Project: **1514**

Project title: **TerraDT's land ice digital twin component**

Principal investigator: **Hauke Schmidt**

Report period: **2025-07-01 to 2026-04-30**

1. Introduction

To guide climate change adaptation and mitigation, reliable information on the regional and local impacts of climate change is needed. The Destination Earth (DestinE; https://destination-earth.eu/) flagship initiative of the European Commission responds to this need by developing Digital Twins (DTs) of the Earth. However, the reliability of the impact assessments of Climate DT depends on the underlying km-scale climate models which fail to represent some key components of the Earth system. The TerraDT project (https://terradt.eu/), funded in the European Commission's Horizon programme, aims at enhancing the DestinE infrastructure by developing a Digital Twin of the Earth system for the cryosphere, land surface and related interactions. This computing time proposal concentrates on developing and applying the first ever coupling of a state-of-the-art land ice model (Elmer/Ice) to a km-scale climate model (ICON). The ultimate aim of this is to better understand atmosphere-ocean-ice sheet interactions that contribute to present-day sea-level rise.

2. Use of resources

The original simulation strategy planned for this project was to run coupled atmosphere-ocean (and eventually land ice) simulations at two different ICON atmosphere resolutions, R2B8 (10 km) on Levante (DKRZ), and R2B9 (5 km) on JUPITER (JSC), with an ICON ocean of the same respective global resolutions, but with further refinements of the coastal regions of Greenland and Antarctica. Central simulations are transient simulations for at least 30 years starting in 1990. However, during the last year, the original plans had to be adapted for three reasons:

- Several bugs were identified in the ICON configuration "Sapphire 2.0" used in several large projects like DestinE or NextGems. One of these bugs led to large temperature biases over high-latitude land areas, i.e. the scientific target region of our project. Removal of these bugs and necessary retuning of the ICON atmosphere ("Sapphire 2.01") has only been finalized in April 2026, such that new control simulations for this project can only be started now. Resources of project bm1514 have contributed to testing and tuning the new model version.
- Due to numerical issues with the coastal refinement approach for the ICON ocean we developed another approach for a refinement near the big ice sheets (see Section 3). Resources of project bm1514 have contributed to testing different variants of this new ocean grid and spinning up the ICON ocean model with the final version of this grid.
- The application for JSC resources was not successful so that we have not transferred any model output from JSC to the archive of DKRZ.

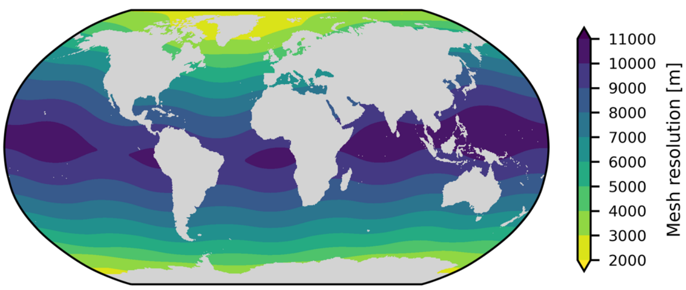

Fig. 1: Grid spacing of an ICON ocean grid with refinement near Earth's big ice sheet on Greenland and Antarctica.

3. Development of a new grid for the ICON ocean model

A new ocean grid was developed based on a R2B9 (5 km) reference grid. The new grid has a higher resolution of around 2.5 km around Greenland and the coast of Antarctica, but a lower resolution of up to 11 km in much of the tropics (Fig. 1). The total number of grid cells is reduced by 48% compared to the reference 5 km grid. However, the finer grid spacing in the high latitudes means that a smaller timestep of 180 s (compared 300 s) has to be used to run the model stably. In coupled setups with an atmosphere timestep of 75 s, the ocean timestep is reduced further to 150 s to allow for frequent coupling. Overall, this means that the new ocean grid is computationally as demanding as the 5 km reference grid.

The new grid was tested in a coupled setup with the R2B8 (10 km) atmosphere and run for 1 year. An identical setup was also run with the reference 5 km ocean grid. For both grids new 5-year ocean-only simulations were conducted to create fully comparable and spun-up initial states. While spinning up the model, several settings for the ocean viscosity were tested to find an appropriate tuning. The atmosphere tuning was taken from the above-mentioned recent developments. Figure 2 shows an advantage of the new ocean grid which better resolves sea ice and small-scale ocean features, for example within the large fjords of Greenland.

