Climate simulations of the Eemian and the subsequent glacial inception with a coupled atmosphere-ocean general circulation model

F. Kaspar[1,2], U. Cubasch[2]
[1]Max-Planck-Institute for Meteorology, Model and Data Group, Hamburg, Germany, kaspar@dkrz.de, [2]Institute for Meteorology, Freie Universität Berlin, Germany

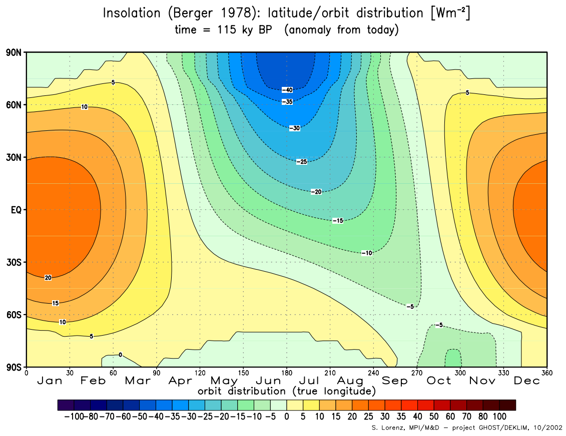
Abstract

The coupled ocean-atmosphere general circulation model ECHO-G has been used used to perform multi-centennial simulations of the climate during and at the end of the Eemian interglacial. Orbital parameters have been adapted to conditions of 125,000 and 115,000 years before present (yBP). These dates represent periods with maximum and minimum summer insolation on the northern hemisphere. The Eemian interglacial had its climatic optimum at around 125,000 yBP and ended at around 116,000 yBP. The simulations show that changes in the orbital parameters are sufficient to (1) simulate seasonal temperature patterns during the interglacial consistent with pollen-based reconstructions and (2) to cause a long-term cooling trend at 115,000 yBP, which is connected with a continuous expansion of perennial snow-covered areas over North America.

The model and the experimental setup

The ECHO-G model (Legutke and Voss, 1999) consists of the ECHAM4 atmosphere model (resolution approx. 3.75°, 19 levels) coupled to the HOPE ocean model (resolution 2.8° with equator refinement, 20 levels). Three simulations with adapted orbital parameters and greenhouse gas concentrations have been performed: They represent conditions at 125,000 and 115,000 yBP, and pre-industrial conditions. Greenhouse gas concentrations are based on Vostok ice cores. As the difference between these concentrations is small, the orbital parameters are the only relevant difference between the simulations.

At 125,000 yBP the seasonal cycle of northern hemisphere insolation is strengthened, whereas it was weakened at 115,000 yBP.



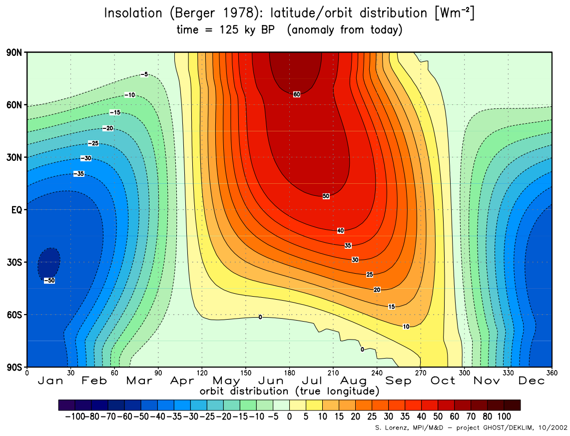


Figure 1: Insolation at 125,000 years BP and 115,000 years BP as anomaly from today (calculated according to Berger, 1978)

Simulation of the early Eemian at 125,000 yBP

This simulation represents the early Eemian. For this phase reconstructed seasonal temperature data are available for Europe (Kühl, 2003). A comparison of simulated temperatures with these pollen-based reconstructions showed that the model simulates a realistic seasonal climate for that region (Kaspar et al., 2005).

Reconstructions and simulation are concordant in showing higher temperatures than today over most parts of Europe in summer and in revealing a west-east-gradient in winter temperature differences with increasing anomalies towards Eastern Europe (Figure 2). This gradient is caused by reductions in sea ice in the Barents Sea and enhanced westerlies at 60°N. The results indicate that differences in the orbital parameters are sufficient to explain the reconstructed Eemian temperature patterns.

