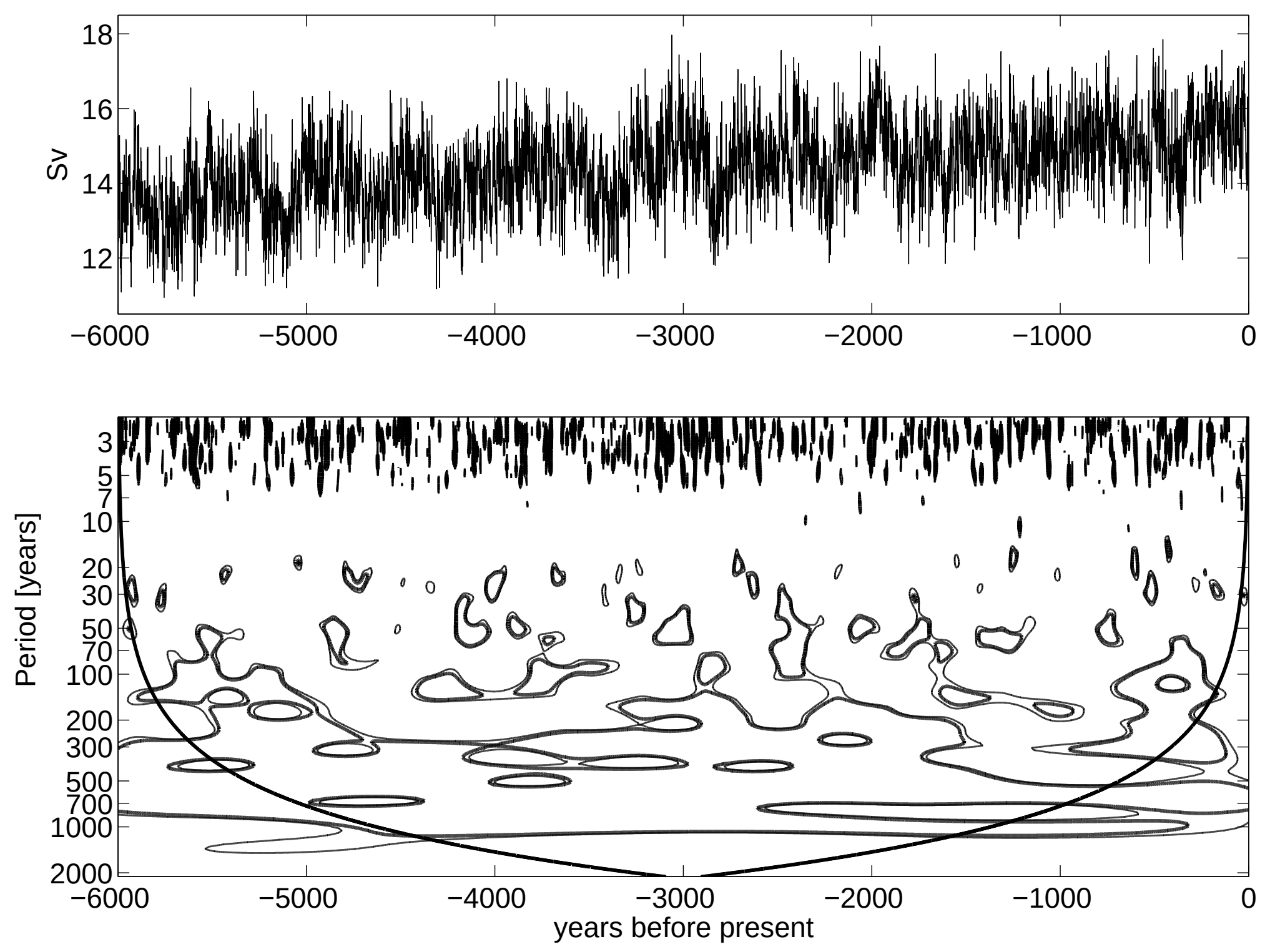
Evolution and Variability of Ocean Circulation in Holocene Simulations with the MPI-ESM

Nils Fischer[1,2] **and Johann H. Jungclaus**[1]
[1] Max Planck Institute for Meteorology, Hamburg, Germany, [2] International Max Planck Research School on Earth System Modelling Hamburg, Germany

