Report: Exploring modeled climate variability in past cold and warm states of the Earth System

Project: 1479

Project title: EXPLAINstates2

Principal investigator: Julia Brugger, Kira Rehfeld

Allocation period: 2026-01-01 to 2026-12-31

Project overview

Over the last two phases of the EXPLAINstates project, we explored two of the CMIP7[1] fast track experiments, *abrupt-127k* (representing the last interglacial, LIG) and *abrupt-0p5CO2*, from a paleoclimate modelling perspective using state-of-the-art climate models. This spans an as-warm-as-present time period, and a simulation that is expected to be as cold as the Last Glacial Maximum 21 thousand years ago. These experiments are of great importance for a better understanding of the effects of various forcing factors on the climate system, their interactions and feedback processes. Exploring the last interglacial also helps to test the ability of state-of-the-art climate models to simulate near-future warming. In this way, these experiments contribute to a better understanding of current and future climate change.

Report on project phase 2

Last interglacial simulations with ICON XPP

The abrupt-127k experiment starts from a pre-industrial simulation for which orbital parameters and greenhouse gases are adjusted to LIG levels. Other boundary conditions (solar constant, ice sheets (prescribed), vegetation (prescribed), aerosols) are kept at pre-industrial values (Sime et al., 2026). We performed this experiment using the new CMIP7 version of ICON-XPP. After several tests with preliminary versions of this model, the final simulations showed that ICON-XPP does not recreate the warming or sea ice reduction in the LIG that we expect given the proxy evidence. Our results show a 0.3 K decrease in global average temperatures and an increase in polar sea ice. This is driven by a summer warming (1.7 K) that does not match the expected magnitude (4.5 K). This result has major implications for ICON-XPP's ability to simulate sea ice melt in a warmer climate. We have begun exploring the drivers behind this response, including by conducting vegetation sensitivity experiments. The next step will be to implement dynamic vegetation to approximate LIG vegetation cover and capture the global biosphere contribution to LIG conditions.

Our results were presented in talks on the ICCARUS conference in Offenbach (March 2026,)[2], at EGU General Assembly in Vienna (May 2026)[3] and on the ICON Seamless All Hands Meeting in Offenbach (October 2026). This gave us a valuable opportunity for exchange with the community and our collaborators.

This year's last steps are to conduct several sensitivity tests in order to identify the missing Arctic climate feedbacks. We are planning simulations with prescribed LIG vegetation and varied parameters in the snow and sea ice schemes.

Isotope enabled simulations with MPI-ESM-wiso

Within EXPLAINstates2, we further investigated whether the CMIP7 fast track experiment *abrupt-0p5CO2* state can serve as an analogue for the Last Glacial Maximum (LGM, ~21,000 years ago; its simulation denoted as *lgm*) and where the

1 Coupled Model Intercomparison Project Phase 7, see https://wcrp-cmip.org/cmip-phases/cmip7/

2 https://dwd.de/EN/specialusers/research_education/seminar/2026/iccarus2026/iccarus_2026_en_node.html

3 Rehfeld, K., Brugger, J., Houston, T., Racky, M., Lorenz, S., Wagner, S., and Köhler, M.: Simulations of the Last Interglacial with ICON-XPP indicate the relevance of correct sea-ice and vegetation feedback for Northern Hemisphere warming, EGU General Assembly 2026, Vienna, Austria, 3–8 May 2026, EGU26-9552, https://doi.org/10.5194/egusphere-egu26-9552, 2026.

analogy breaks. We improved the statistical methods of the model-data comparison and included more proxy data. We extended the *abrupt-0p5CO2* experiment for another 1000 years in order to eliminate remaining cooling trends. For the *lgm* simulation, our cooperation partner Alexandre Cauquoin set up a new simulation to overcome problems of the previous simulation but we are still facing spurious trends in the seawater isotope concentration during the spin-up, which limits our ability to analyse the simulation.

Additionally, we created simulations of the LIG with MPI-ESM-wiso which were used in a Master thesis project.

References:

Otto-Bliesner, B. L., Brady, E. C., Zhao, A., Brierley, C. M., Axford, Y., et al.: Large-scale features of Last Interglacial climate: results from evaluating the *lig127k* simulations for the Coupled Model Intercomparison Project (CMIP6)–Paleoclimate Modeling Intercomparison Project (PMIP4), Clim. Past, 17, 63–94, https://doi.org/10.5194/cp-17-63-2021, 2021.

Sime, L. C., Diamond, R., Stepanek, C., Brierley, C., Schroeder, D., Kageyama, M., Pollock, M., Malmierca-Vallet, I., Blockley, E., West, A., Feltham, D., Ridley, J., Braconnot, P., Williams, C. J. R., Shi, X., Otto-Bliesner, B. L., Macarewich, S. I., Ramos Buarque, S., Zhang, Q., LeGrande, A., Zheng, W., Jiang, D., Morozova, P., Guo, C., Zhang, Z., Yeung, N., Menviel, L., Narayanasetti, S., Yoshimori, M., Reeves, O., and Zhao, A.: A sea ice free Arctic: CMIP7 Assessment Fast Track *abrupt-127k* experimental protocol and motivation, Geosci. Model Dev., 19, 5881–5905, https://doi.org/10.5194/gmd-19-5881-2026, 2026.