Project: 1551

Project title: **Paleo-ICON-XPP: Simulating the climate for selected periods of the late Quaternary with different paleo versions of ICON-XPP**

Principal investigator: **Sebastian Wagner**

Report period: 2025-11-01 to 2026-10-31

1.1 Results from abrupt127k simulations [LIG]

Before running simulations of the LIG, we conducted extensive testing to ensure the suitability and robustness of the new kepler orbit scheme in the CMIP7 version of ICON-XPP. Following this, we used ICON-XPP to complete two simulation runs (PI and LIG) described in the abrupt-127k CMIP7 Fast Track protocol (Sime et al. 2026). Similar to Rehfeld et al. (2025), this revealed insufficient sea ice feedbacks and Arctic amplification in the LIG. To investigate this, we have conducted a number of ongoing sensitivity experiments implementing: snow on sea ice, sea ice ridging parameterisation (lead closure), snow on sea ice and ridging parameterisation, and an increase in boreal forest in the arctic. As shown in Figure 1, the Arctic sea ice state of the LIG is sensitive to changing sea ice parameters. While the initial LIG simulation featured warmer Northern Hemispheric summers (and melting sea ice) cancelled out in the annual mean by colder winters (and refreezing sea ice), the altered parameters increase albedo feedback, insulate sea ice in the winter, and affect the growth of new sea ice. This demonstrates that ICON-XPP may be capable of simulating the conditions indicated in proxy data. Further work will require tuning of the model with altered sea ice parameters, and further simulations of the LIG to understand its potential to simulate a warmer climate state.

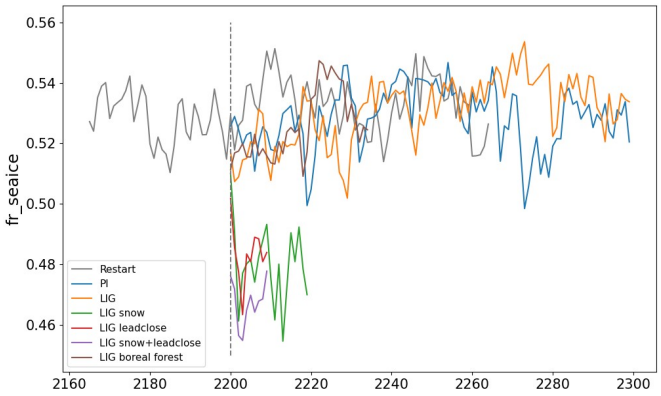


Figure 1: Annual mean sea ice fraction in the arctic (60° - 90° N) for abrupt127k simulations and sensitivity experiments.

1.2 Regional ICON-CLM simulations [regional ICON]

A migration to ICON-CLM-2026.10 is planned once the COPAT4 reference setup become available. The domain (Fig. 2) was defined starting from the standard EURO-CORDEX domain that was extended south-east to cover the Ottoman trade corridors. The resulting domain is both larger and coarser than the EURO-CORDEX standard, with 20 km grid spacing against 12 km. The purpose of the first tests is to establish whether that combination of a larger domain and a lower resolution degrades the solution, particularly in eastern sectors. Two ERA5-driven simulations were therefore run, over the standard EURO-CORDEX and the extended domain at 20 km resolution, covering the period 2002–2008, with 2002 discarded as spin-up. These simulations have identified noise entering through the northern lateral boundary, which is being addressed by adapting the relaxation-zone parameters to the 20 km resolution. The next step is to compare them with COPAT3 simulations to assess the resolution choice.

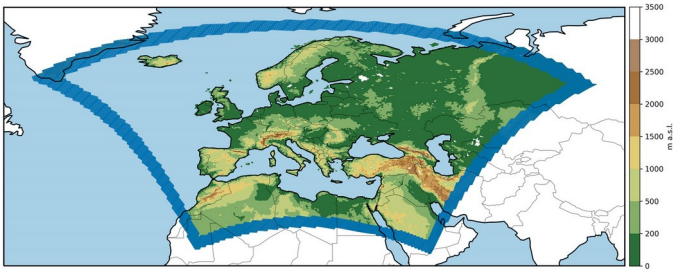


Figure 2: Orography of the simulation domain. In blue, the buffer zone.

For the EUROpest domain the full SPICE chain requires 53 node-h and 2.3 TiB of output per simulated year. The ICON integration runs on 4 nodes and the complete chain takes 1.83 SYPD end-to-end. The storage figure

reflects the test configuration, which writes the complete 3D model output at high frequency and is deliberately verbose for evaluation purposes. A minimum storage, that would still grant us the possibility to perform a nesting (3D variables written 6-hourly) is 0.4 TiB of output per year.

A proxy network optimisation framework is being developed to identify informative proxy networks and improve reconstruction skill. Development of a monthly AI-surrogate model has also been initiated to emulate the dynamical evolution of coupled Earth system models over the past millennium.

