Project: **989**

Project title: **Long transient simulations of the last deglaciation (last 30,000 years) and the development of lithosphere and ice sheet models in the framework of PalMod Working Group 1, Physical System**

Project lead: **Gerrit Lohmann**

Report period: **2016-01-01 to 2016-12-31**

We report on our modelling efforts on Mistral during the first 9 months of the allocation period 2016, covering proposed simulations with MPI-ESM-LR (AWI), PISM (AWI), and VILMA (GFZ). Our proposed time schedule has been delayed for various reasons as we outline in detail below.

In the first 10 months of DKRZ-Project 989 a first subset of the proposed simulations utilizing MPI-ESM-LR (ECHAM6.3 T63/L47 / MPIOM GR15/L40) were preformed in PalMod 1-3-1, AWI. We conducted first sensitivity studies with respect to individual forcings – land ice albedo, radiative active trace gases (GHG), and orbit – that shape glacial and Last Glacial Maximum (LGM) climate, and created a first simulation representing a full glacial state for 21 ka. Interestingly, these test runs (Fig. 1) show that the full ice sheet height provides strong cooling over the ice sheets, but over the North Pacific/Atlantic realm a warming due to different atmospheric circulation and teleconnection patterns is detected. The set of sensitivity studies became more extensive than initially planned as the glacial meridional overturning circulation in the Atlantic Ocean (AMOC) is for LGM conditions of GHG, orbit, land ice albedo, and ice sheet height significantly stronger than in similar simulations with our former model ECHAM5/MPIOM (Zhang et al., 2013, Climate of the Past). As AMOC-strength is crucial to our analysis of climate stability/dynamics during deglaciation, a detailed exploration of ocean circulation in the climate forcing phase space was necessary.

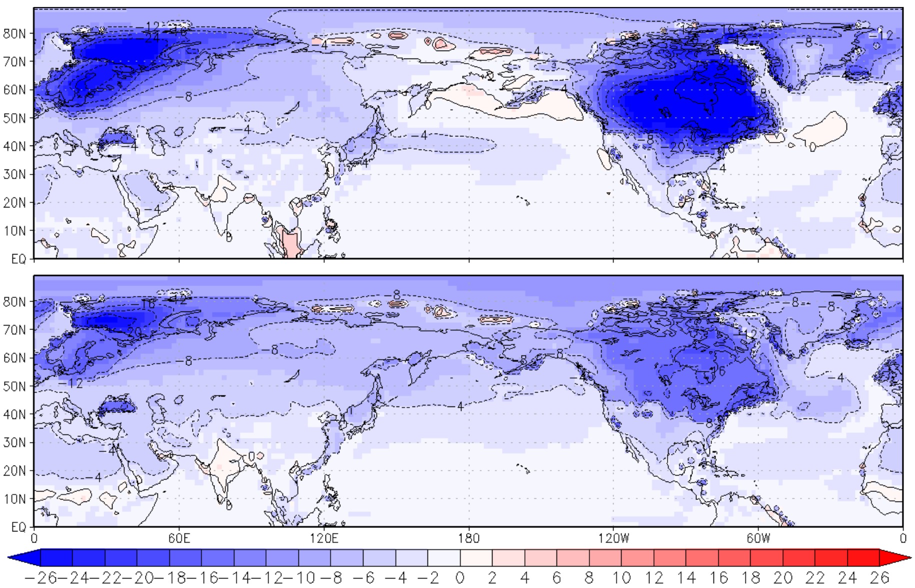

Fig. 1: Simulated surface air temperature anomaly (°C) with respect to the PI control state for the full glacial setup (21 ka before present, top) and a sensitivity study of a glacial setup (except for orography, bottom).

The execution of the full glacial transient simulations and of any simulations that request a change in orography with MPI-ESM in T63L47/GR15L40 resolution (LR) had to be delayed from the originally envisioned start in March 2016 to September 2016. Reasons are: (1) changes in the personal planning during the first year of the PalMod project, (2) delayed model availability, and (3) after provision of the model we experienced instable model behavior immediately after adjustment of the orography change away from the present day condition. It was a time-consuming process to devise a methodology that overcomes these problems via utilizing a slow transient modification of orography, but this problem is solved now. We do believe that the investment of manpower and computational resources into this unforeseen task has been well spent considering that our method of slow orography adjustment is actually a necessary part of the model setup that is now applied in the transient simulations of deglaciation.

