Water isotope modeling for the last glacial cycle

Joint state-parameter estimation for the Last Glacial Maximum with CESM1.2

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In Short

- This project aims at providing climate reconstructions for different periods of the last glacial cycle. Focus is on the direct forward modeling of stable water isotopes using the Community Earth System Model (iCESM1.2).
- A long (5500 years) steady-state run for the Marine Isotope Stage 3 (38 thousand years ago) shows multicentennial oscillations in the strength of the Atlantic Meridional Overturning Circulation (AMOC).
- The model results suggest a strong link between AMOC strength and patterns of N. Atlantic surface temperature changes with precipitation δ18O variability over Greenland.

This compute project is set within the framework of PALMOD, a BMBF-funded project that seeks to understand climate system dynamics and variability during the last glacial cycle. Our main focus is the modeling of stable water isotopes, combined with a comprehensive analysis of reconstructed and simulated isotope distribution.

The main outcome of this compute project since the last report was the analysis of our steady-state model run for the Marine Isotope Stage 3 (MIS3). The MIS3 lasted from about 60 to 27 ka (thousand years before present), and is characterized by climate varibility on different time scales: most notably, by climate transitions between cold stadial and warm interstadial states on a multi-millennial time scale called Dansgaard-Oeschger events.

Our MIS3 simulation uses boundary conditions and greenhouse gas and orbital forcing representative of 38 ka, and has been intergrated to 5500 years to allow equilibrium even in the deep ocean. However, this equilibrium is only true on a longer time scale, as the model results show multicentennial oscillations in the strength of the Atlantic Meridional Overturning Circulation (AMOC). These are presented in Fig.1a that shows the time series of strength of the upper, North Atlantic Deep Water cell of the AMOC. According to Fig.1a the AMOC oscillates with an amplitude of nearly 7 Sv (Sverdrups; 1 Sv = 10^6 m^3s^{-1}) in terms of extreme annual values, and its strength varies between 20 and 16 Sv when we apply a 100 years low-pass filter to remove sub-centennial signals from the series. The spectral analysis of the series in Fig.1b shows that it is dominated by a fluctuation of about 500 years.

The variations in AMOC strength lead to changes in sea ice edge and surface temperature that are strongest in the North Atlantic Ocean. In order to evaluate the characteristics of surface temperature variability and their potential links to regional changes in the isotopic composition of precipitation, we have performed a Redundancy Analysis (RDA), a method that is able to identify pairs of patterns that are linked through a regression model. An example of the application of the method in climate sciences can be found in [1]. Here in our analysis the predictor is δ^{18}O in precipitation and the predictand is surface temperature.

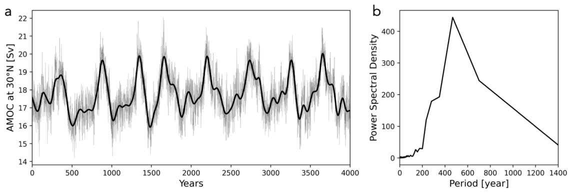

***Figure 1:** Simulated maximum AMOC strength at 30°N. Annual (grey) and 100 years low-pass filtered (black) time series (a) and Power spectral density (b).*

The results of the redundancy analysis suggest that the AMOC-related variations in North Atlantic surface temperature are tightly linked to regional changes in δ^{18}O in precipitation. According to Fig. 2a, the first RDA mode of δ^{18}O in precipitation is centered over Greenland, with very weak or no signal elsewhere, and although it describes only 11.8% percent of predictand variance, it is the pattern that best represents the main mode of variance in the predictand, surface temperature, seen in Fig.2b. The predictand pattern describes 35.2% of variance in surface temperature, and has two centers of action of the same sign: in the Labrador Sea and in the Nordic Seas. The time series of predictor and predictand patterns, plotted in Fig.2c, are significantly correlated with a correlation coefficient of 0.87.

The model results show that changes in δ^{18}O in precipitation over Greenland best represent North Atlantic surface temperature variations that are caused by the AMOC oscillations. This suggests that the isotopic composition measured in local ice cores is a potential proxy for AMOC variability. Therefore, we have analyzed δ^{18}O measurements in Greenland ice cores to search for variations analogous to those in our simulation.

