Digital Twin for Paleoclimate

Close integration of the ESMs with empirical data observations will encourage collaboration between disciplines who traditionally work separately. We made already the step to combine different methods to learn from past climate changes (e.g., Stein et al., 2017; Maier et al., 2018; Lembke-Jene et al., 2018; Klages et al., 2020). The aim is to evaluate the processes leading to Antarctic and Southern Ocean warming, deep-water formation, and to examine the feedbacks on long time scales. This will include the explicit simulation of the geometry of the cavities, vertical stratification and surface ocean processes. We will use the paleoclimatic information to assess further the impact of external forcing (solar insolation, CO_2 and tectonic changes) on internal variability and extremes in the atmosphere-ocean-ice system (Lohmann et al., 2020).

The dynamics in high-resolution simulations has a completely different structure including eddies than the structure in coarse-resolution models. With this, we will evaluate how the system has reacted regionally differently under different forcing mechanisms (e.g., circumpolar deep-water shelf incursions). Small-scale eddies play an important role in preconditioning and re-stratifying the water column before and after mixing events, thereby affecting deep water formation, melt rates, the regional and large-scale surface ocean and climate. To improve the quality of the climate model, high spatial model resolution is required around the coasts and ice shelves, which makes traditional ocean-climate models with uniform meshes impractical. Recent developments have considerably improved the computational efficiency and scalability of high-resolution unstructured-mesh approaches on high-performance computing systems (e.g., Streffing et al., 2022; Danek et al., 2023).

Pioneering work has been performed at AWI facilitated by the considerable increase in computational capacity. The application to the past warm climates is the logical next step, providing the opportunity to test the climate model out of the comfort zone of present climate. Investigate the implications for Antarctic ice-shelf melting, occurrence of extreme marine events in the Southern Ocean and potential changes in the cavities for the past-present-future. Our model is expected to open new possibilities for how the system responds to a warming world by assessing the impact on past and future climate and environmental extremes.

As a work horse, we shall apply an eddy-resolving/permitting (up to 5 km local horizontal resolution) ocean model FESOM coupled to 25 km resolution atmosphere openIFS, that will provide a step change for paleoclimate models. Our approach provides valuable out-of-sample tests for the tools used to simulate future climate and environmental changes suitable for assessment reports.

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