Joint Report of PalMod Projects 989, 1030, 1029, 993 and 1192

Project: 989
Project title: PalMod WG1, Physical System
Project lead: Gerrit Lohmann (AWI), Gregor Knorr (AWI), Volker Klemann (GFZ), Uwe Mikolajewicz (MPI)
Report period: 2023-01-01 to 2023-12-31

Overview

During the allocation period of 2023 several effects led to a less-than-anticipated use of computational resources. These can be summarized as follows: further developments of the model systems at MPI-Met and at AWI, the need for which became obvious from the results derived from the simulations produced; problems with getting the model systems to run stable on Levante plagued PalMod WG1 far into 2023; an uncertain funding situation regarding the third phase of PalMod led to less-than-optimal working conditions; see below for details. Nevertheless, we derived relevant results from our work at DKRZ computing systems. Part of our work that will not be finished by the end of the year as a result of the aforementioned hurdles will be proposed for the upcoming allocation period.

Work at AWI

At AWI the focus was on investigating transient ice sheet growth and decay phases using AWI-ESM with interactive ice-sheets. Our different simulations show that initial phases of ice growth at the last glacial inception was influenced by the choice of initial conditions. However, after 117 ka changes in atmospheric greenhouse-gas concentrations and Earth‘s orbital configuration are more important, with the latter forcing factor being dominant. These findings at the very beginning of the last glacial cycle differ from the ice growth dynamics that dominate into the Last Glacial Maximum (LGM, 21 ka before present (BP)).

For this phase three transient simulations (experiments Tran_Glac1d, Tran_Paleomist and Tran_PISMindex) have been conducted (Figure 1) with the same insolation configuration (Berger, 1978) and atmospheric greenhouse gas concentration changes (Köhler et al., 2017) covering the period from 38 ka to 21 ka. The experiments only differ in their initial ice sheet configurations (especially over North America, NA) at the starting point 38 ka as they are based on three different ice sheet reconstructions (Glac1D-38k, Paleomist-38k and PISM-index-38k, Fig. 1b-d). Two of the initial conditions are taken from the Glacial Isostatic Adjustment (GIA)-based ice sheet reconstructions Glac1D (Tarasov et al., 2012) and Paleomist (Gowan et., al 2021), respectively. Another initial condition is obtained by a standalone ice sheet simulation using a glacial index method (PISM-index). The Laurentide Ice Sheet (LIS) coverage in Glac1D-38k is comparatively extensive (the southwestern margin of the LIS almost reaches the LGM extent already at 38 ka), while in Paleomist-38k ice sheets are significantly reduced. In PISM-index-38k, an asymmetrical distribution of the LIS is exhibited, with the ice sheet over the eastern region being more extensive, while largely reduced over the western region. Based on these different initial ice sheet conditions our simulations of NA ice sheet evolution, from an intermediate size towards their full LGM extent, show that initial NA ice sheet differences at 38 ka (i.e., prior to the final phase of major ice growth) are erased by feedbacks between atmospheric circulation and ice sheet geometry that modulate the ice sheet development during this period. Most notably, different atmospheric moisture transport regimes from the North Atlantic warm pool towards the interior of the NA continent during summer control the NA ice sheet advance via a net surface mass balance gain at the southern ice sheet margin (Fig. 1). This provides a self-adaptative mechanism in the development of a fully-grown NA ice sheet that might hint to a preferred state via interactions between different Earth System components (Niu et al., 2023).

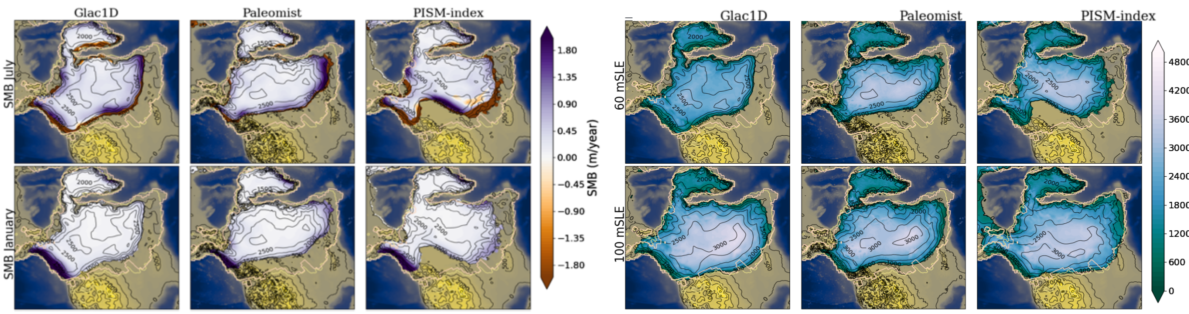

Figure 1: *Ice sheet surface mass balance for July (first row) and January (second row) and associated simulated ice sheet thicknesses (m) for initial conditions at 38 ka BP from GLAC1D (left), PaleoMist (middle), and a glacier index simulation (PISM index, right). The simulated ice sheet configurations are equivalent to sea level changes of 60 m (upper right row) and 100 m (lower right row) for volumes.*

Work at GFZ

At GFZ (WP1.4), we improved the global 3D viscosity structure in VILMA. We implemented an improved global lithosphere model that is derived from the better constrained WINTERC-G (Fullea et al., 2021) temperature model and embedded it in the global VILMA viscosity structure following Bagge et al. (2021). Furthermore, we developed a global structure that is refined for Antarctica including geodynamic realizations from Haeger et al. (2019). Using these new Earth structures we performed VILMA-3D test runs on Levante. In addition, we improved the rotational feedback implementation in VILMA-3D (Klemann et al., in prep) and performed ensemble model runs for VILMA-1D and VILMA-3D with and without the new rotational feedback component in VILMA. The 3D model ensemble differs in 18 3D Earth structure realizations (Bagge et al., 2020). With the new implementation the typical rotational 2-1 pattern is visible, with higher present-day uplift rates in South America and Western Asia and reduced present-day uplift rates in North America and Australia (Figure 2, right). The present-day polar motion in the 3D model ensemble is closer to the observations than the 1D models (Figure 2, left).