1 Introduction

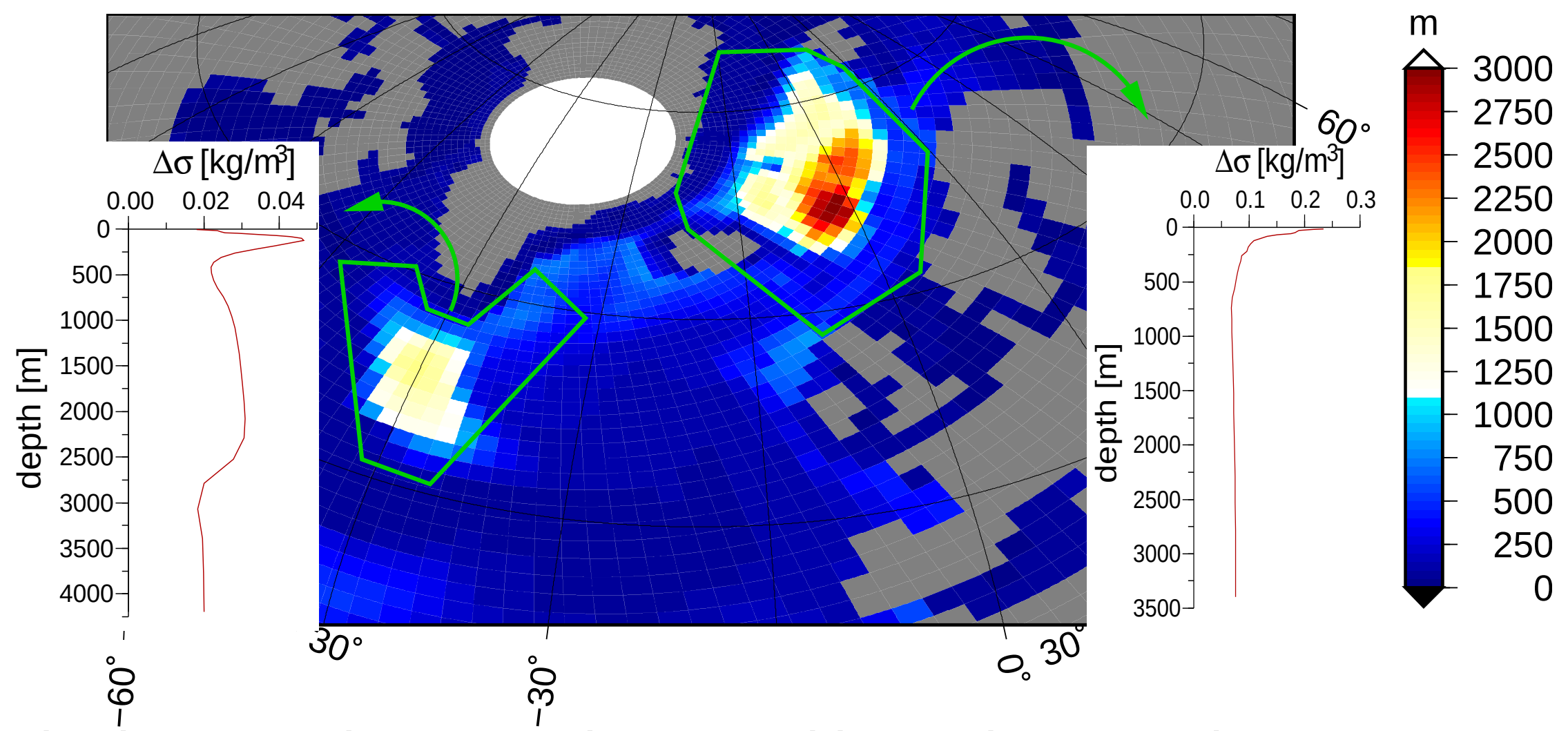
In the Atlantic, ocean circulation transports large amounts of heat from low- and mid latitudes to high latitudes which leads to comparably high temperatures in northern Europe. This heat transport is connected to the Atlantic meridional overturning circulation (AMOC), which brings warm and saline water from the tropics to high latitudes. Sparse temporal and spatial measurements of the AMOC limit a thorough understanding of its driving mechanisms. We approach the problem by analyzing results from a transient Earth-system-model experiment.

3 AMOC Evolution and Variability



The time-series of AMOC at 30°N, 1000 m depth (top) shows an overall increase from 14 to 16 Sv and variability from annual to multi-centennial time-scales. The wavelet transform (bottom) shows continuous significant variability (95% significance indicated by solid lines) on interannual and multi-centennial time-scales.

