NOTES AND CORRESPONDENCE

Influence of the Multidecadal Atlantic Meridional Overturning Circulation Variability on European Climate

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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/Max Planck Institute Ocean Model (MPI-OM). The results show that Atlantic MOC fluctuations, which go along with changes in the northward heat transport, in turn affect 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 of 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, does 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). The global meridional temperature gradients are reduced partly by atmospheric and partly by oceanic heat transports. The recent estimation of Trenberth and Caron (2001) attributes the atmosphere with 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. 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. Furhermore, a collapse of the Atlantic THC in response to global warming is discussed (Broecker 1987; Manabe and Stouffer

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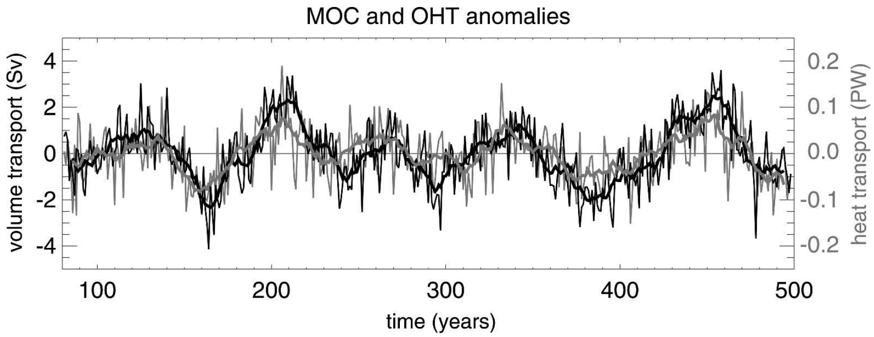

FIG. 1. Time series of the Atlantic MOC (black) and OHT (gray) anomalies at 30°N of the ECHAM5/MPI-OM control integration starting at year 80. The mean of the Atlantic MOC amounts to 19 Sv (1 Sv ≡ 10^6 m^3 s^{-1}) and that of the Atlantic OHT is 0.8 PW (1 PW = 10^{15} W). The data are detrended prior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

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). 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 have shown the predictability of the North Atlantic multidecadal climate variability (e.g., Griffies and Bryan 1997). In this study, however, the focus is on the influence of the multidecadal Atlantic climate variability on European 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, is formulated on a horizontal Arakawa C grid and uses geopotential vertical coordinates (Marsland et al. 2003). It is run on a bipolar orthogonal spherical coordinate system with 23 vertical levels. The poles are rotated to positions over Greenland and Antarctica to avoid the singularity at the North Pole. The grid has a nominal resolution of 2.8°. The actual resolution varies from about 10 km near Greenland and the Weddell Sea to more than 300 km in the Pacific. The meridional resolution is gradually increased between 10°N and 10°S to 0.5° at the equator. 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-yr-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, the same ensemble experiments as in Pohlmann et al. (2004) 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 of six ensemble members realized with slightly perturbed atmospheric initial conditions. The ensemble predictability experiments are integrated over a period of 20 yr.

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 yr) of the integration is characterized by the spinup of the coupled system and therefore is not considered. However, rather strong MOC fluctuations with a period of 70–100 yr (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 notably the Labrador Sea, which is sensitive to freshwater anomalies from the Arctic (Jungclaus et al. 2005). MOC fluctuations go along with changes in the northward heat transport and have therefore the potential to influence North Atlantic/European climate. Some evidence exists from a study with another climate model that changes

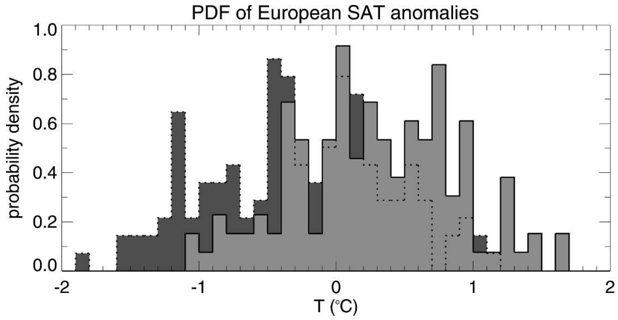

FIG. 2. PDFs of the European SAT anomalies for years with strong (light gray/solid) and weak (dark gray/dotted) anomalies of the North Atlantic MOC, defined as exceeding ±0.44 standard deviations, respectively.

in oceanic heat transports are compensated by changes in atmospheric heat transports (Shaffrey and Sutton 2006).

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 PDFs of European SAT anomalies 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 0.5 K. The two distributions are significantly different at the 95% level according to a Kolmogorov–Smirnov and a *t* test.