Further problems were related to instability of the MPI-ESM for colder-than-present climate states. Simulations of recent climate (DKRZ-Project 989) on the other hand have met our expectation of a stable model behavior, which is also the case for much warmer-than-present climate (DKRZ-Project 1006). This problem has also been solved now via dedicated technical procedures so that simulations of glacial climate are possible now. As precondition for the simulation of the climate transition currently two spinups (27 ka and 21 ka before present) are being finished (note the slight change in the choice of the initial condition for the transient simulation in the submitted follow-up proposal). In 2016 we will still start the transient glacial transition simulations and expect for each of them to finish the first 2000–3000 model years of transient deglaciation with MPI-ESM-LR until the end of the year. In our follow-up proposal we request additional simulation time for the allocation period of 2017 in order to continue these simulations. Due to personal-changes, the coupling of the Ice Sheet Model (ISM) to our version of MPI-ESM is also behind schedule and will commence in the first weeks of November.

With respect to the simulations with the ISM at AWI our detailed analysis of spin-up simulations for Antarctica, based on PISM version 0.6.2, revealed a major bug in the enthalpy (thermal) scheme. This bug has affected simulations at least from PISM version 0.4 to the latest stable PISM version at that time (v0.7.1). By using the heated slab enthalpy benchmark experiment (Kleiner et al., 2015, The Cryosphere) we were able to identify the errors in the enthalpy implementation. Our proposed bug fixes have been reported to the PISM maintainers and are now included in PISM (since v0.7.2). Numerical simulations for the Greenland Ice Sheet based on paleo climate forcing show significant differences in e.g. ice thickness (several hundred meters) compared to the original PISM version for many of the outlet glaciers (Fig. 2). We have rerun some of the previous spin-up simulations for Antarctica and found that the model now needs to be re-calibrated according to the changed physics. While performing simulations for Antarctica we discovered another bug in PISM that prevented to run PISM with bedrock elevation and subgrid grounding line treatment enabled. Both features are essential to apply the model for the proposed experiments for PalMod 1-2-1, AWI, but generally support the success of PalMod in the WPs 1.1, 1.2, and 1.3. We have isolated and reported the bug to the PISM maintainer. A running PISM v0.7.3 for paleo climate applications is only available since 25. Jul. 2016.

In summary, none of the proposed experiments (ISM-1 to ISM-3) have been done yet due to the reported model issues. The fourth quarter of 2016 is reserved to start with the recalibration runs of the model. We propose to perform the simulations, that were initially planned for this year on Mistral, during the DKRZ allocation period of 2017.

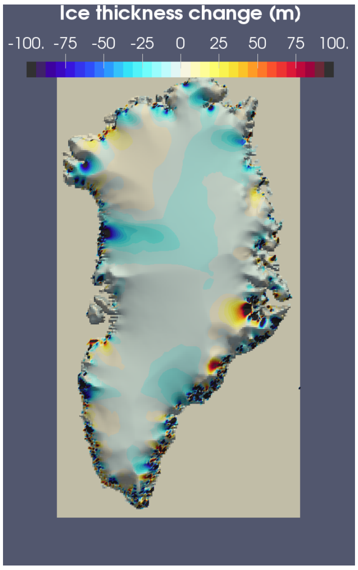

Fig. 2: Ice thickness change between two different PISM versions (v0.7.3 – v.0.7.1) illustrating the impact of the observed bug in the enthalpy scheme. The colour scale is saturated at +/- 100m, but locally the differences reach approx. 800m. (Greenland, 10km, 125ka paleo climate forcing).

At the GFZ (PalMod 1-1-3), the VILMA code had to be modified in order to fulfill the requirements for the intended dynamic coupling to the components of the earth system model. We decided on a redesign of the code from FORTRAN 77 to FORTRAN 90 in order to provide the restart capability required for the dynamic coupling, and to standardize the input/output interface to netcdf format. The programming and debugging of the modifications were executed on a local computing system at the hosting institute GFZ. Due to problems in personal plan, the proposed work was partly delayed. First successful tests of the updated model system were performed on Mistral during Sep. 2016.