4 AMOC Increase

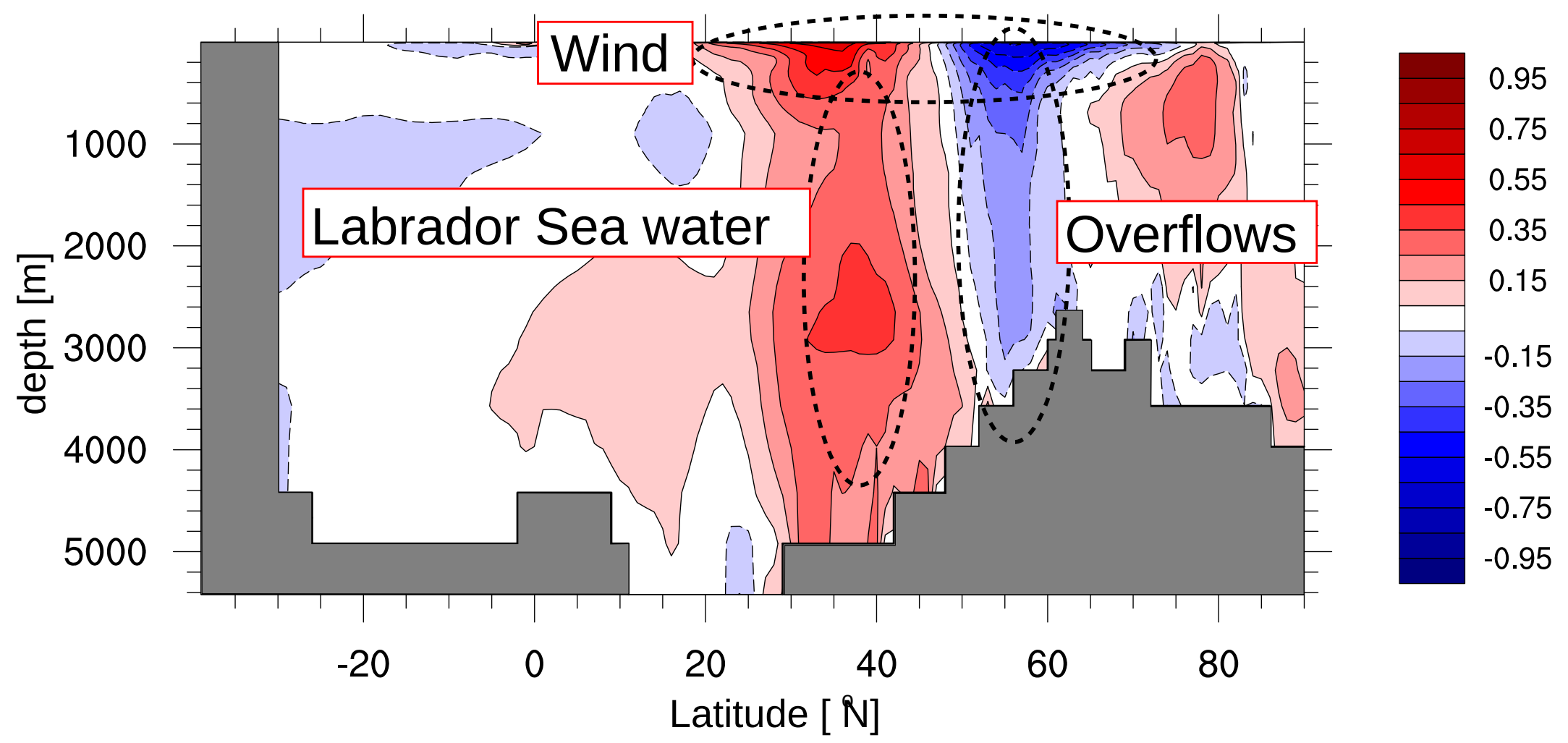


The increase in AMOC is caused by an increase in water mass density in the deep water formation regions in the Nordic Seas and the Labrador Sea region (green areas). The xy-plots show the density difference between the first and the last 1,000 years of the simulation in the depicted areas.