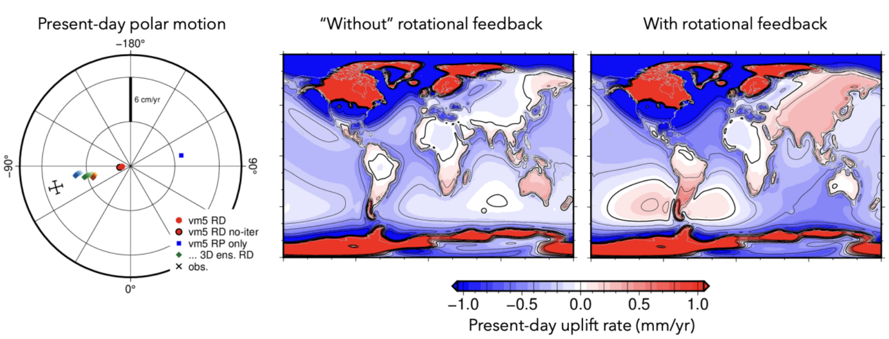

Figure 2: *Present-day polar motion for the 1D VILMA model with old (RP only) and new (RD) implementation of the rotational feedback and for the 3D VILMA ensemble with new rotational feedback implementation. The observation is shown as comparison (left). Present-day uplift rates for the VILMA model with old (center) and new (right) rotational feedback implementation.*

Work at MPI

At MPI-Met, we performed our first fully synchronously coupled simulation from 49 ka BP to present-day with our MPI-ESM-CR-mPISM-VILMA model system. The simulation covers parts of the last glacial period and of the last deglaciation. The simulation successfully produces episodic ice-discharge events from the northern hemispheric ice sheets, known as Heinrich Events and regarded as one of the dominant signals of glacial climate variability during the Marine Isotope Stage 3 (MIS3, ca. 65–25 ka BP) era. The addition of freshwater to the North Atlantic through Heinrich Events immediately results in a weakening of the AMOC, which in turn triggers more climatic changes such as a decrease in precipitation over the European continent. This first experiment indicates the potential and highlights the necessity of using coupled climate-ice sheet-solid earth models to capture abrupt climate changes during the last glacial cycle.

To gain a more detailed understanding of the driving processes behind Heinrich Events, we have used coupled ice sheet-solid earth simulations driven with climate forcing from the fully coupled simulation with the MPI-ESM-CR-mPISM-VILMA model system. We identified surface mass balance and surface temperature as key parameters for controlling the timing of Heinrich Events. These findings enabled us to propose a new physical mechanism behind Heinrich Events that is based on internal ice-sheet oscillations that are paced by an atmospheric perturbation signal caused by Dansgaard-Oeschger cycles. Unlike earlier theories, our mechanism is able to reproduce the main characteristics of Heinrich Events as known from the paleo record.

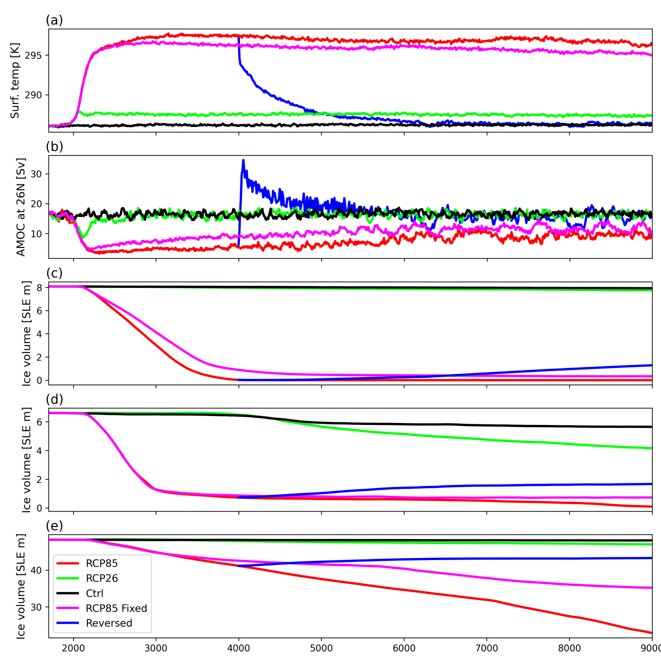

Figure 3: *Projection under different emission scnearios of (a) global mean surface temperature, (b) AMOC strength, (c) Greenland ice sheet volume, (d) West Antarctic ice sheet volume, and (e) East Antarctic ice sheet volume.*

We used the most realistic fully-coupled deglaciation simulation with our MPI-ESM-CR-mPISM-VILMA model system as initial condition for our first set of long-term future projections (Figure 3). The projections were integrated for 7,000 years into the future and covered the low (RCP26) as well as the high (RCP85) emission scenarios. In the RCP26 scenario, all ice sheets, except for the West Antarctic ice sheet, show little ice-volume changes. A notable sea-level rise contribution is only simulated 4,000 years into the future and the overall contribution of 4 m after 7,000 years is relatively low. The stability of the global climate is also illustrated by the moderate global temperature increase of 1.5°C and a stable AMOC throughout the simulation. In contrast, in the RCP85 scenario, the global temperature increases of ~10°C results in much more dramatic ice-sheet changes and weakening of the AMOC. The Greenland ice sheet has largely disappeared by the year 4,000. Large portions of the West Antarctic ice sheet have disappeared by year 3,000, with only a significant fraction of the East Antarctic ice sheet remaining. Overall, the global simulated sea-level rise after 7,000 years amounts to ca. 40 m.