The regional patterns of the influence of the North Atlantic MOC on European climate are presented in Fig. 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-yr 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

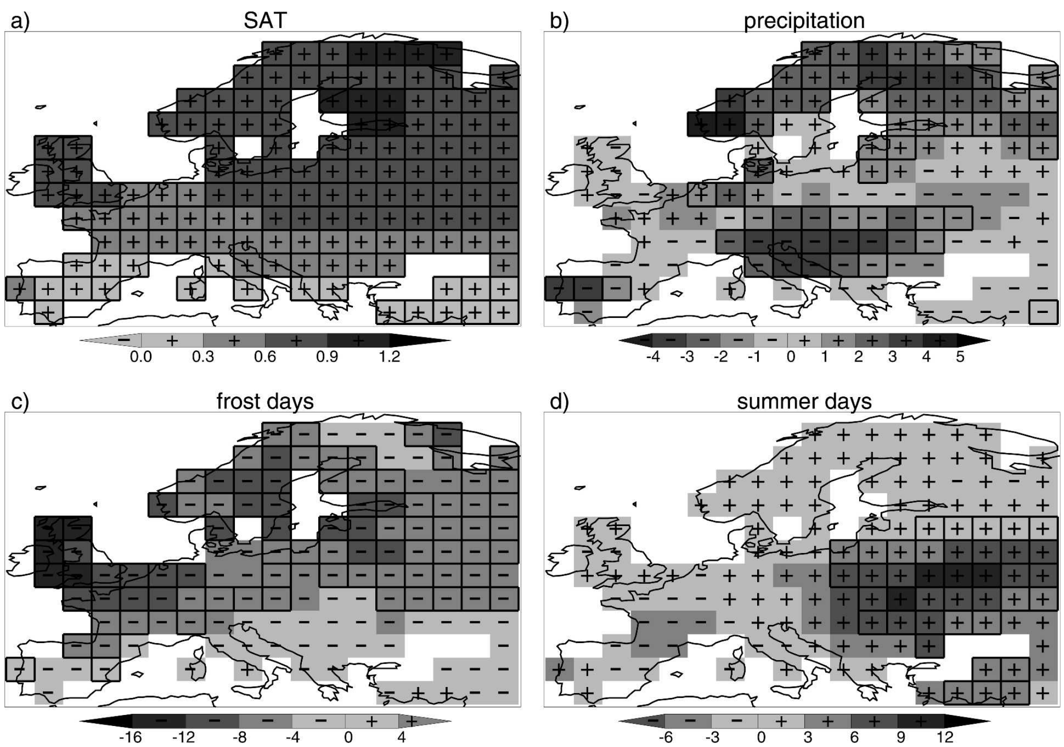

FIG. 3. Difference of (a) SAT (°C), (b) precipitation (mm month^{-1}), and days per year with temperature (c) below 0°C and (d) over 25°C over Europe between years with strong and weak Atlantic MOC conditions exceeding ±0.44 standard deviations. Grid cells where the differences are significant on the 95% level according to a *t* test are framed.

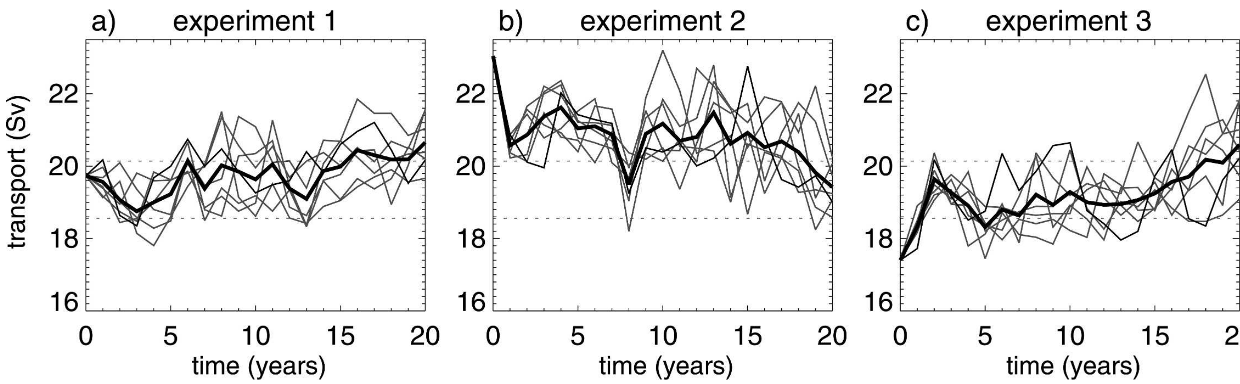

FIG. 4. Atlantic MOC of the control run (thin black curves) for the years 90–120, 125–145, and 170–190, respectively, together with ensemble predictability experiments started from the control simulation with slightly perturbed atmospheric initial conditions (thin gray curves) and the ensemble mean (thick black curves). The dotted lines represent the ±0.44 standard deviation range around the mean of the Atlantic MOC of the years 80–500 in the control run.

up to 1 K. 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 are present in the Iberian Peninsula and around the Adriatic Sea with values up to 4 mm $month^{-1}$. 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 yr^{-1} in Great Britain. The difference in summer days, defined as days reaching 25°C, between strong and weak MOC conditions shows a significant increase over eastern Europe of more than 9 days yr^{-1}.