2 Experimental Set-Up

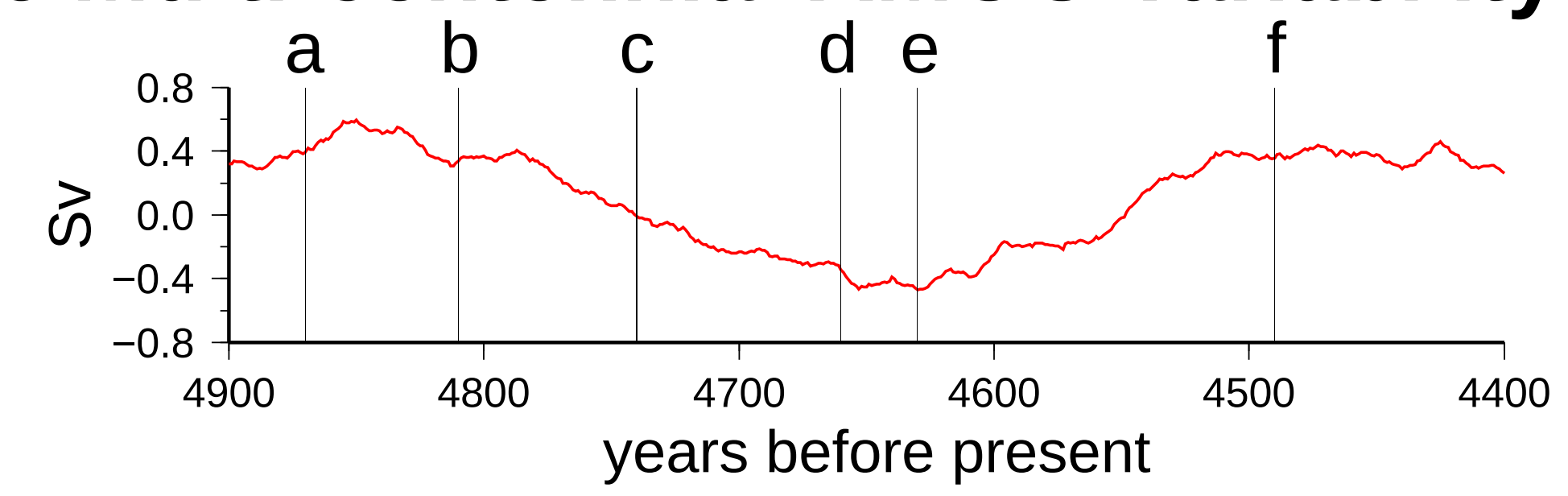
We perform a transient simulation of the last 6,000 years from the mid-Holocene to today with the coupled atmosphere-ocean general circulation model including a land surface model (ECHAM5/JSBACH/ MPIOM) with applied orbital forcing. The model resolution is 3.75° in the atmosphere and ≈3° in the ocean component, respectively. We investigate how changes in insolation forcing affect the overall AMOC strength and on what time-scales and amplitudes ocean circulation variability occurs.