The projections of the RCP85 scenario revealed that the ocean model grid did not extend far enough south to simulate the strong retreat of the Antarctic ice sheet. As a consequence, additional model development was necessary. We used this opportunity to implement a higher ice-sheet resolution in the Southern Hemisphere and include a dust scheme into the model system. The ongoing model development in combination with continuing run problems of the model system on Levante as well as an uncertain funding situation over the last months however resulted in far fewer production simulations than initially planned, and consequently lead an expiration of computational resources. With the improved model system nearly ready and the funding secured, we have shifted a number of simulations planned for the previous allocation period to the coming allocation period.

Project: 1030

Project title: PalMod WG2

Project lead: Victor Brovkin

Report period: 2023-01-01 to 2023-12-31

Overview

WG2 of PalMod aims at understanding and quantifying feedbacks between biogeochemistry and climate during glacial cycles.

PalMod WG2 contains work packages WP2.1 “Marine carbon cycle“, WP2.2 “Terrestrial carbon cycle”, and WP2.3 ”Methane cycle”. During the reporting period all work packages requested computation time from DKRZ.

WP 2.1 “Marine carbon cycle“, CAU Kiel

We are investigating how the acceleration or slow-down of the sinking of marine detritus, especially due to variations of particle ballasting, may have affected atmospheric pCO_2 during glacial-interglacial cycles.

For 2023, 22240 node hours were allocated to our subproject (after a 60% cut; 55600 node hours had been requested). To be in line with PalMod3 project goals (focusing on the deglaciation) and to adapt to the 60% cut in computation time, we decided to postpone the originally planned glacial inception runs and to use our 2023 resources in the following two ways:

1. For PI and LGM time-slice simulations with prognostic pCO_2 including particle ballasting. For simplicity and to save computational time, we used a closed carbon cycle setup with neither sediments nor weathering fluxes from land.
2. To start a transient simulation of the last deglaciation, as above, with prognostic CO_2, closed carbon cycle and ballasting.

Within the first three quarters of 2023 we have used 73% of our resources (2134 / 8810 / 5273 node hours in the first / second / third quarters, respectively) and we expect to use all remaining resources by the end of the year to continue the transient deglaciation run.

Based on the time-slice experiments (Fig. 2.1), we found that the acceleration of marine detritus by ballasting shows potential to contribute to the glacial pCO_2 draw-down (Fig. 2.1a,c; ~8.5ppm for only positive LGM-PI sinking speed anomalies). However, local acceleration (mostly due to widely enhanced dust deposition and reduced primary production) is counter-balanced by the slow-down in other regions (e.g., reduced Saharan dust). A comparison of our simulations to runs by our project partners at MPI-M using the M^4AGO scheme, which in addition to ballasting also accounts for aggregate size and micro-structure changes, indicates that, for now, ballasting is the dominant effect for glacial-interglacial sinking speed changes (compare Figs.2.1a and 2.1b).

Even without accounting for the expected release of carbon from the land biosphere, our LGM model ocean did not take up enough carbon to draw down atmospheric pCO_2 to 190ppm (Fig. 2.1c). Additional CO_2 uptake and more realistic LGM initial conditions could be achieved by enlarging phosphate, DIC or alkalinity stocks (Fig. 2.1d). The transient deglaciation simulation itself has subsequently been started with increased DIC and alkalinity (from 'low CO_2-I' in Fig. 2.1d), but it has not yet reached interesting phases and will be analysed later. Publication of these results is in preparation and planned for 2024.

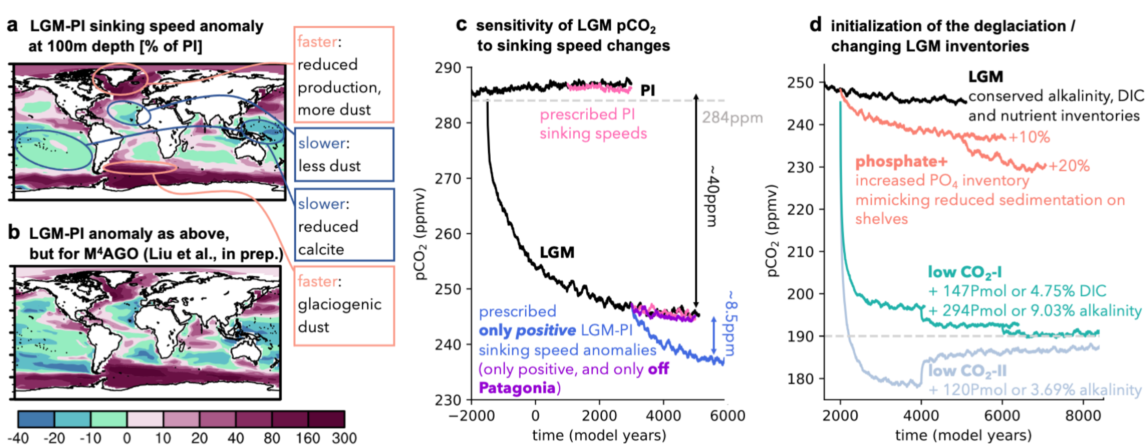

Fig. 2.1-1: MPI-ESM pre-industrial (PI) and Last Glacial Maximum (LGM) time-slice simulations with particle ballasting. Please see text and labels for explanations. Panels a,c,d show our results; panel b results based on MPI-ESM with the M^4AGO scheme by our project partners Liu et al. at MPI-M.

WP 2.1 "Marine carbon cycle", MPI-M

By the time of the report (Oct 2023), we used 44434 node hours, more than that granted to our subproject (41820 for Jan-Oct, which is 19.4% of the computing time allocated to bm1030).