The Atlantic MOC of the control run and the ensemble predictability experiments started from the control run with slightly perturbed atmospheric initial conditions are shown in Fig. 4. The experiments are started from intermediate, strong, and weak MOC conditions. The ensemble mean MOC of experiment 1 stays in the intermediate and that of experiment 2 in the strong range of the MOC variability of the control run. Toward the end of the 20-yr prediction period the ensemble mean MOC of experiments 1 and 3 show positive MOC anomalies while that of ensemble 2 shows an intermediate MOC. The predictability of the Atlantic MOC over the 20-yr prediction period is shown by Pohlmann et al. (2004). In contrast to results with the AOGCM ECHAM3/(Large-Scale Geostrophic ocean model) LSG (Grötzner et al. 1999), the MOC variability affects in ECHAM5/MPI-OM the 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 Fig. 5. 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 probability of European SAT anomalies being in the warm tercile of the climatological PDF is in all three experiments higher in the second then in the first prediction decade. This is in agreement with the tendency of the ensemble mean Atlantic MOC to stronger conditions in the second prediction decade in experiments 1 and 3. In experiment 2 the ensemble mean Atlantic MOC is on average considerably strong over both decades.

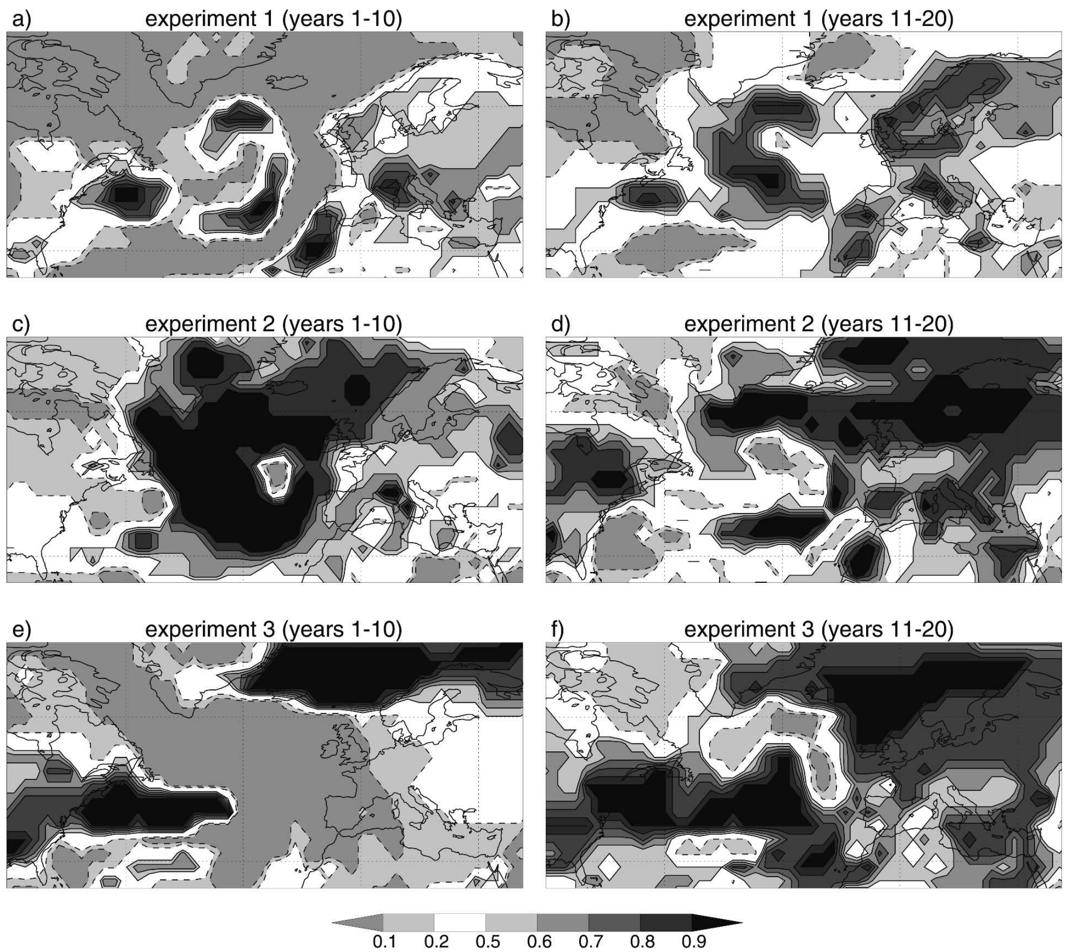

FIG. 5. Probability of SAT anomalies being in the warm tercile of the climatological PDF (equivalent to exceeding of 0.44 standard deviations) averaged over the (left) first and (right) second prediction decade and the (top) first, (middle) second, and (bottom) third ensemble experiment. Values below 0.2 are contoured with a dashed line, and values over 0.5 are contoured with a full line.

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 potential 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 is reduced. The precipitation is enhanced in northern and decreased in southern Europe, and the number of summer days per year is particularly increased in eastern Europe.

Although predictability measured by classical methods 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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