Computations for investigating the model sensitivity to present-day loading were therefore the main focus in the first three quarters of 2016. Therein, features of the Earth's elastic structure, that are to be considered in VILMA-1D, were tested against atmospheric- and ocean-loading processes. The fourth quarter of 2016 is reserved for validation of the sea level equation in VILMA-1D and VILMA-3D, and for creating the set up of ensemble runs with respect to predefined earth structures and glaciation histories.

Project: **948**
Project title: **PalMod_WG1M – Transient simulations of the last glacial cycle with the coupled atmosphere-ocean-ice sheet model MPI-ESM-PISM**
Reporting Period: **2016-01-01 to 2016-12-31**

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Project summary

The ultimate goal of the the BMBF funded project PalMod is a transient simulation of the last glacial cycle with a comprehensive earth system model coupled to an ice sheet model. The last glacial cycle, especially the termination of the last glacial period, is one of the best constrained global-scale climate change signals in Earth history documented by climate archives. Nevertheless, the understanding of the underlying dynamics of glacial inception and termination is still limited. Further enigmas are posed by the Dansgaard-Oeschger and Heinrich events, abrupt climate shifts and associated changes in the sea level and Atlantic Meridional overturning circulation (AMOC) during glacial periods (Dansgaard et al., 1984; Heinrich, 1988).

During the first project phase (09/2015–08/2019) our goal is to perform a simulation of the last glacial termination starting at the last Glacial Maximum (LGM, 21 000 years ago) with prescribed atmospheric greenhouse gas concentration and insolation with the earth-system model MPI-ESM1 coupled to the ice sheet model PISM.

Results

In 2016 we focused studies based on coupled simulations with our old model setup, the modified Parallel Ice Sheet Model (mPISM0.3) coupled with ECHAM5/MPIOM/LPJ, and on the development of an updated coupled model system, comprising mPISM0.7 and MPI-ESM1.2. In the course of this model development effort, we performed uncoupled experiments with mPISM0.7 and MPI-ESM1.2.

While working on the new setup, we studied the last Glacial and the deglaciation in simulations performed with our old model setup, with only greenhouse gases and insolation prescribed (*Fig. 1*). These are the first transient deglaciation experiments with a fully coupled GCM-ISM system. To investigate the effects of different coupling strategies, we used simulations with asynchronous coupling (e.g. Ziemen et al., 2014), periodically synchronous coupling (Voss and Mikolajewicz, 2001; Mikolajewicz et al. 2007), and synchronous coupling.

For future PalMod simulations the ECHAM5/MPIOM/LPJ climate model was replaced by MPI-ESM1.2. For mPISM we updated the underlying PISM version from 0.3 to the newest version 0.7 and are working on transferring the coupling schemes from the old setup into the new MPI-ESM1.2/mPISM0.7 setup. Further, the simple surface mass balance (SMB) parameterization using positive degree days used for the coupling between ECHAM5 and mPISM0.3 was replaced by a scheme based on an energy balance model (EBM; Vizcaíno et al., 2010). As the EBM needs atmospheric model-data that resolve the diurnal cycle we implemented, with the help of DKRZ, a module in MPI-ESM1.2 that allows to write hourly output for only the necessary fields in 2D only.

Due to the above mentioned updates, the individual model components needed to be (re-) tuned. We tuned the coarse resolution version of MPI-ESM1.2 (MPI-ESM1.2 CR; T31 spectral resolution) for pre-industrial (PI) and LGM climate conditions. The specific focus was on a realistic representation of processes that are important for glacial transitions, i.e. AMOC and processes that determine the evolution of ice sheets. This includes a realistic representation of the SMB. For this, the EBM was forced with MPI-ESM1.2 CR data and compared to SMB reconstructions from observations (RACMO) for present day conditions. The results show that the SMB derived from the tuned MPI-ESM1.2 CR is very similar to the SMB retrievals for Greenland (*Fig. 2*) and Antarctica (not shown). We also tuned a modified MPI-ESM CR version that comprises processes related to permafrost. As permafrost influences the hydrological state of soil and acts as a storage for greenhouse gases it might contribute significantly to climate change responses. We used the EBM scheme in combination with T63 MPI-ESM1.2 LGM and PI output for mPISM simulations that we submitted to the ISMIP6 INITMIP model intercomparison. The comparison with the results of the other modeling groups will contribute to the validation of our new setup.