Our work in 2023 encompasses four key topics on glacial ocean carbon sequestration and deglacial oceanic carbon and nutrient cycling.

A) We investigate the impact of ocean circulation and marine particle sinking on LGM ocean carbon and nutrient distributions in MPI-ESM. The simulations were first conducted in 2022. After a bug fix in the sediment module, we had to re-spin up the runs in 2023. Based on these runs, we are finishing the manuscript and plan to submit it in November.

B) An ocean biogeochemical model intercomparison project (OBGC-MIP) has been initiated within the PalMod OBGC groups to investigate which are the most robust mechanisms for glacial CO2 drawdown. Following the joint protocol, we conducted time-slice simulations for pre-industrial and LGM. We have conducted a preliminary comparison among models and to some proxy data (e.g. CO3). Based on this, protocols for new experiments are designed to improve, e.g. the respired carbon storage in the LGM ocean.

C) We conducted our first transient deglaciation simulation with prognostic CO2. In this run, the deglacial ocean CO2 outgassing is only about 30 ppmv, mainly driven by the solubility pump, and the biological carbon pump makes hardly any contribution. To investigate the role of model tuning and a sediment module on the deglacial carbon and nutrient cycling, we compared this new run to our previous transient deglacial simulation (under the same physics). We also compared the pre-industrial states in these simulations to present-day observations. We found that some variables, such as NPP, are sensitive to model tuning, and the sediment module strongly impacts surface alkalinity and silicate cycling. The comparison of existing deglacial runs provides directions for the future tuning for ocean biogeochemistry.

D) Our transient deglacial simulations contributed to a multi-model study conducted by CC1 (Fanny Lhardy), which used multi-model data to constrain deglacial changes in weathering alkalinity fluxes. This study suggests a significant deglacial decrease in alkalinity fluxes, which could contribute to removing excess alkalinity along transient runs if sources & sinks were both explicitly represented. Thus, the next deglacial simulations should take this into account.

WP2.1"Marine carbon cycle", AWI Bremerhaven

Four sensitivity experiments planed for 2023 (LGM equilibrium simulations, 4000 model years) were already conducted during November and December 2022, using ~16% of the computing time applied for 2023.

Due to the high uncertainty whether there will be a Phase III of PalMod, the PostDoc at AWI was paid by PalMod (50%) and another project from January to June 2023, so that finances for her position are covered over the entire year. Therefore, a part of the experiments originally planned for the first half year were shifted to the second half and the transient simulations will be started in November 2023. Taken together, about 50000 CPU hours are expected to be used until the end of 2023 and totally ~40% of our applied computing time will be used.

Another reason for this lower and delayed usage is the version change of the ocean circulation model (FESOM). Some improvements of the ocean physical states in the pre-industrial period have been achieved. However, tuning experiments are still required, postponed to the end of 2023 and the beginning of 2024.

Experiments conducted were:

1. LGM experiments with alkalinity boosting

Four LGM time slice simulations were conducted with alkalinity boosting by 60, 80, 100 and 120 mmol m-3 in the initial alkalinity fields. All simulations were run for 1000 years after a physic spinup of 1000 years. The atmospheric CO2 was lowered from 284.5ppm to 222, 214, 202 and 192ppm, respectively, indicating that an alkalinity boosting of at least 120 mmol m-3 is required to reach the LGM CO2 level in the current AWIESM simulations with prognostic CO2 concentrations. These simulations were used for the model intercomparison project within WP2.

2. Fully coupled AWIESM with the sediment model MEDUSA

The development of the esm-tools to install, compile and run MEDUSA standalone was completed during 2022. The fully coupled AWIESM with MEDUSA was tested during 2023. The coupling of FESOM-REcoM and MEDUSA was published as preprint in Geoscientific Model Development Discussion (Ye et al. 2023) with two other papers describing the new released version of the biogeochemistry model RECOM3 (Gürses et al. 2023) and carbon isotopes in it (Butzin et al. 2023). Fully coupled simulations with MEDUSA will be done during Phase III.

3. Sensitivity simulations with respect to the impact of ocean circulation on marine carbon storage

A few ocean-only LGM simulations were run for 300 years with different states of ocean overturning and another 300—500 years with biogeochemistry. The preliminary results show that the depth and strength of LGM AMOC significantly affect the depth of the maximal carbon storage in the Atlantic Ocean (Fig. 2.1-2). However, the atmospheric CO2 does not much differ between these experiments. These preliminary results were presented at the KickOff meeting of Phase III in September in Bremerhaven and more in-deep analysis will be done until the end of 2023.

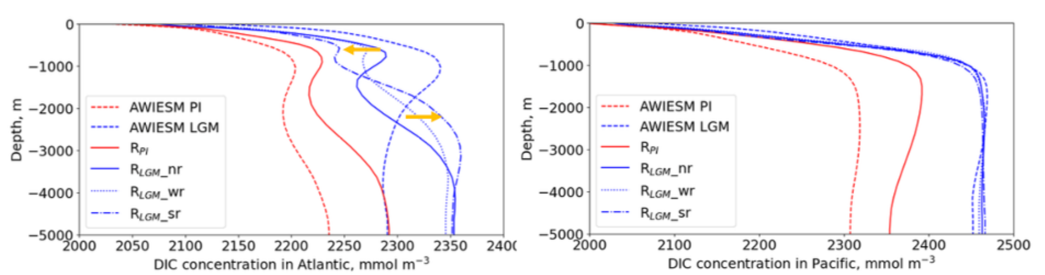

Fig.2.1-2: Comparison of basin-averaged DIC profiles of the coupled simulations for PI and LGM and ocean-only simulations with different overturning patterns. The yellow arrows show that the shallowing of AMOC shifts the DIC storage from the upper (around 1000m depth) to the deep ocean (below 1500m).