5 Inter-annual AMOC Variability



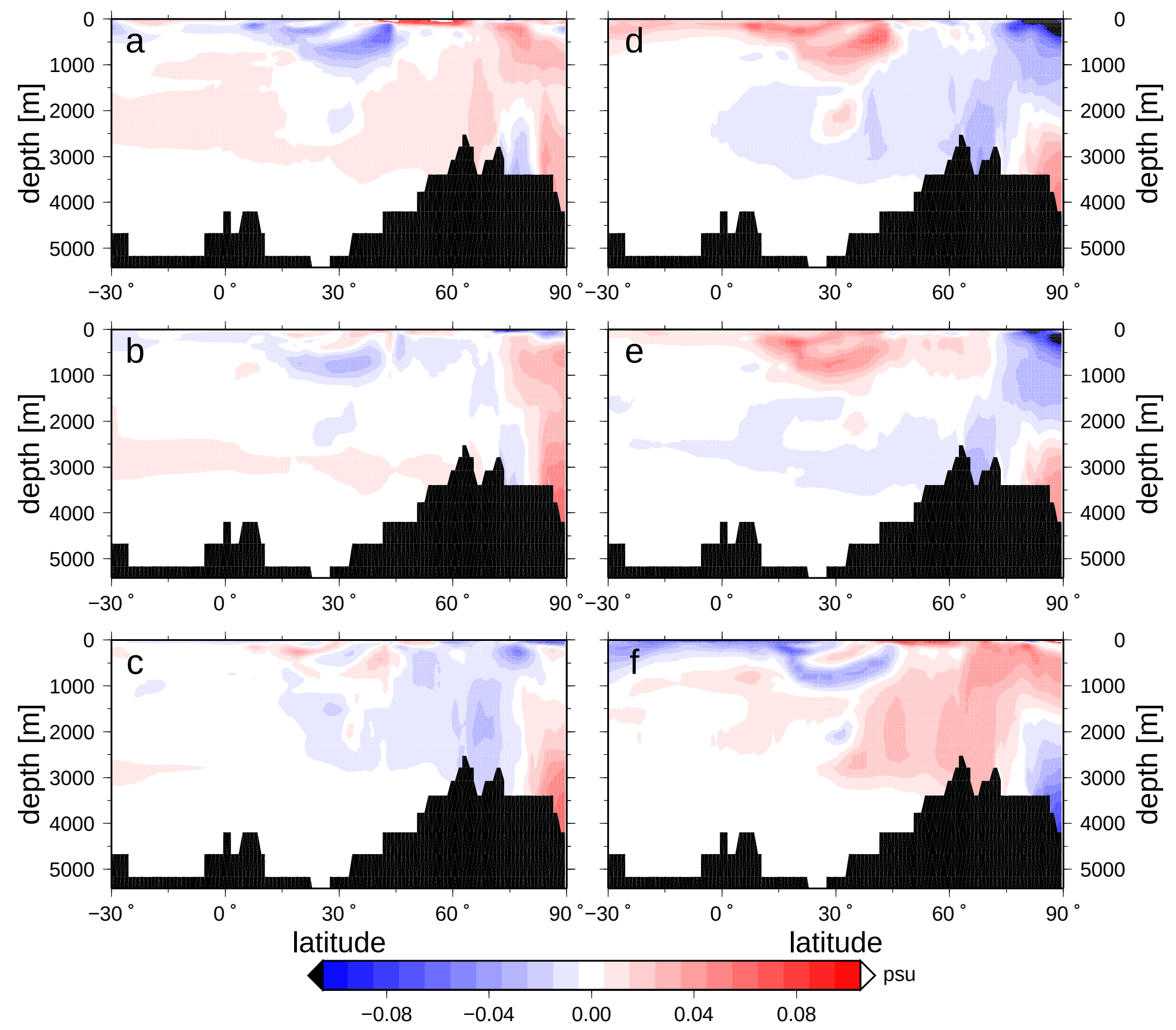
Interannual AMOC variability is dominated by the North Atlantic Oscillation (NAO). The Figure shows the correlation between the NAO-index and the 2D-streamfunction in the Atlantic basin at lag zero. At the surface between 30° and 60°N wind anomalies associated with the NAO+ phase strengthen the northern limb of the sub-tropical gyre and weaken the southern limb of the sub-polar gyre. Cold conditions over the Labrador Sea enhance winter convection causing a positive AMOC response around 35°N, whereas relatively fresh and warm conditions over the Nordic Seas cause a negative response of the overflow's contribution to AMOC at 60°N.

6 Multi-centennial AMOC Variability



The top figure shows a section of the AMOC-time-series detrended and with a 100-year running-mean applied.

The right figure shows the zonal mean salinity anomalies (100-year running mean) of the Atlantic basin at different snapshots marked from a to f in the time-series above. During a strong state of the AMOC positive salinity anomalies prevail in the deep water formation regions and are advected southwards in the deeper ocean. At the same time negative anomalies accumulate in the sub-tropical gyre region (a). After reaching a threshold these negative anomalies reach the deep water formation regions (b) and are convected to the deeper ocean (c) which leads to a slowdown of the AMOC. Now, positive anomalies accumulate in the sub-tropical gyre (d) that again reach the deep water formation region (e) and complete the cycle (f).