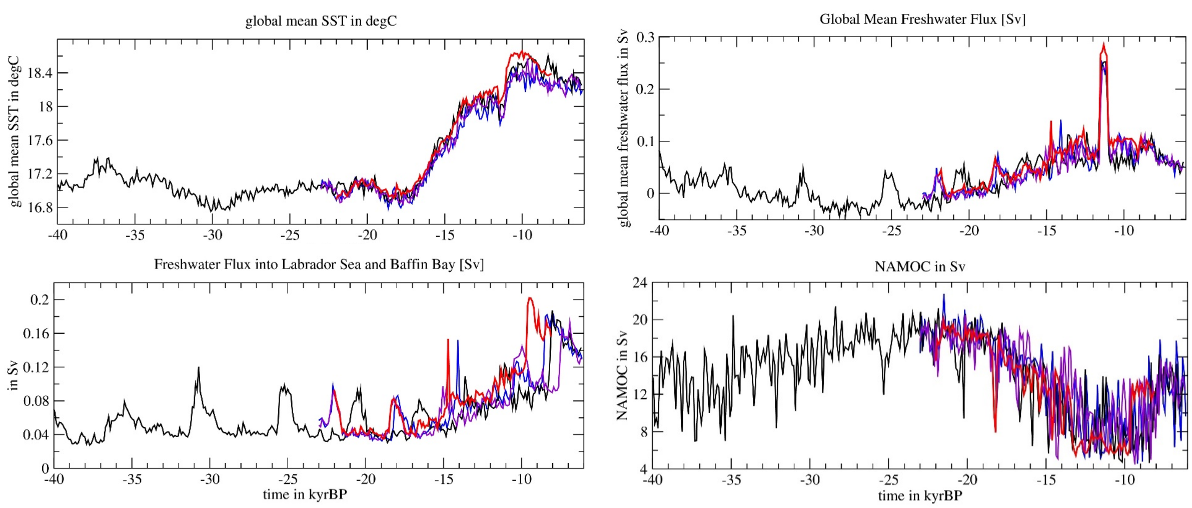

Fig. 1: Coupled transient simulations with the ECHAM5/MPIOM/LPJ – mPISM setup for different coupling setups forced with greenhouse gases and insolation. Shown are the global mean sea-surface temperature (top, left) and the freshwater flux (top, right), freshwater flux in the Labrador Sea (bottom, left) and the Atlantic Meridional Overturning Circulation (AMOC; bottom, right) for one simulation with synchronous coupling and three simulations with periodical synchronous coupling for different initial conditions (black, blue, purple).

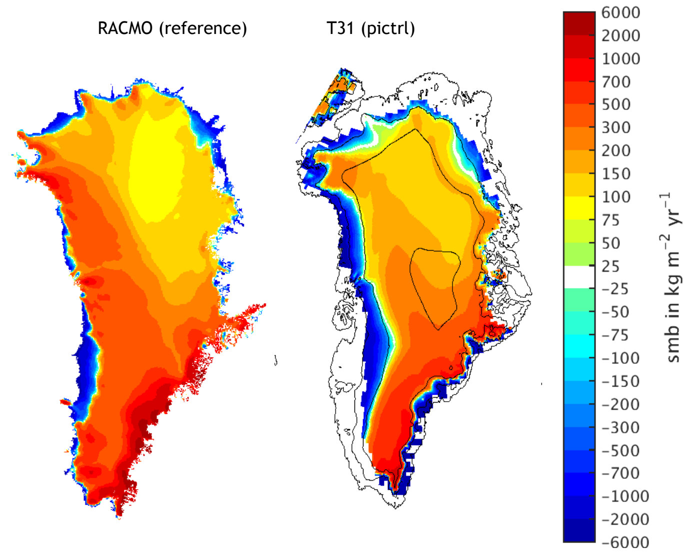

Fig. 2: Surface mass balance from observational reconstructions (RACMO; left; Noël et al., 2015*) and obtained with the energy balance model (EBM) from hourly* MPI-ESM1.2 CR data.

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