WP2.2 "Terrestrial Carbon Cycle", MPI-M

In 2023, WP2.2 continued developing and testing the testing the representation of carbon isotopes in JSBACH, performing numerous shorter transient experiments in order to investigate carbon isotope sensitivity to uncertain model parameters. Furthermore, we conducted a first experiment covering the entire last glacial cycle, together with WP2.3, to get an initial understanding of the dynamics of vegduring the early to mid glacial.

Finally, the main focus of WP2.2 during 2023 was the NH forest expansion during the deglaciation simulated by MPI-ESM 1.2 . These model results lead the forest expansion reconstructed from pollen data by several millennia (Dallmeyer et al., 2022). In 2023, the experiments performed aimed at clarifying the impact of a possibly to early expanding NH forest in the model on the simulated climate.

While an increase in forest cover during the deglaciation leads nearly everywhere on Earth to a local increase in precipitation, the simulated annual mean temperature is only remarkably increased in Asia (Fig.2.2-1), pointing to strong differences in the response of the climate to vegetation changes in Asia compared to the rest of the world. The impact of the Asian forest on the climate has been further investigated by time-slice sensitivity experiments, in which we kept the vegetation constant or tried to artificially slow-down the vegetation.

Due to delays in the project, the simulations could only be started recently. Therefore, we will use significant computing time in the last quarter of the year. Additional experiments will be needed in 2024 to better understand vegetation dynamics and their impact on atmospheric circulation and climate.

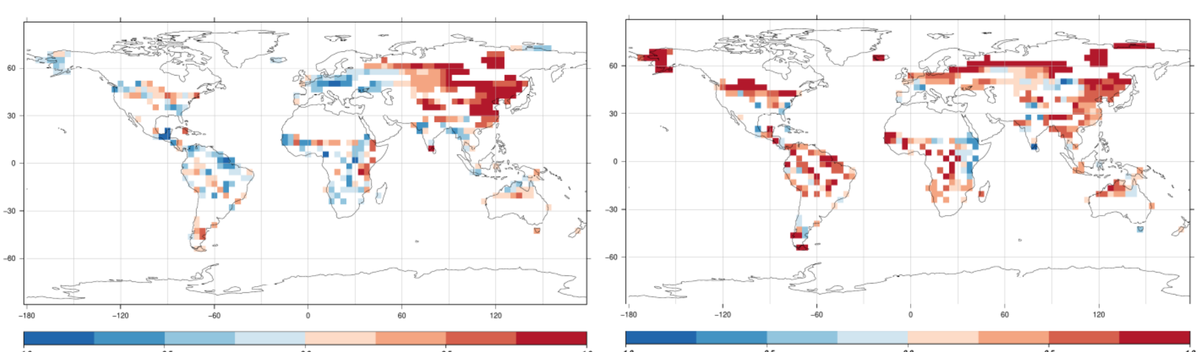

Fig. 2.2-1: The impact strength of forest cover changes on annual mean temperature (left) and precipitation (right), expressed by the Pearson correlation coefficient

WP 2.3 "Methane cycle" (MPI-M)

For 2023, WP 2.3 had planned to investigate MIS3 and the glacial inception. Due to the BMBF decision to delay funding the third phase of Palmod, funding of personnel ended in April 2023 and work on the project had to be reduced. Therefore a number of the experiments planned for later in 2023 could not be performed.

For MIS3 we did not manage to set up appropriate dynamical boundary conditions — while we could artificially induce Heinrich events in the model, we were unable to force the model into the warming cycle of D/O events, and the fully coupled system including the ice sheet is still not available from WG1.

We did manage to perform one full glacial cycle experiment from the Early Eemian to the present, forced by the prototype of an ice sheet reconstruction spanning 122 ka BP to LGM.

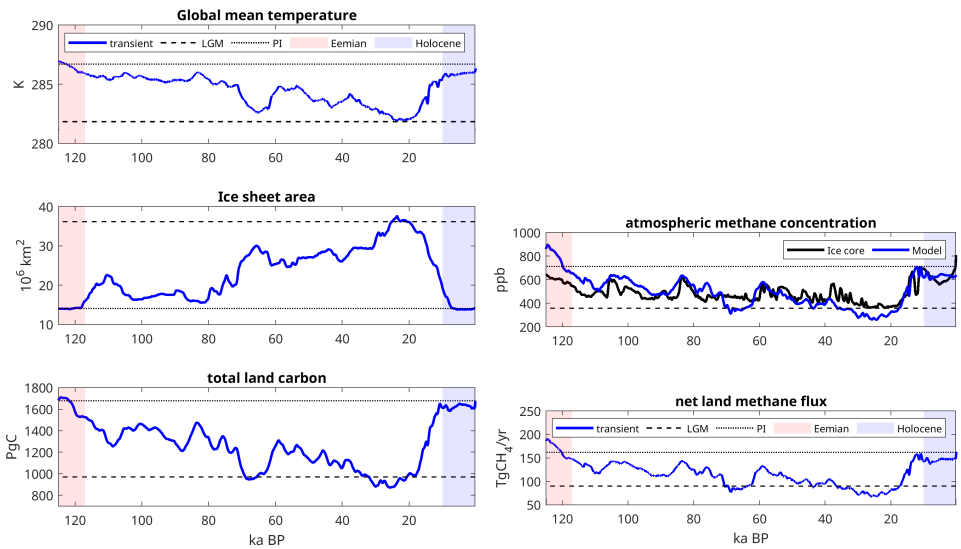

Fig. 2.3-1: *Glacial cycle in MPI-ESM. Left: temperature, ice sheet area and land carbon, right: atmospheric methane and methane flux.*

These initial tests are extremely promising: The climate evolution is largely within the range of reconstructions, through methane is overestimated during the Eemian and underestimated at LGM.