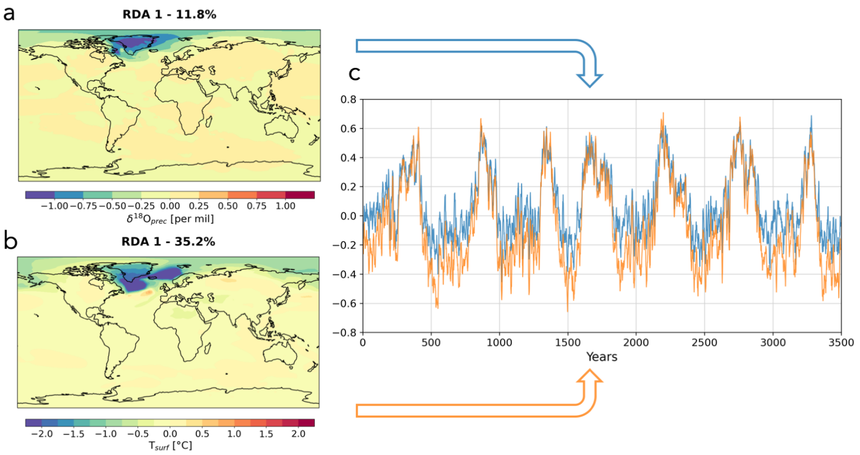

Figure 2: *First redundancy mode between simulated $\delta^{18}O$ in precipitation as predictor (a) and surface temperature as predictand (b) and their time series (c).*

Fig. 3a shows time series of δ^{18}O measured in the ice core from the North Greenland Ice Core Project (NGRIP) site [2] covering most of the MIS3 period from 48 to 33 ka. The time series is dominated by large, multicentennial variations of abrupt enrichments followed by gradual depletion, resembling the typical sawtooth pattern of the Dansgaard-Oeschger events. These are different both in timing and shape from the oscillations in our model results. However, there are also occasional smaller variations on a centennial scale, for example in the period highlighted with grey background in Fig.3a, enlarged in Fig.3b.

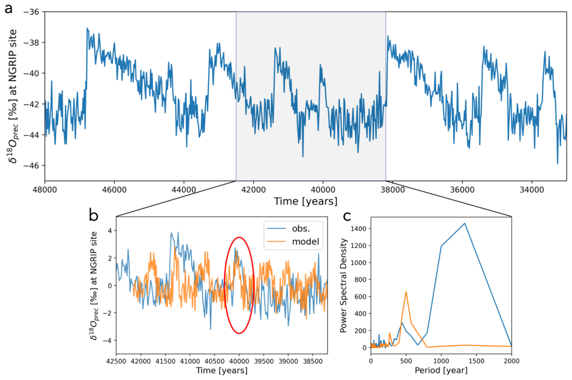

Figure 3: *$\delta^{18}O$ in precipitation in Greenland at the NGRIP site. Time series reconstructed from ice core observations by [2] (a), and comparison of anomalies in ice cores and iCESM1.2 model simulations for the period 38.2ka-42.5ka (b) and their power spectral densities (c).*

Comparing the event around 40 ka we can see that the time scale and amplitude of this observed event (in blue) is very similar to the oscillation in our model simulation for the same location (in orange). A spectral analysis for this selected shorter period in Fig.3c shows that the modeled series are dominated by a fluctuation of about 500 years, and while the observations are dominated by lower frequency variations, there is a smaller local maximum around 500 years in the ice core data too. This provides evidence of an event similar to the variations in our model results both in amplitude and time scale.

WWW

https://www.palmod.de

More Information

[1] F. Kauker and H. E. M. Meier (2003): Modeling decadal variability of the Baltic Sea: 1. Reconstructing atmospheric surface data for the period 1902–1998, *JGR Oceans*. **108** `doi:10.1029/2003JC001797`

[2] J. A. Badgeley, E. J. Steig, G. J. Hakim, and T. J. Fudge (2020): Reconstructions of mean-annual Greenland temperature and precipitation for the past 20,000 years and the ice-core records used to create the reconstructions, *Arctic Data Center*. `doi:10.5194/cp-16-1325-2020`

Project Partners

AWI, CAU, DKRZ, GEOMAR, HZG, IfBM, University of Mainz, FUB, KIT, TROPOS, MARUM, MPI-C, MPI-M, MUN, University of Bonn / HErZ, PIK, University of Hamburg

Funding

Federal Ministry of Education and Science (BMBF)

DFG Subject Area

313-02