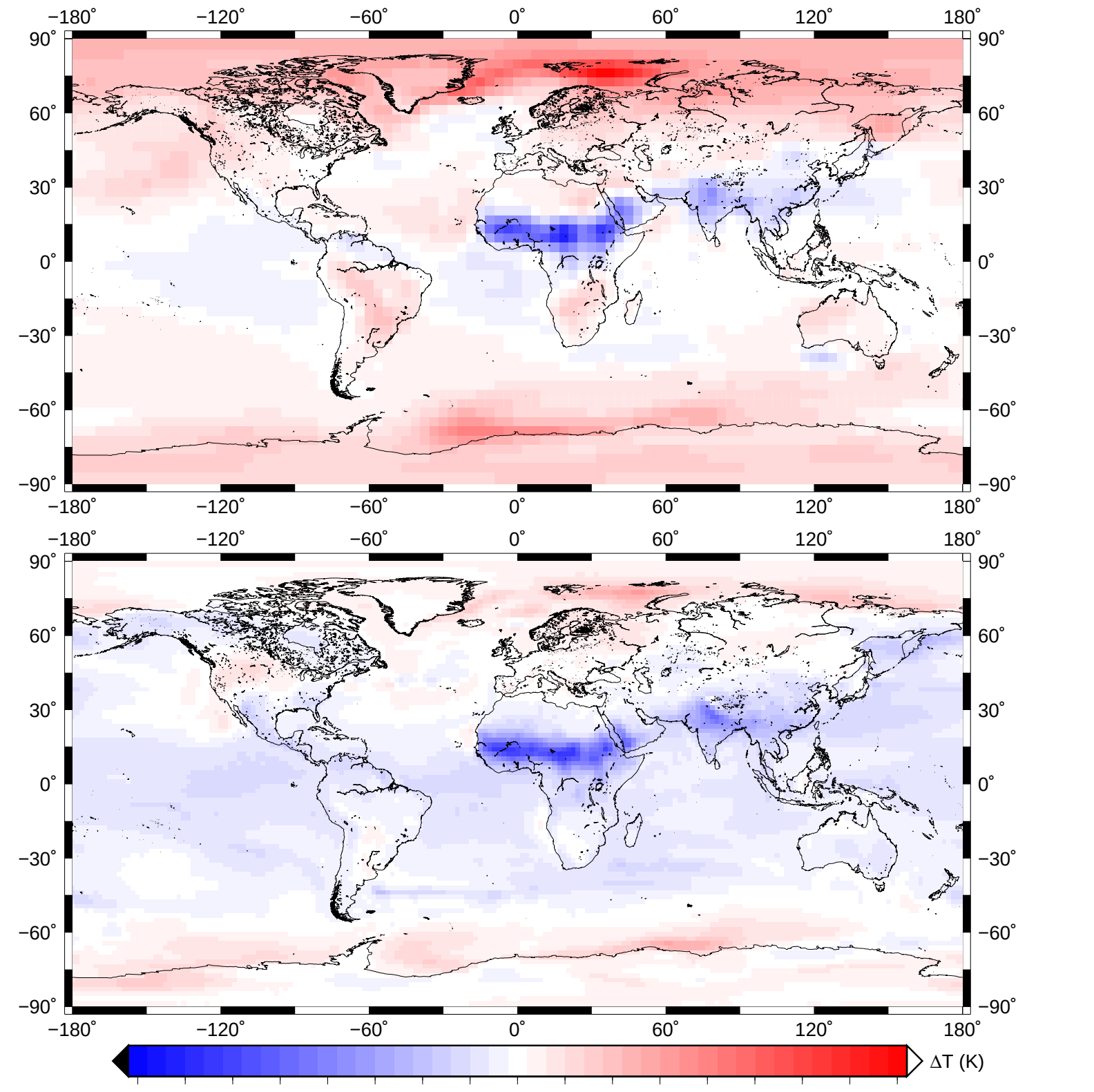


7 Preliminary Results from the CMIP5 Holocene Experiments with the new MPI-ESM

The CMIP5 model set-up for the MPI-ESM consists of the new version of the atmosphere general circulation model (GCM) ECHAM6 in resolution T63 with 47 vertical layers including the land surface model JSBACH coupled to the ocean GCM MPIOM in resolution GR15 with 40 vertical layers. Land vegetation is prescribed.