Finally, WP 2.3 published the methane experiments undertaken in previous years (Kleinen et al., 2023a), also publishing the full model output defined for Palmod in the ESGF (Kleinen et al., 2023b).

Project: 1029

Project title: PalMod II, Isotope modeling with AWI-ESM

Project lead: Martin Werner (AWI)

Report period: 2023-01-01 to 2023-12-31

1. Used resources in 2023

During the year 2023, we have so far consumed about 55,000 node hours within the framework of PALMOD. The granted numerical resources for our sub-project WP3.3-TP2 were used for a number of simulations including

(1) new equilibrium simulations under pre-industrial (PI), mid-Holocene (MH), and last glacial maximum (LGM) boundary conditions,

(2) a fully-transient continuous simulation of the last 8,200 years, starting with the early-Holocene (EH) cold event around 8.2k by prescribing a 100-year constant freshwater input over the Labrador Sea,

(3) a continuation of accelerated transient simulation experiments spanning the time periods 21-9k.

If not mentioned otherwise, all the above-mentioned experiments were performed using AWI-ESM-wiso, an AWI-ESM model version enhanced by stable water isotope diagnostics.

The responsible PostDoc scientist for this sub-project, Dr. Xiaoxu Shi, left the institute by the end of the year 2022 to take a new position as an associate professor at the Frontier Research Center of the Southern Marine Science and Engineering Guangdong Laboratory, Zhuhai, China. She has continued some of her unfinished work within the PalMod project as an associated guest researcher since then.

In the meantime, it took several months to find a suitable candidate to continue her work at AWI for the remaining PalMod II phase. Since June 2023 Dr. Yuchen Sun is employed for this project. Due to this change in personnel, some of DKRZ's HPC resources (approx. 21,000 node hours) could not be used as planned, especially in the second quarter of 2023.

2. Summary of achieved results

2.1 Pre-industrial and mid-Holocene equilibrium simulations

The simulations carried out in recent years with AWI-ESM-wiso for the PI and MH climate were completed at the beginning of 2023 and the results are now published. Key findings of this study are that AWI-ESM-wiso reproduces the observed PI isotope compositions in both precipitation and seawater well and captures their major differences between the PI and MH conditions. The simulated relationship between the isotope composition in precipitation ($\delta^{18}O_p$) and surface air temperature is very similar between the PI and MH conditions, and it is largely consistent with modern observations despite some regional model biases. However, the ratio of the MH–PI difference in $\delta^{18}O_p$ to the MH–PI difference in surface air temperature is comparable to proxy records over Greenland and Antarctica only when summertime air temperature is considered. For more details on the results, we refer to Shi et al. (Geoscientific Model Development, 2023). As the FESOM ocean model has been updated to a new model release with several important bug fixes in the first half of 2023, we have started to re-run the PI and MH simulations with this updated model version for comparison reasons in the more recent months. This will help us to distinguish model result changes due to this new FESOM release from changes due to changed boundary conditions for the transient deglacial and Holocene experiments planned for PalMod Phase III.

2.2 Transient simulations of the Holocene and last deglaciation

In 2023, we have finalized a fully-transient simulation of the last 8,000 years with AWI-ESM-wiso, starting at the 8.2ky event. To our knowledge, this is the first isotope-enabled simulation without any acceleration technique covering this long Holocene period. For the low latitudes, initial analyses of the model results reveal that the monsoon domains experience a drying trend (with an increasing $\delta^{18}O_p$) from 8k to present

(Fig. 1). Simulated trends in $\delta^{18}O_p$ are in good agreement with subtropical speleothem and Antarctic ice core records, and for both Greenland and Antarctica, the temporal $\delta^{18}O_p$-T slope seems to remain stable during the whole Holocene. The analyses of this transient simulation are still in progress and work has begun on preparing a publication of these results.

During the year 2023, we have also continued our work on transient simulations of the last deglaciation with AWIESM-wiso. While initial simulations could already be performed (see last year's report) some more technical work was the focus of the last months to enable the usage of different prescribed ice sheet extents, to fully consider the temporal change of ice sheet height as additional meltwater input at the glacier boundaries, and to correctly initialize additional ocean grid points due to a changed sea level. Analyses are ongoing and detailed results of these simulations will be shown in the next report.

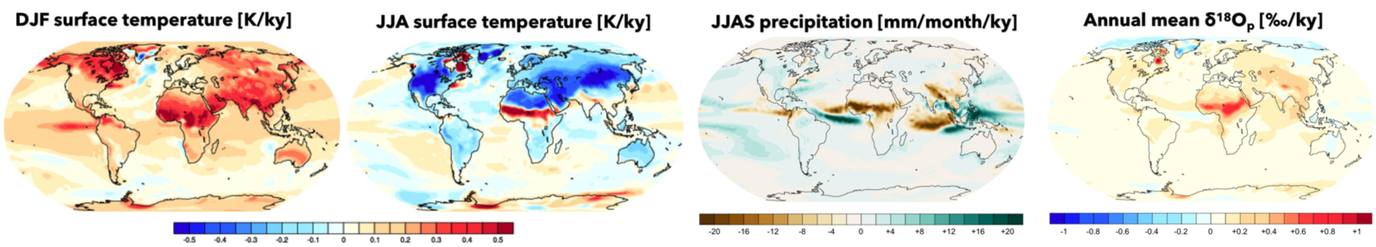

Figure 1. Simulated temperature, precipitation and $\delta^{18}O_p$ trends during the last 8,000 years, as modelled by AWI-ESM-WISO (from: X. Shi et al., A 8,300-year transient simulation with stable water isotopes based on AWIESM-wiso, PalMod General Assembly, 2023).

