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

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In Short

• The project provides state-of-the-art climate reconstruction of global Last Glacial Maximum climate with uncertainty bounds

• Homogenized multi-proxy observations within the scope of PALMOD are assimilated into an isotope-enabled comprehensive Earth System Model (CESM v1.2)

• Ensemble reconstructions from coupled atmosphere-ice-ocean global at the LGM will be analysed along with transient higher resolution simulation of the post LGM-deglaciation

This compute proposal is set within the framework of the BMBF-funded project PALMOD, now in its 4rd and last year within its 1st Phase. In this compute project we use the comprehensive Community Earth System Model (CESM v1.2) to do time-slice ensemble climate simulations at the Last Glacial Maximum (LGM, 19–23 kyr BP. One project goal is to evaluate how the use of uncertain parameters for the model physics as control variables and assimilation of available state-of-the-art paleoclimate proxies (homogenized within the framework of PALMOD) serves for climate reconstruction and, possibly, for constraining future climate projections. The model consists of components for the atmosphere, ocean, land and sea ice, which communicate with one another via a central coupler module. We use Finite Volume solvers, and from an earlier coarser grid in the project we have now moved into a regular horizontal grid of ~ 2.0° for the atmosphere and land, and a displaced pole (centered at Greenland) ~ 1.0° irregular grid for ocean and sea ice. The vertical representation of the atmosphere comprises 30 layers in a hybrid sigma-pressure system. The ocean has 60 vertical levels with thicknesses increasing with depth.

Ensemble experiments are being carried out in LGM steady-state conditions for 400 years with the aim to reconstruct the LGM climate with CESMv1.2. For the first time a comprehensive isotope-enabled Earth System Model is aimed to be used for online assimilation of paleoclimate proxy records at the LGM. The resolution and ensemble requirements for sound estimation of the model climate sensitivity to the control variables, which feeds the assimilation scheme, make this project computationally very challenging. As a result from previous experiments in HLRN3, we have now moved into using the finite difference sensitivity iterated Kalman smoother (FDS-IKS; [2]) as assimilation approach, which can take into account non-linear sensitivities of the observation space (e.g. sea surface temperature, or ocean isotopic composition $\delta^{18}O$) to the control variables. The selection of the FDS-IKS against an iterated version of an ensemble Kalman filter (FDS-IKS; [2]) as assimilation approach, which has been shown that for similar computations the FDS-IKS behaves better than a standard (linear update) ensemble transform Kalman filter (ETKF) in synthetic experiments with CESM [2].
With the new increased resolution, we have now conducted in HLRN4 an initial run at LGM without water isotopes (which is still converging towards its equilibrium [LGM.PHY]), and a run with a new atmospheric component (CAM5) including water isotopes. A fully coupled model including water and carbon isotopes is also currently running towards its equilibrium for preindustrial conditions [PI.ISO]. Figure 1 shows an example of these model runs. The last step in this sequence is the combination of LGM.PHY and PI.ISO into a water and carbon isotope enabled model run for LGM conditions [LGM.ISO]. This one has to be run then in ensemble mode to allow for the assimilation of the paleoclimate proxy database at LGM and corresponding climate reconstruction. The availability of the 2nd Phase of HLRN4, and augmented computational power, will be crucial for the project success.

The most recent and careful dynamical reconstruction of the global ocean during the LGM is [1], which uses an ocean-only global circulation model (the MITgcm). Still, it cannot account for possible atmosphere feedbacks. Thus the question remains open about whether a fully coupled global (an isotope-enabled) Earth System model would yield a similar reconstruction, also considering the new updated of the proxy record within PALMOD. A second question is whether the corresponding assimilation experiments can serve to constrain future climate projections via insight into sensitivity of the model departure from relatively stable situations to small modifications of the model parameter space, which is not possible to explore with the instrumental record just covering the climate scenario of the current interglacial.

Our previous work indicates that it seems possible to use selected model parameters for the model physics as control variables for climate reconstructions, but care must be taken to have a consistent solution. An identical twin experiment with observations from a true run taken at MARGO locations [3] showed that not all control variables (in a selected set of parameters for cloud processes, sea ice and ocean diffusion) were identifiable with preindustrial forcings. As one of our initial examples, we updated a background 20-yr annual mean zonal salinity profile in the South Atlantic (strongly related to the AMOC patterns) via an assimilation of “observations” of salinity profiles constructed as an average from previous existing reanalyses (C-GLORS, ECCOv4, ORAS4, SODA) as analysis target. Figure 2 summarizes the sensitivity of the estimated (a posteriori) mean zonal salinity in the South Atlantic to the uncertainty in the observations errors. The plot shows that it is possible to very much approach the observations as their uncertainty is reduced. However, this does not implies a good result, as the augmented system shows that the jointly estimated parameters give unrealistic values and climate projections for an over-fitted ocean salinity. On the other hand, a climate reanalysis can still be reasonable even the corresponding jointly estimated model parameters are not suited for climate projections.

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Project Partners

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