength of the overturning circulation is related to the convective activity in the deep-water formation regions, most notable the Labrador Sea, which is sensitive to fresh water anomalies from the Arctic (Jungclaus et al. 2004). MOC fluctuations go along with changes in the northward heat transport and have therefore the potential to influence North Atlantic/European climate. The influence of the Atlantic MOC on European climate cannot be strictly separated from that of the North Atlantic Oscillation on interannual timescales. However, on longer timescales the North Atlantic MOC variability leads European climate variability, which indicates an influence from the ocean to the atmosphere (not shown).

The influence of the Atlantic MOC on European surface air temperature (SAT) is investigated by calculating the probability density functions (PDFs) of European SAT for strong and weak overturning conditions. Figure 2 shows the fitted PDFs of European SAT averaged over the region 35°-75°N, 10°W-40°E for years in which the maximum Atlantic MOC anomalies at 30°N exceed ± 0.44 standard deviations (i.e., a third of the years as the data are Gauss distributed), respectively. In the case of weak MOC conditions the SAT averaged over Europe is colder than in the case of strong MOC conditions, and vice versa. The difference of the mean European SAT for these two cases amounts to 0.5K. The two distributions are significantly different at the 95% level according to a Kolmogorov-Smirnov test.

The regional patterns of the influence of the North Atlantic MOC on European climate are presented in Figure 3. Years with anomalously strong and weak Atlantic MOC conditions are defined, as above, as exceeding ± 0.44 standard deviations, respectively. The differences of the mean SAT and precipitation between high and low phases of the MOC are based on annual means, which are available from the complete control run. The differences of the mean frost and summer days are calculated from daily means, which are processed from daily maximum and minimum SAT for a 100 year segment of the control integration. The difference of the mean SAT between years with strong and weak MOC conditions is strongest in the Baltic region with values up to 1K. Additionally, a separate analysis based on seasonal means shows that the differences are strongest in winter. Strong anomalies of the Atlantic MOC are associated with enhanced northward oceanic heat transports, which generally lead to increased atmospheric temperatures over the North Atlantic/European region. The difference of the mean precipitation between strong and weak MOC conditions displays a north – south orientated dipole with an enhancement over northern Europe and a reduction in southern and eastern Europe. Strongest increases are present in southern Norway and strongest decreases on the Iberian peninsula and around the Adriatic Sea with values up to 4 mm/month. An enhanced MOC leads to a reduced number of frost days over the whole European continent. The reduction is strongest in western and northern Europe with a maximum of more than 12 days/year in Great Britain. The difference in summer days, defined as days reaching 25°C, between strong and weak MOC conditions displays a west – east orientated dipole with a reduction over western Europe of more than 3 days/year and an enhancement over eastern Europe up to 9 days/year.

The decadal Atlantic MOC predictability of the AOGCM ECHAM5/MPI-OM is shown in Pohlmann et al. (2004) using ensemble predictability experiments. In contrast to results with the AOGCM ECHAM3/LSG (Grötzner et al. 1999) the MOC variability is affecting North Atlantic SST north of 30°N resulting in SST predictability comparable to the MOC predictability. In this study a different method of predictability is applied to the same ensemble experiments, which estimates predictability in a probabilistic manner. This method is commonly used for seasonal forecasts and also to estimate decadal predictability (Collins and Sinha 2003). The probabilistic method decides, whether the ensemble mean is significantly shifted with respect to climatology. A shift to stronger (e.g., warmer) or weaker (e.g., colder) conditions is defined for the probabilistic forecast commonly by reaching the upper or lower tercile of the climatological PDF, which is equivalent to exceeding 0.44 standard deviations. The probability of this shift in the forecast ensemble gives a measure for predictability, which is by chance 33% for each case.