2.3 LGM equilibrium simulations

For the simulation of the LGM, analyses and improvements of our AWI-ESM-wiso simulations are ongoing. The already reported erroneous local warming simulated in our LGM experiment for Baffin Bay could so far only be improved to a limited extent by various model tuning or the consideration of icebergs (see last year's project report). Through the analysis of a series of AWI-ESM simulations, it could be shown that a rather complex interplay between the different boundary conditions and forcings exist (Shi et al., Climate of the Past, 2023). The model results reveal that both greenhouse gases and ice sheets play a major role on defining the LGM surface temperature change. Decreased greenhouse gases in LGM as compared to present-day leads to a non-uniform global cooling with polar amplification effect. The presence of LGM ice sheets favours a warming over Arctic Ocean and North Atlantic in boreal winter, as well as a cooling over regions with the presence of ice sheets. The former is induced by a strengthening in the Atlantic meridional overturning circulation transporting more heat to high latitudes, whilst the latter owing to the increased surface albedo and elevation of ice sheets (Fig. 2). It is not yet clear which of these factors is leading to the simulated pronounced local warming in Baffin Bay in the current AWI-ESM model release.

3. Future plan

The remaining resources in 2023 will be used for several long-term stochastic hosing simulations under the LGM boundary conditions. In cooperation with the physical modelling of WG1 we will also continue working on the proposed transient simulations of the last deglaciation and the last inception. For 2023, details of our work plan are described in the computing resources application request.

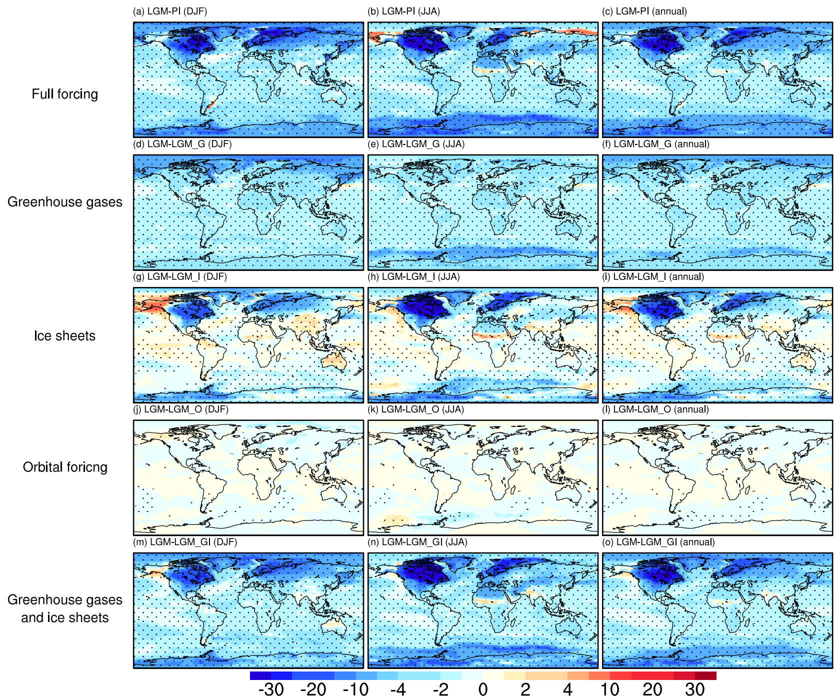

Figure 2. Simulated LGM-PI surface air temperature anomalies (in degree K) for different LGM boundary conditions and forcings. See Shi et al. (ClimPast, 2023) for details.

Project: 0993
Project title: PalMod II, CC1 – Cross Cutting Activities
Project lead: Hendryk Bockelmann (DKRZ)
Report period: 2023-01-01 to 2023-12-31

Overview

In subproject TP3 we developed a combined dynamic lake and river model for MPI-ESM transient climate runs to model the large proglacial lakes that formed along the edge of the retreating ice-sheets during the deglaciation and other paleo-lakes. This builds on an existing model of dynamic rivers from a previous stage of the project. Changing lakes and rivers affect the climate through their effect on the rate and distribution of fresh water input into the ocean (include lake outburst floods) and the interaction between lake surface and the atmosphere. In 2023 we performed a series of transient deglaciation experiments with MPI-ESM to test and iteratively develop this combined lake and river system model. This included testing for a closed fresh water budget and testing our lake-atmosphere coupling scheme. The model is now complete with the first version of the lake-atmosphere coupling and further development is ongoing of a second version of the lake-atmosphere coupling scheme with an improved treatment of lake temperature and to analyse the chronology of the formation and drainage of Lake Agassiz (the most significant pro-glacial lake during the last deglaciation).

In subproject TP4 we improved the ice shelf-ocean melt module PICO coupled to the ice sheet model PISM. In collaboration with partners in WP1.4 at GFZ we have coupled PISM-PICO with the GIA model VILMA. In 2023 we used DKRZ resources to run simulations of the Antarctic Ice Sheet over the last two glacial cycles, coupled to a new version of the solid-Earth model VILMA, with improved implementation of the rotational feedback (Klemann et al. in prep). One challenge was the maximum grounding line retreat during interglacial climates, in which WAIS collapse enhanced by PICO ocean melt can be mitigated by local effects of isostatic rebound from VILMA. We tested the sensitivity for different 3D Earth structures as VILMA input to investigate feedbacks with the ice sheet grounding lines during glaciation and deglaciation. Moreover, we investigated the resolution of the sea-level component and of the visco-elastic part in VILMA (n128, n256, n512) during grounding line migration, as well as coupling interval length (1000yr, 100yr, 10yr). The results will be published in Albrecht et al.2023 (submitted).