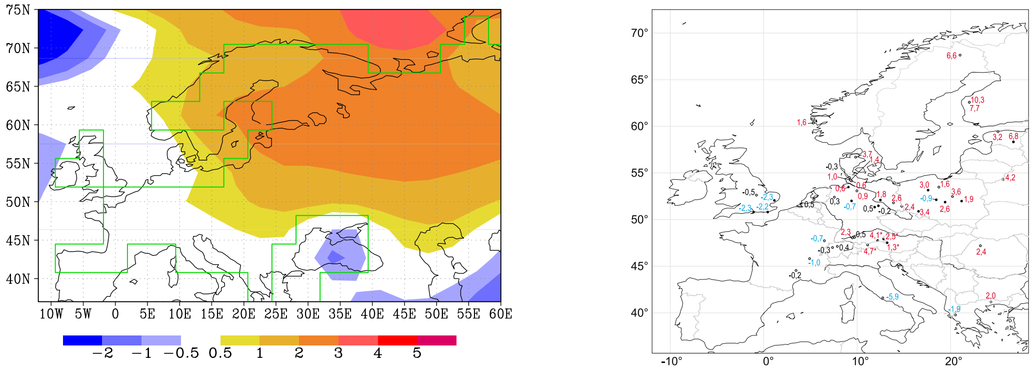
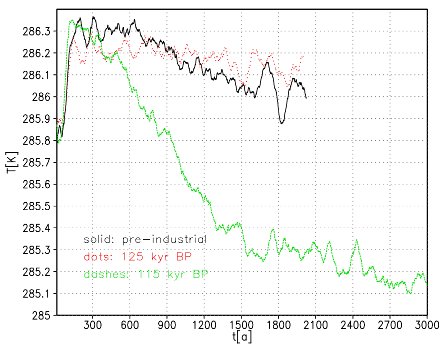


Figure 2: Comparsion of simulated European January temperature anomalies (left) with pollen-based reconstructed temperatures (right, Kühl, 2003) for the Eemian. The simulated near surface temperature is averaged over 100 year interval plotted as anomaly from a simulation with pre-industrial conditions. Reconstructions are deviations from observed present-day climate.

Simulation of the glacial inception at 115,000 yBP

In case of the simulation for 115,000 years BP the model reacts with a long-term cooling trend (Figure 3). This trend is connected with a continuous increase in northern hemispheric sea ice volume and an expansion of the permanently snow-covered areas over North America (Figure 4). During the 3000 years of the simulation 892,000 km^3 of water are accumulated as snow on the North American continent. The accumulation rate is increasing during the progression of the simulation and is equivalent to a decrease in sea level of approx. 18 cm per century at the end of the simulation.



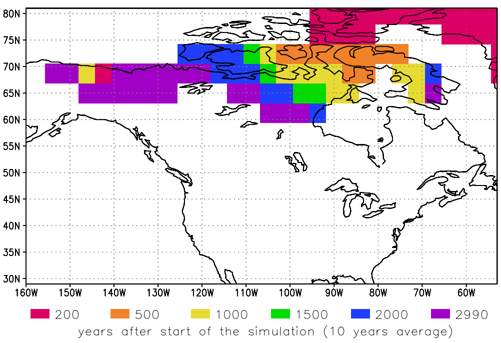
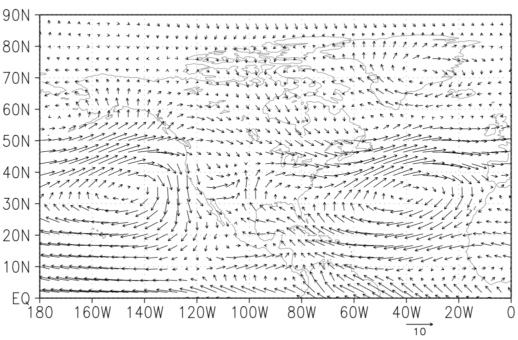


Figure 3 (left): Time series of the global annual mean near surface temperature as 50 year running mean.

Figure 4 (right): Expansion of areas with perennial snow coverage after different periods in the simulation for 115,000 years before present.

Mechanisms of snow accumulation

The snow accumulation starts in north-eastern Canada where southward winds transport cold Arctic air into the continent. Alaska and the Rocky Mountains are dominated by warm northward winds in summer which prevents the development of a perennial snow coverage (Figure 5). The simulated start of the glaciation in north-eastern Canada is consistent with geological records (Clark et al., 1993). Several papers discussed the relevance of an increase in northward moisture transport. Figure 6 shows that increase northward moisture transport occurs in summer over the Pacific and Atlantic region. However, this does not result in an increase of precipitation over North America (Figure 7). The increase in snowfall (Figure 8) and net precipitation (precipitation-evaporation) is mainly caused by the decrease in temperature.