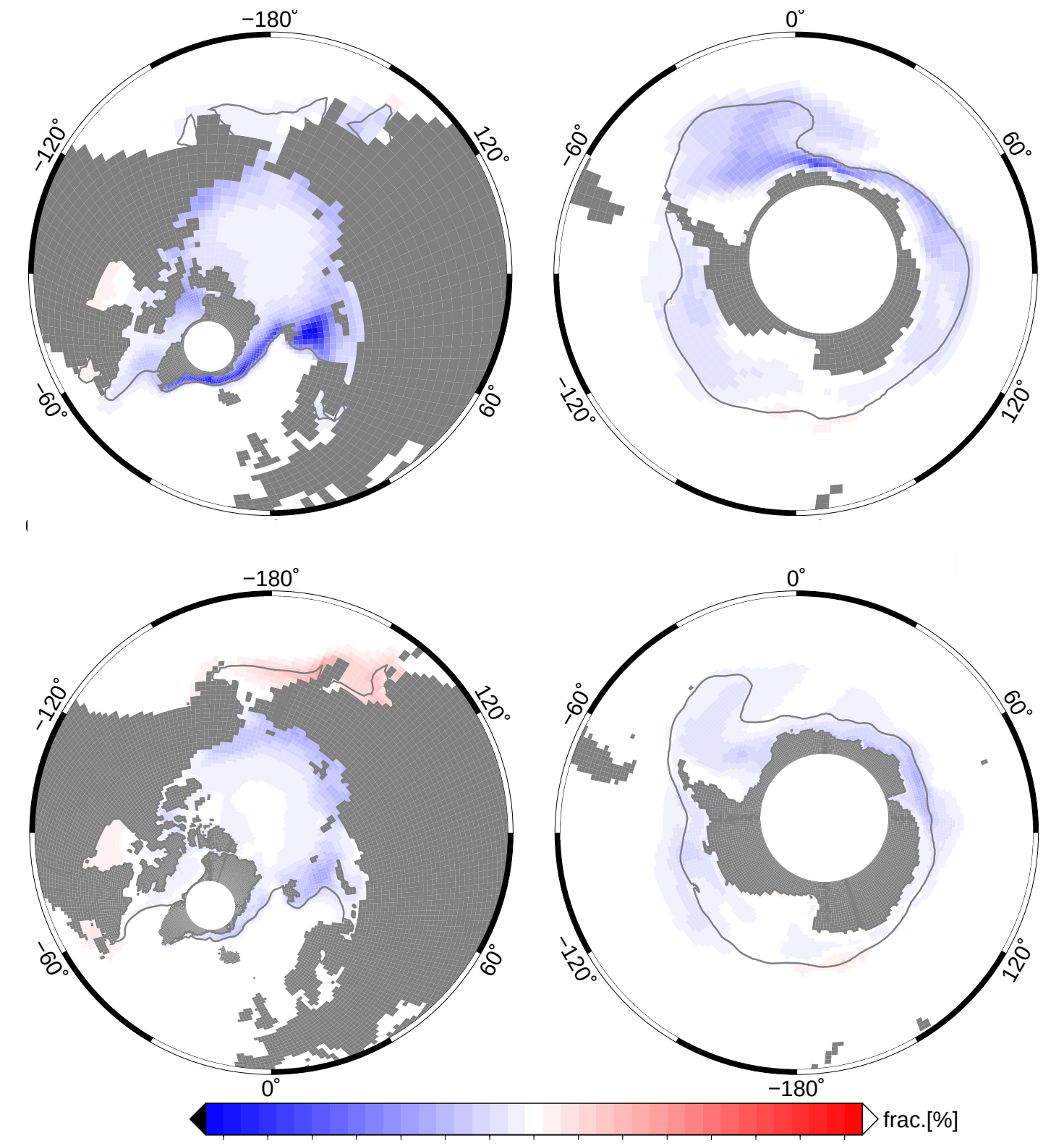
The comparison plots show differences in the time means of 100 years of the mid-Holocene minus the pre-industrial control time-slice simulations for both, the model version employed in the older study (top) and the CMIP5-set-up (bottom). In both model versions, only orbital forcing is applied.