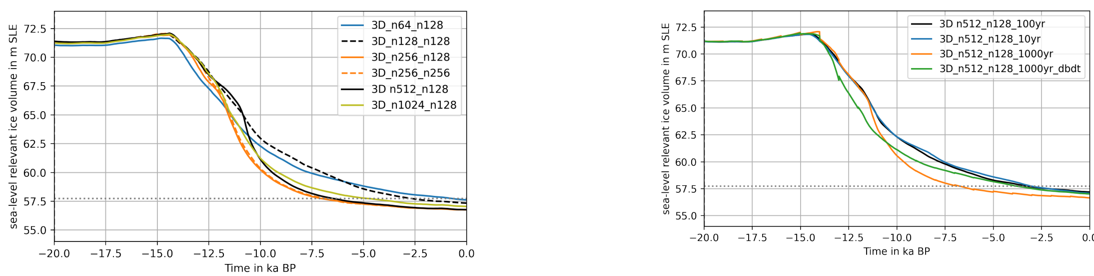

Figure 1: Sea-level relevant Antarctic ice volume over last 20 kyr for different coupling intervals (a) and different spatial resolutions (b).

Project: 1192
Project title: PalMod II, PalMod Data Project
Project lead: Swati Gehlot (DKRZ)
Report period: 2023-01-01 to 2023-12-31

Overview

The project will be led by PalMod Phase III cross cutting working group Data Hub (subproject CC1) which manages the model data produced and used by WG1, WG2, WG3.

The project was created as a data project as an integral part of the PalMod Phase II Verbundprojekt CC.2 in year 2021. As described below, the project bk1192 provides a so-called “PalMod internal data pool” that stores and manages core results and data of the scientific modelling WGs WG1, WG2 and WG3 of the PalMod Phases II and III. Moreover, this will allow researchers from other work packages and working groups to use these data sets of common interest. Besides facilitating the intra-project collaboration, we assume that this will maximize data reuse while minimizing duplication of datasets on multiple accounts.

For this, all PalMod scientists, who need access to that data pool, which will be created during the runtime of the project PalMod and stored under account bk1192, will become members of the project.

The project is expected to exist throughout the Phase III of the project runtime and possibly afterwards provide a space, where the scientific community will still be able to access and work with the (adhoc)data.

Summary of the work in 2023

A workflow and a recipe detailing the import, access, share and distribute the data via the common data pool supplied by bk1192 was developed (and distributed among the PalMod community) in close collaboration with the scientists with respect to their concrete requirements. Fig. 1 shows a systematic usage plan of bk1192 for inflow and outflow of PalMod data.

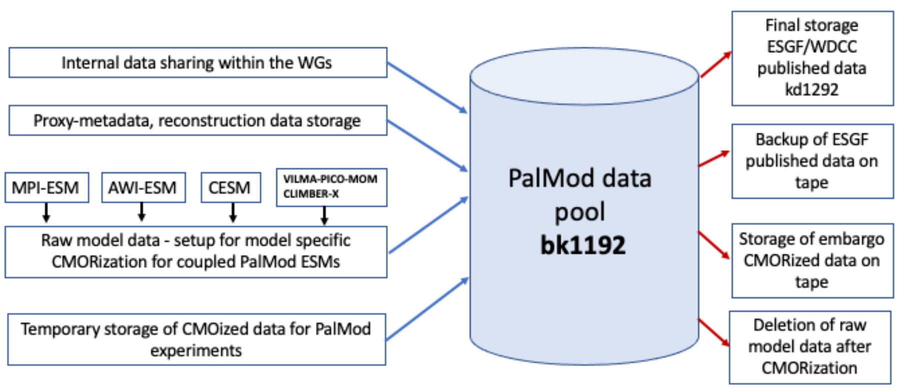

Fig. 1: *Storage workflow for PalMod data pool bk1192 resource. The multiple sources of data input are shown with black blue arrows. The red arrows show the subsequent movement of data after the CMORization is completed for coupled ESMs.*

Since the first allocation of space bk1192 in early 2021 (105TB available each for /work and /arch), the PalMod data pool continues to build up and grow in storage with the shared data from project partners (currently using ~80TB, with more data (AWI and CESM models) planned to be shared in October 2023). The table below lists the current overview of storage of shared data at bk1192.

Overview storage space for the data project bk1192

Working Group/ Work package	Lustre work [GByte]	/arch [GByte]	/docu [GByte]
WG 1/ WP 1.1 (MPI-ESM)	38.608	0	0
WG 1/ WP 1.4 (VILMA)	68	0	0
WG 2 / WP 2.1 (MPI-ESM)	9.100	0	0
WG 2 /WP 2.3 (MPI-ESM)	6.100	0	0

WG 3/ WG 3.2	0.04	0	0
WG 1/ WP 1.1 (MPI-ESM) - v2	112.000	0	0
WG 1/ WP 1.2 (AWI-ESM)	9.884		
CMORized data storage (temp.)	700 (till 06.2023)		
Total used	**178.000**	**0**	**0**

Since August 2021, the PalMod data pool is used as a primary resource for development of model specific CMORization, ESGF publication and WDCC archiving workflows within PalMod-II, and to be extended towards PalMod Phase III. Currently the test setups consist of data from all the three coupled PalMod ESMs.

Two sets of PalMod experiments for MPI-ESM were published on DKRZ ESGF portal (https://esgf-data.dkrz.de/search/palmod/) in 2022-23.

These ESGF published simulations comprised of MPI-ESM transient simulations in Kapsch et al., 2022, (https://doi.org/10.1029/2021GL096767), and MPI-ESM transient deglaciation runs with Methane Future Scenarios in Kleinen et al, 2021 (doi:10.1088/1748-9326/ac1814).

The final set of CMORized data is stored at dedicated long term PalMod tape resource (kd1292), along with a backup on bk1192 tape resources and via long term archival via WDCC (World Data Centre for Climate).