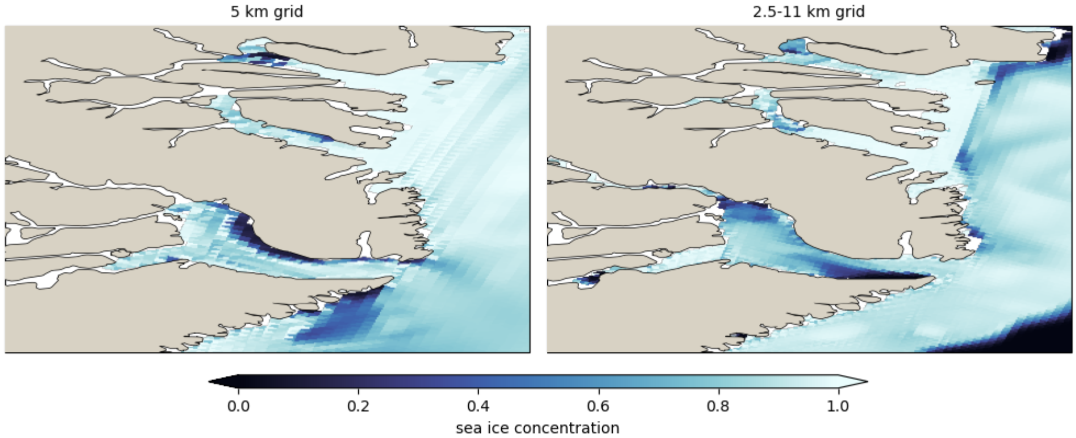

Fig. 2: Maps of sea ice concentration in the Kangertittivaq fjord for the reference 5 km grid and the new refined grid. Shown are daily averages on February 15, 1990, from the coupled simulations

4. Development of an ICON configuration coupled to a land ice model

A central component of our work involved the initial development of the coupling framework between ICON, Elmer/Ice, and the Energy Balance and Firn Model (EBFM). The aim of the coupling framework was to primarily employ online coupling via YAC and to keep coupling via the modification of restart files to a minimum. To enable the coupling using YAC, we introduced coupling interfaces to the individual model components. So far, we have established the bi-directional coupling between Elmer/Ice and EBFM and the uni-directional coupling between ICON and EBFM. The remaining coupling interfaces are still being developed. As the testing of the coupling interfaces is in large parts technical, we focused on short (3-5 days), coarse resolution (R2B4) simulations of the coupled model system ICON-EBFM-Elmer/Ice (Fig. 3, right panel). Hereby, coarse refers to the ICON component as this is by far the most expensive component, while EBFM and Elmer/Ice already run on the desired mesh resolutions. The advantage of the coarse model is that it requires the same technical know-how as the high resolution, but at a fraction of the cost of the targeted R2B8/R2B9 resolution. To ensure a seamless transition between different ICON resolution, we developed non-standard runscripts based on mkexp. These scripts allowed us then to run also a first test simulation using the atmospheric target resolution of R2B8 (Fig. 3, left panel).

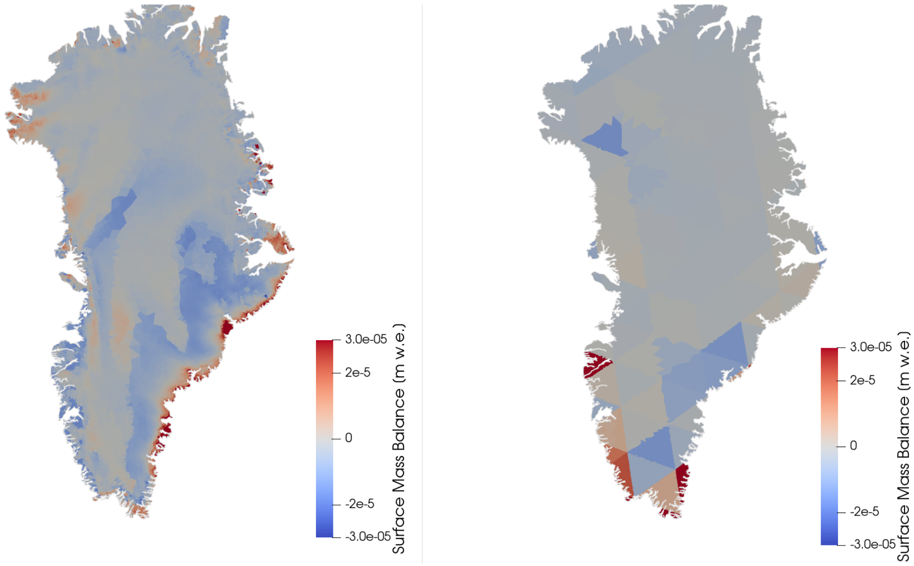

Fig. 3: Examples for the surface mass balance fields passed from the EBFM to Elmer/Ice via YAC for atmospheric grids R2B8 (left panel) and R2B4 (right panel).