Project: **903**

Project title: **Kohlenstoff im Permafrost: Bildung, Umwandlung und Freisetzung – CarboPerm**

Principal investigator: **Victor Brovkin**

Allocation period: **2019-01-01 to 2019-12-31**

Project overview

The goal of subproject 2 of the KoPf project is to provide quantitative projections of greenhouse gas emissions due to the degradation of permafrost under low- and high-end scenarios of anthropogenic warming and to investigate under which conditions the current Arctic carbon sink will turn into a future carbon source. This requires improving and further developing the MPI's earth system model (MPI-ESM) with respect to the processes relevant for the carbon dynamics in permafrost affected regions. The development encompasses the representation of mechanisms that dominate the formation of soil carbon stores in permafrost affected region, their decomposition as a result of permafrost degradation and the subsequent release of carbon to the atmosphere. The model's performance will be evaluated with respect to observations of emissions of greenhouse gases in the permafrost region in North-Eastern Siberia, and regional CO2 and CH4 budgets will be compared to the results of an atmospheric inversions, provided by the Max Planck Institute for Biogeochemistry.

Range of planned work from the scientific view

In the present standard version of JSBACH, i.e. the model version used for CMIP6, the process of melting and freezing of water within the soil is not accounted for, as it substantially increases the coupled model's existing warm bias in high northern latitudes. For projections of greenhouse gas emissions due to the degradation of permafrost, however, this is a key process as it strongly influences soil moisture and temperatures within permafrost affected areas and, consequently, the input, storage and decomposition of soil organic material. Here, we aim to perform additional simulations that will help to better understand the effect of the phase change on the existing model bias and, if possibly, to devise a strategy that will allow us to use the fully coupled MPI-ESM in the KoPf project.

Additionally, we found that the inclusion of the melting and freezing process, in combination with a more realistic representation of the soil's thermal and hydrological properties, strongly affects the simulated vegetation dynamics on the intermediate timescales (30 - 100 years) relevant for the KoPf project. This is mostly a result of the effect of changes in the soil's hydrological properties on the plant-available water and nitrogen and will require adapting the respective parametrizations.

With respect to the carbon cycle in permafrost regions, especially wet- and peatlands have a high relevancy as they store almost a third of the soil organic matter, i.e. about 300 Pg,C in the affected regions. The wetland scheme that was implemented in JSBACH in the course of this project does not affect the hydrological cycle as it merely allows a diagnostic sub-grid scale division into dry and wet fractions. However, wetlands also act as an additional water storage at the surface that adds retention capacity and mitigates peak flows. This aspect needs to be better represented in the model as it has a strong influence on the seasonality of methane emissions. Furthermore, the formation of peatlands does not only depend on physical properties of the terrain and the soil but on soil and vegetation interactions. These interactions are not yet represented in JSBACH and further model development is required to study the importance of peatlands for CH4 and CO2 emissions.

Finally, we found that the active layer depth is directly affected by the vertical discretization of the soil column. In JSBACH, a given soil layer is represented by just one temperature and, in addition, this temperature can only rise above 0.0°C whenever all soil ice has completely melted. As a consequence, a finer vertical discretization leads to a deeper active layer, as the energy present in a given coarse layer may not suffice to melt all ice and raise the layers temperature above 0.0°C, while it would be enough to do so in a given number of finer layers that are contained in this coarse layer. Here, further studies are required to evaluate different model setups with respect to their suitability to yield an appropriate representation of the active layer depth.

Mathematical and/or computational aspects / Algorithmic/mathematical/numerical methods and solution procedures / Particular suitability to solve the problem with help of HLRE-3 / Performance benefits depending on the number of used CPUs (scalability)

For all our we use the MPI-ESM or its component JSBACH. As this is a standard case, we do not provide any Information about mathematical/computational aspects, HLRE-3 suitability, and scalability.

Required computing time and amount of storage space

Especially the nitrogen cycle is connected to very long timescales. Hence, most of the simulations required for tuning will be performed using the low-resolution (LR) stand-alone model (JSBACH) with a monthly output time-step. Additionally, the open model development will also be performed using an LR setup of JSBACH. In contrast, the effect of melting and freezing of soil water on surface temperatures is negligible when using the stand-alone model. Hence, investigating the respective impacts on the model's warm bias requires using the fully coupled model (LR). For evaluation, further simulations with the coupled model (LR) are required. It should be feasible to complete the abovementioned steps using approximately 23000 (20000 offline and 3000 coupled) simulation years. The detailed simulation plan is listed in Tables 1. In summary, we request 25400 node hours computing time and 21 TB storage space.

Table 1. Required computing time and storage space for year 2019

Testing (offline)	**Run years**	**Node-hours**	**Storage**
Thaw depth	100 * 10	0.04 /year	200 MB/year
Wetlands	100 * 20	0.04 /year	200 MB/year
Vertical C-pools	100 * 20	0.04 /year	200 MB/year
Vegetation dynamics	1000 * 15	0.04 /year	200 MB/year
Testing (Coupled)	Run years	Node-hours	Storage
Warm bias	50 * 20	8.2 /year	5.4 GB/year
Carbon cycle	1000 * 2	8.2 /year	5.4 GB/year
Total computing time: 25400 node hours, total storage space: 21 TB			

Additional value compared to other projects

The KoPf project uses an adapted version of the latest MPI-ESM release to quantify greenhouse gas emissions resulting from the degradation of permafrost. Hence, the project benefits from the most recent implementations of biogeochemical processes that are highly relevant for the carbon cycle in arctic regions, such as an explicit representation of the terrestrial nitrogen cycle. At the same time, the project's specific requirements lead to substantial advances in model development with respect to the terrestrial carbon cycle in the MPI-ESM, e.g. introducing a vertical structure for the representation of the soil carbon dynamics.