1.3 Past1000 experiments with ICON-XPP paleo [past1000]

For the past1000 experiments in the previous allocation period activities were related to the implementation of the orbital module and test experiments for selected volcanic events (Tambora 1815, Krakatoa 1883 and Pinatubo 1991). For this the original EVA software (Toohey et al. 2016) was used to create a volcanic forcing data set. In contrast to the previous MPI-ESM-P, forcing changes in the EVA needed to be applied to be consistent with the routines, reading in the according information for the Tambora eruption, where no information for the CMIP7 was provided. Fig 3. shows a sample plot as difference between the Tambora eruption and an undisturbed pre-industrial climate, showcasing that the module is able to simulate the effect of volcanic eruptions. It is expected that the full data set for the past2000 years including volcanic forcing will be released in late 2026/early 2027 (M. Sigl, pers. comm).

In addition, a considerable amount of CPU resources was used for simulations of the pre-industrial climate with the specific settings of the ICON-XPP paleo configuration (i.e. simulations were continued from PI-control runs started at the DWD RCL system and HAMOCC module was de-activated).

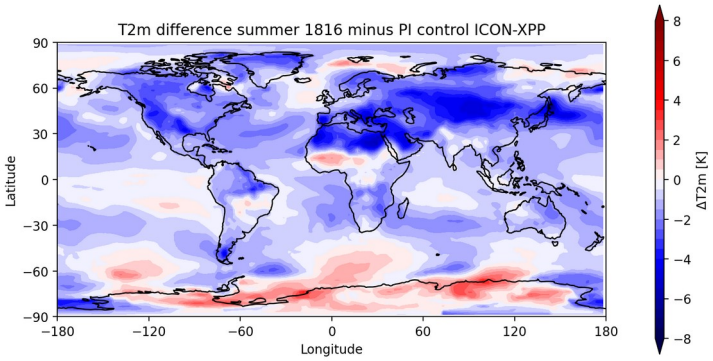


Figure 3: Difference near-surface temperatures for ICON-XPP for the Tambora eruption for the following summer 1816 vs. an undisturbed pre-industrial control climate. Note the stark temperature decline, especially over the continental areas in the simulation with the volcanic eruption.

1.4 Updates on emulator side [AI Emulator]

We built a probabilistic emulator called Functional Graph Transformer (Fig 4) and trained it on ERA5. It shows skill in forecasting on subseasonal and seasonal scales up to 6 months in advance. While, other emulators have shown stability on these long timescales, our model is the first one to verifiably establish that (Fig 5). The resources from the project enabled us to iterate on the design of the emulator and perform ablations to establish which aspects of the system are important for achieving skillful predictions.

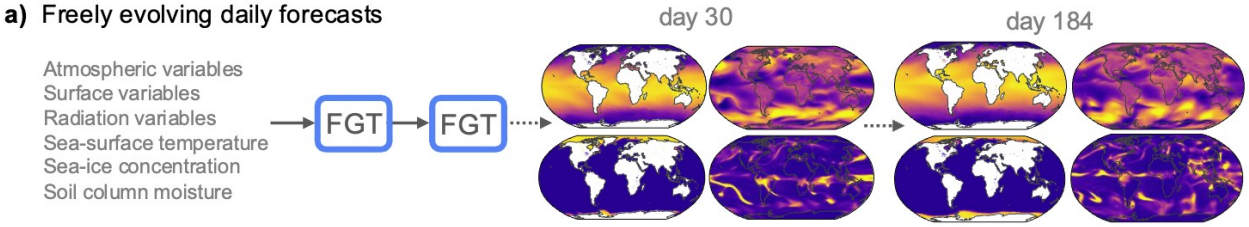


Figure 4: Schematic of the autoregressive emulator free evolving daily forecasts without past or future boundary conditions.

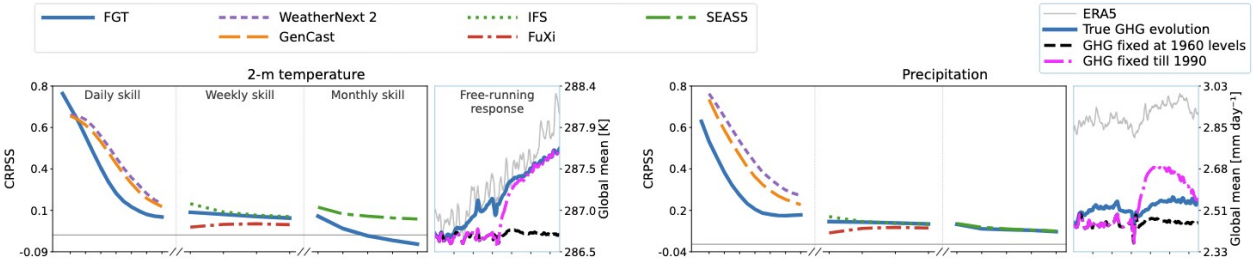


Figure 5: Multihorizon predictive skill and long-term evolution of FGT compared with available AI and operational numerical forecast systems available at particular horizons. We additionally run FGT freely for 65 years from 1960 under three greenhouse-gas (GHG) trajectories.