The probability of the SAT being in the warm tercile of the climatological PDF for the three ensemble experiments averaged over the first and second prediction decade are shown in Figure 4. In all experiments and in both prediction decades there exists predictability of SAT over parts of Europe. The experiments are started from intermediate, strong and weak Atlantic MOC conditions, which are associated with intermediate, warm, and cold SAT over the North Atlantic, respectively. The SAT anomalies over the North Atlantic mainly persist during the first, but not the second

prediction decade. Additionally, the probability of European SAT anomalies being in the warm tercile of the climatological PDF is in all three experiments higher in the second than in the first prediction decade.

We note one important caveat. The predictability experiments used in this study are idealized, since the initial oceanic conditions were not perturbed. This implies the assumption that the AOGCM could be initialized perfectly by ocean observations. Thus, since this is not possible, we show here only the usefulness of decadal forecasts with respect to European climate.

4. Summary and Discussion

The experiments with the AOGCM ECHAM5/MPI-OM indicate an influence of the internal multidecadal variability of the Atlantic MOC on European climate. Strong overturning conditions coincide with strong northward heat transports in the Atlantic. During such conditions the European SAT is enhanced, and the number of frost days per year are reduced. The precipitation is enhanced in northern and decreased in southern Europe. The number of summer days per year is decreased in western and increased in eastern Europe.

Although predictability measured by classical measures is mostly restricted to oceanic regions in ECHAM5/MPI-OM (Pohlmann et al. 2004), the probability density functions of SAT and precipitation are significantly affected by the large-scale oceanic circulation changes also over Europe. Thus some useful decadal predictability of economic value

may exist in the Atlantic/European sector. To exploit this decadal predictability, however, a suitable oceanic observing system must be installed, since the memory of the climate system resides in the North Atlantic Ocean. In particular, the North Atlantic MOC should be monitored carefully, since its variations are most interesting in the light of decadal predictability.

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Figure 1. Time series of the Atlantic MOC (black) and OHT (red) anomalies at 30°N of the ECHAM5/MPI-OM control integration starting at year 80. The mean of the Atlantic MOC amounts to 19 Sv ($1\text{Sv}=10^6 \text{ m}^3\text{s}^{-1}$) and that of the Atlantic OHT is 0.8 PW ($1\text{PW}=10^{15}\text{W}$). The data are detrended prior to the analysis. The thick curves are the corresponding 11-year running means, used to low pass filter the data.

Figure 2. Fitted probability density functions (PDFs) of the European SAT for years with strong (red/solid) and weak (blue/dashed) anomalies of the North Atlantic MOC, defined as exceeding ± 0.44 standard deviations, respectively.

Figure 3. Difference of (a) SAT [$^{\circ}\text{C}$], (b) precipitation [mm/month], and days per year with temperature (c) below 0°C and (d) over 25°C over Europe between years with strong and weak Atlantic MOC conditions exceeding ± 0.44 standard deviations.

Figure 4. Probability of SAT anomalies being in the warm tercile of the climatological PDF (equivalent to exceeding of 0.44 standard deviations) averaged over the first (left column) and second (right column) prediction decade and the first (top), second (middle), and third (bottom) ensemble experiment.