Surface Temperature Difference



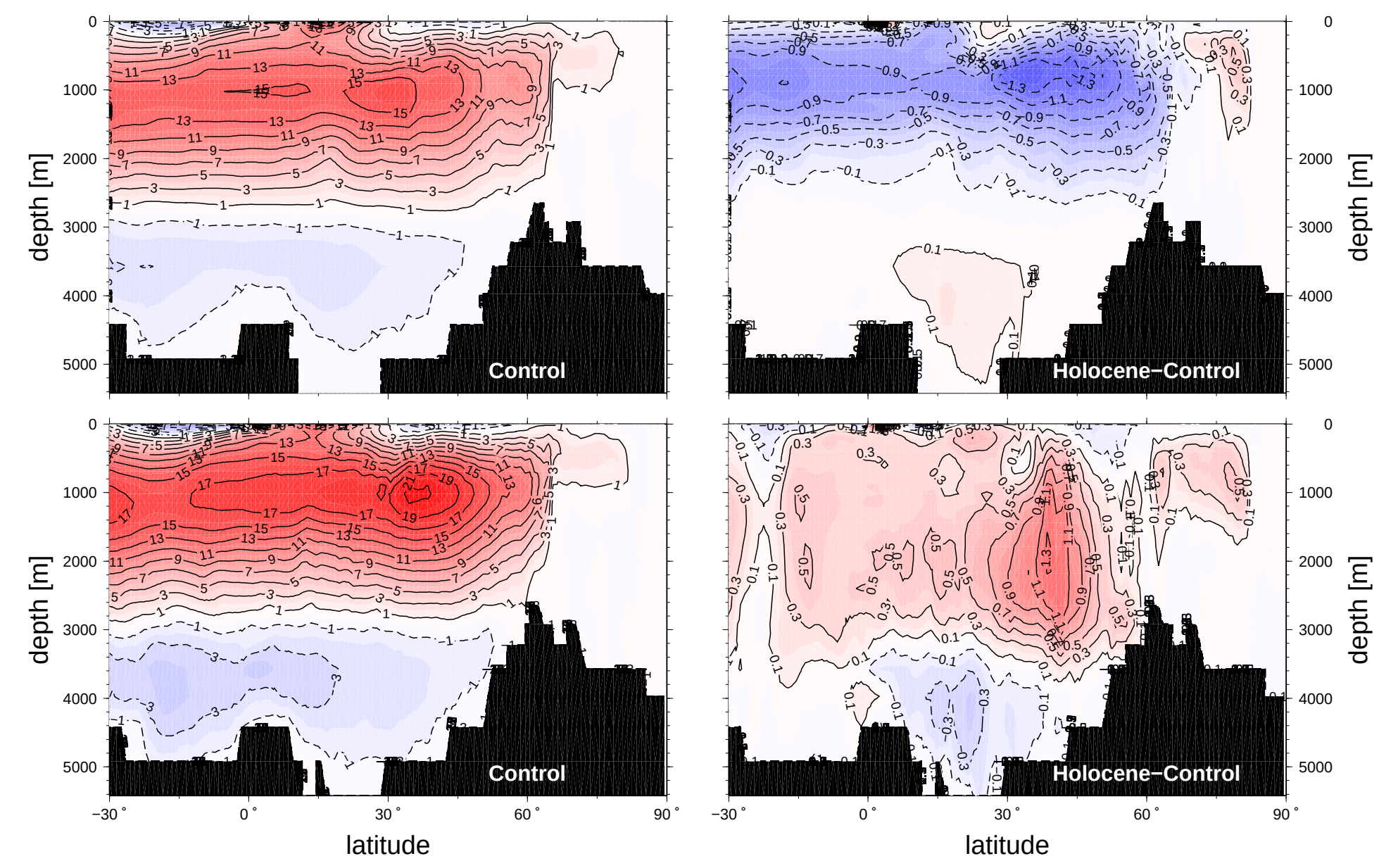
The surface temperature response of the two model set-ups is qualitatively similar, a decrease in temperature in the low latitudes and an increase in the high latitudes. The CMIP5-set-up (bottom), however, has a much smaller temperature increase in the high latitudes compared to the older set-up. Additionally, the cooling extends to the mid-latitudes in the CMIP5-set-up, in contrast to the older set-up.

Sea-Ice Extent Difference



The gray contour line shows the yearly mean sea-ice extent in the control and contours show sea-ice extent changes in the Holocene simulation. The CMIP5-set-up (bottom) produces more realistic sea-ice extend ind the Northern Hemisphere but underestimates sea-ice extent in the Southern Hemisphere. Changes in the Holocene simulations are qualitatively similar but with much lower amplitude in the CMIP5-set-up.

Atlantic Meridional Overturning Circulation



Plots on the left side show the mean state of the Atlantic Meridional Overturning Circulation (AMOC) in the control simulations. The CMIP5-set-up (bottom) has a maximum of about 21 Sv at 35°N. The maximum of the older set-up is about 16 Sv and further south at 30°N. The response to Holocene orbital conditions (right plots) is quite different in both set-ups. Where the CMIP5-set-up shows an increase in AMOC, especially at the maximum, the older set-up produces a weakening of the whole AMOC cell.

8 Conclusions

In a transient AO-GCM study of mid-Holocene, we assess AMOC evolution and variability and identify the corresponding mechanisms:

An increase in AMOC throughout the experiment can be explained by an increase in water-mass density in the deep water formation regions. In the Labrador Sea, a density increase of the convected deep water is due to increased salinity advection from the eastern North Atlantic. In the Nordic Seas, lower temperatures cause a substantial density increase and result in enhanced overflows.

The AMOC exhibits persistent significant variability on interannual and multi-centennial timescales. The interannual variability is dominated by the NAO, the multi-centennial variability by accumulating salinity anomalies. The amplitude and period of the multi-centennial variability depends on the interplay of various processes in different ocean basins.

In the new CMIP5-set-up of the MPI-ESM, however, the climate system's response to Holocene orbital forcing is in certain aspects quite different compared to the older set-up. This is especially true for the Atlantic meridional overturning circulation. Thus, the presented results seem to be model dependent. The reasons and mechanisms responsible, are subject to further investigations.

Nevertheless, our findings with the older model set-up add to the understanding of ocean circulation obtained from simpler model set-ups and are supported by paleo reconstructions of AMOC strength and variability.

Max-Planck-Institut
für Meteorologie

contact: **nils.fischer@zmaw.de**

International Max Planck Research School
on Earth System Modelling