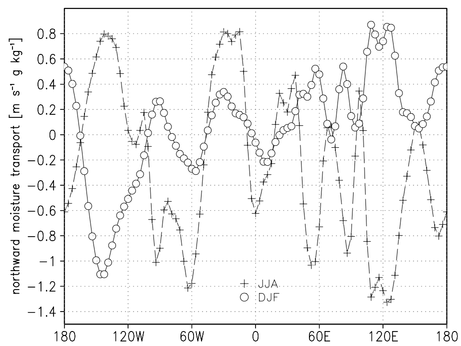
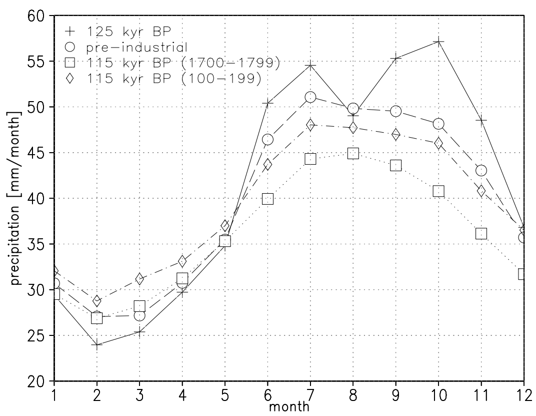


Figure 5 (left): Winds at 850 hPa in summer (JJA) in the simulation for 115,000 yBP.
Figure 6 (right): Northward meridional transport of moisture on the northern hemisphere at 115 kyBP as anomaly from the pre-industrial simulation (product of meridional wind component v and specific humidiy q, vertically integrated).



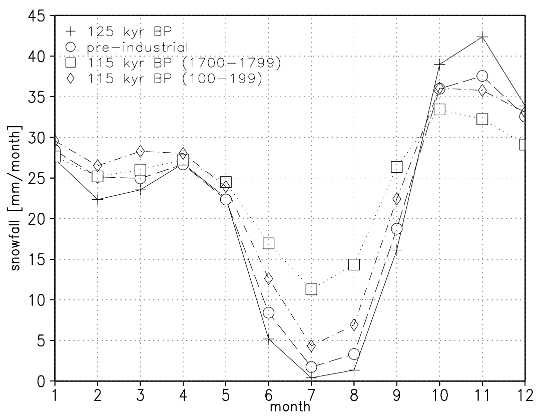


Figure 7: Annual cycle of precipitation for 125 kyBP, 115 kyBP and pre-industrial) over the northern part of North America (130°W-60°W; 50°N-80°N; averaged over the interval 1700-1799 yrs, and 100-199 yrs for the 115 kyBP simulation).
Figure 8: Annual cycle of precipitation in the three simulations for the same region as in Figure 7.

Publications of the project:

Cubasch, U, E. Zorita, F. Kaspar, K. Prömmel, H. von Storch, F. Gonzales-Rouco: *Simulation of the role of solar and orbital forcing on climate.* Advances in Space Research, accepted.

Groll, N., M. Widmann, J.Jones, F. Kaspar, S. Lorenz: *Simulated differences in the relationships between regional temperatures and large-scale circulation during the early Eemian interglacial (125 kyr BP) and the pre-industrial period.* Journal of Climate, accepted.

Kaspar, F., N. Kühl, U. Cubasch, T. Litt (2005): A model-data-comparison of European temperatures in the Eemian interglacial. Geophysical Research Letters, accepted.

Other references:
Berger, A. L. (1978): *Long-term variations of daily insolation and Quaternary climate changes.* Journal of Atmospheric Science, 35, 2362-2367
Clark, P. U., Clague, J. J., Curry, B. B., Dreimanis, A., Hicock, S. R., Miller, G. H., Berger, G. W., Eyles, N., Lamothe, M., Miller, B. B., Mott, R. J., Oldale, R. N., Stea, R. R., Szabo, J. P., Thorleifson, L. H., Vincent, J.-S., (1993): *Initiation and development of the Laurentide and Cordilleran ice sheets following the last interglaciation.* Quaternary Science Reviews 12, 79-114.
Kühl, N. (2003): *Die Bestimmung botanisch-klimatologischer Transferfunktionen und die Rekonstruktion des bodennahen Klimazustandes in Europa während der Eem-Warmzeit.* Dissertationes Botanicae 375.
Legutke S. and Voss, R. (1999): *The Hamburg Atmosphere-Ocean Coupled Circulation Model ECHO-G.* Tech. Rep. No. 18, DKRZ, Hamburg