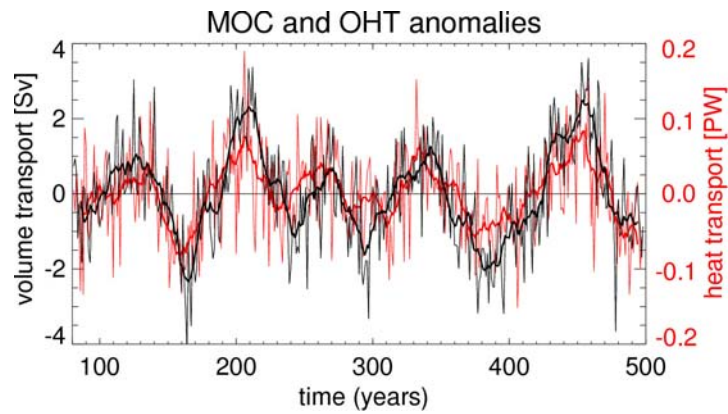


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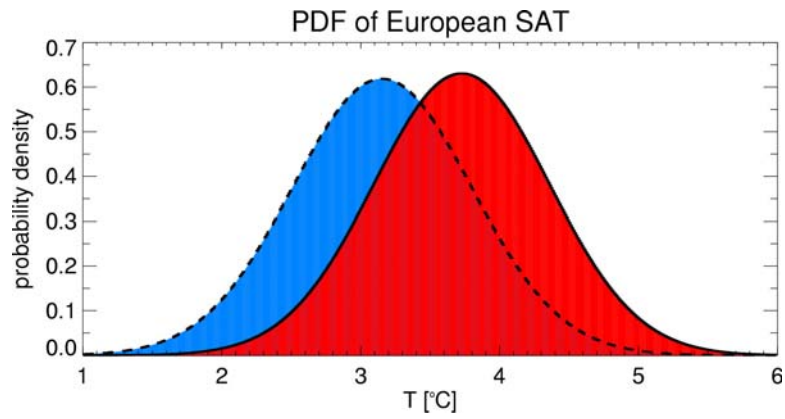


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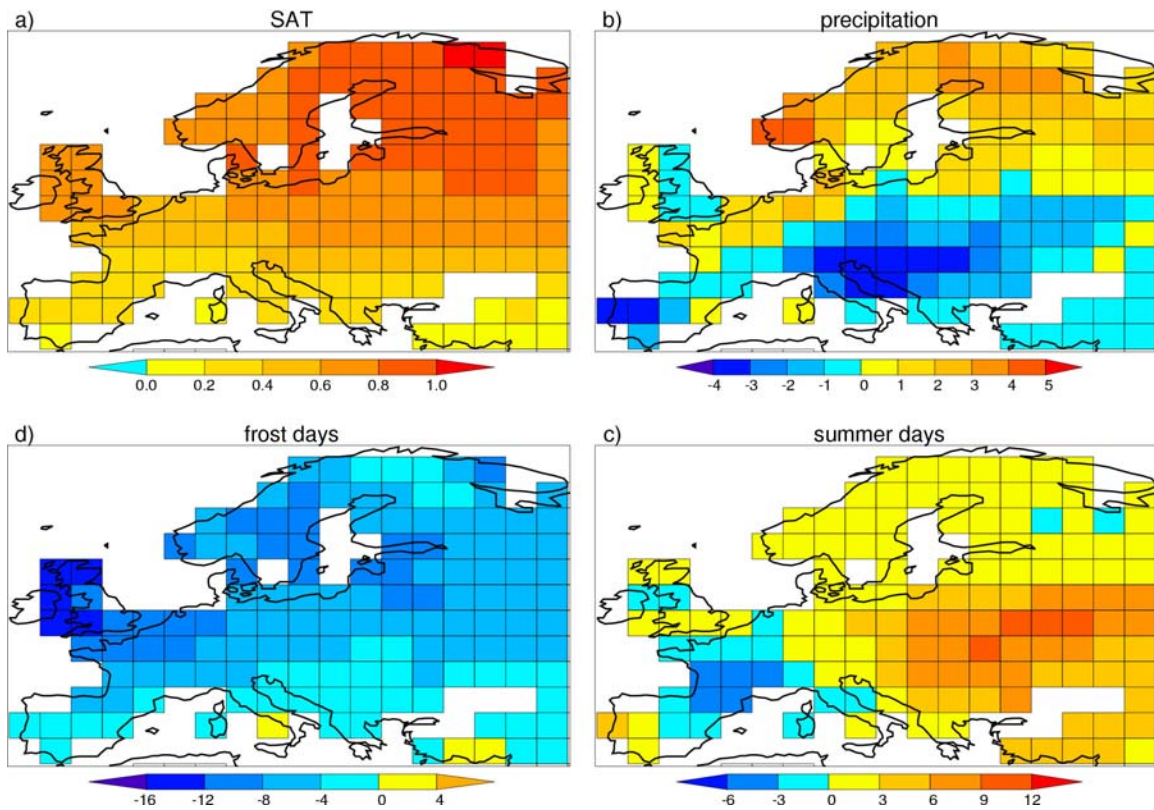


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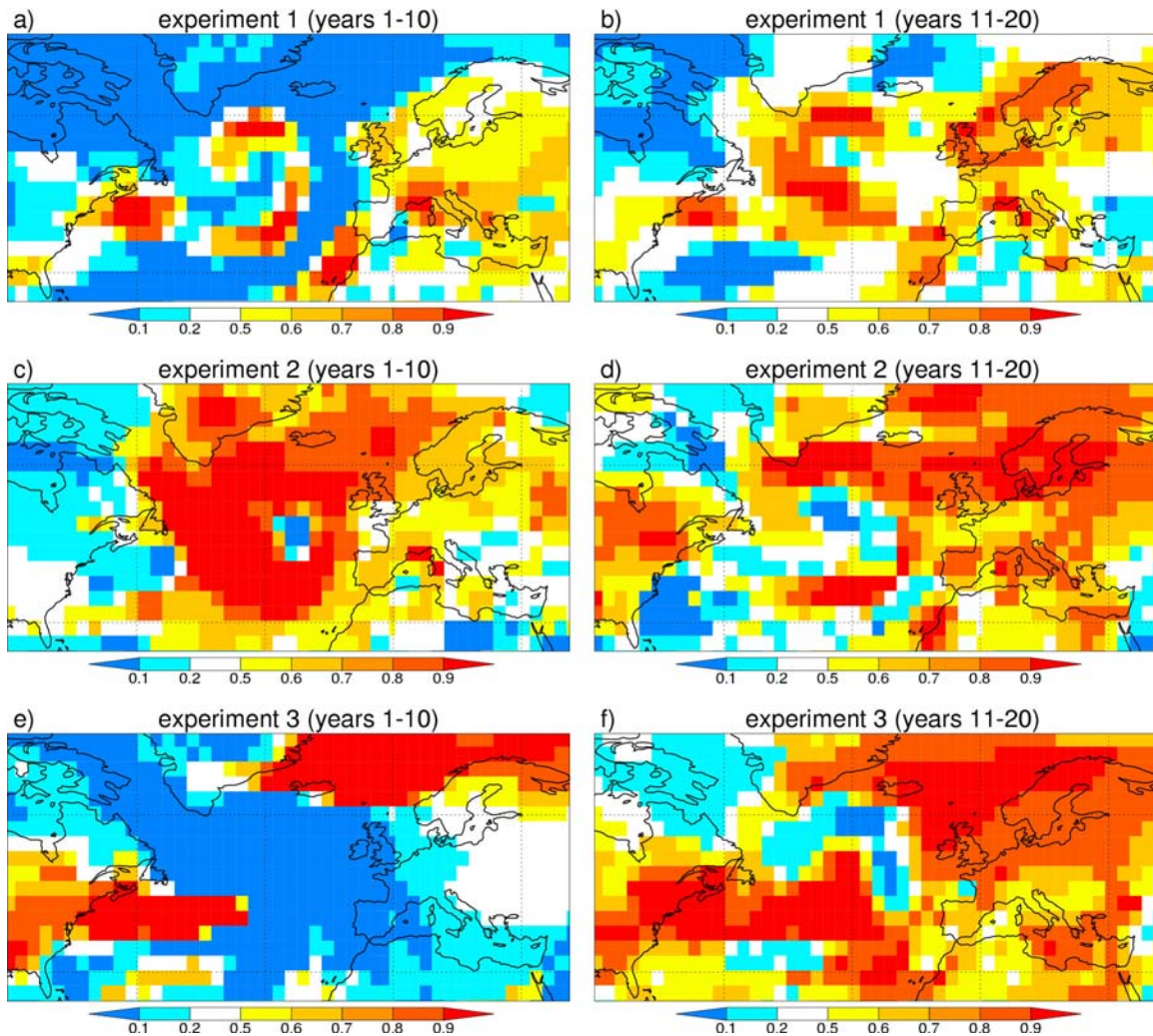


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