Project: 903

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

Principal investigator: Victor Brovkin

Report period: 2019-01-01 to 2019-12-31

Model development

1 Surface atmosphere interactions

The simulated surface temperatures are substantially larger in coupled simulations with the MPI-ESM (ECHAM6/JSBACH), if phase changes in the soil are taken into consideration. This is especially the case for the summer temperatures in Siberia. Unfortunately, the temperature increase adds to an existing warm bias, which becomes so large that the respective simulations can not be used for scientific studies.

The increased surface temperatures could be linked to a decrease in evapotranpisration and the resulting decrease in latent cooling. The main cause for this lies in the representation of plants in JSBACH which have a fixed rooting depth and can not adapt to continuously frozen soils by developing shallower roots. There are similar problems for the evaporation from bare parts especially when accounting for the presence of organic material at the surface which facilitates the percolation into deeper soil layers. Another issue is the model's infiltration parametrization that does not allow water to enter the soil when temperatures are at the melting point, causing the entire snow melt flux to enter the surface runoff.

Here, the respective formulations were adapted and the surface temperature bias could be reduced substantially. This greatly increases the chances to conduct fully coupled simulations within the KoPf project (Fig. 1).

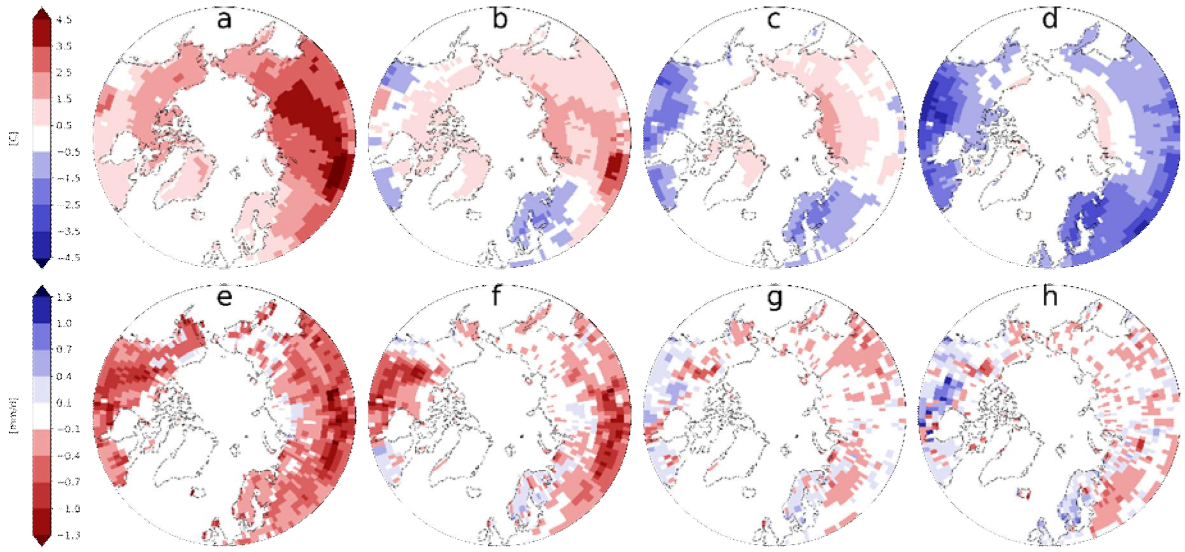

Figure 1: a) Differences in simulated surface temperature (April – September mean; over the period 1980 - 2009) between MPI-ESM versions with and without accounting for phase changes in the soil (the latter being the standard CMIP6 model version). b) Same as a, but with adapted formulations for transpiration and evaporation. c) same as b but with adapted formulations for infiltration and drainage. d) Differences in simulated surface temperature between the MPI-ESM version used in the KoPf project and the standard model version (for the KoPf model all parameters were chosen in a way to achieve a maximum cooling of the surface). e-h) same as a-d but for evapotranspiration.

Unfortunately, we could not complete the tuning of the model as a large part of the preparatory work relies on JSBACH offline simulations for which the appropriate forcing (derived from the CMIP6 scenario simulations) became available only late during this year. This prevented the planned use of our allocated resources and means that the main focus of our work during the remainder of the KoPf project will be on completing a model version that allows fully coupled simulations with an adequate representation of the high northern latitudes.

2 Wetlands and inundated areas

Inundated areas are highly relevant for the biogeochemical processes at and below the surface and their extent largely determines the production of methane within the soil.

During the first year of the KoPf project we implemented a wetland scheme (Kleinen et al., 2012) that uses a TOPMODEL-approach to estimate the fully saturated fraction of the grid box in which methane is produced. However, in large areas, especially in western Siberia, the surfaces are flooded as a result of the spring snow melt and these areas are not well captured with the above approach.

For a better representation of inundated areas, we implemented the WEED scheme – short for wetland extent dynamics --, which is currently being developed at the MPI. The scheme provides a surface reservoir that stores water before it either infiltrates into the soil or enters the surface runoff, allowing for extensive wetland areas to form following the snowmelt peak in spring. This substantially improved the representation of wetlands in Siberia (Fig. 2).

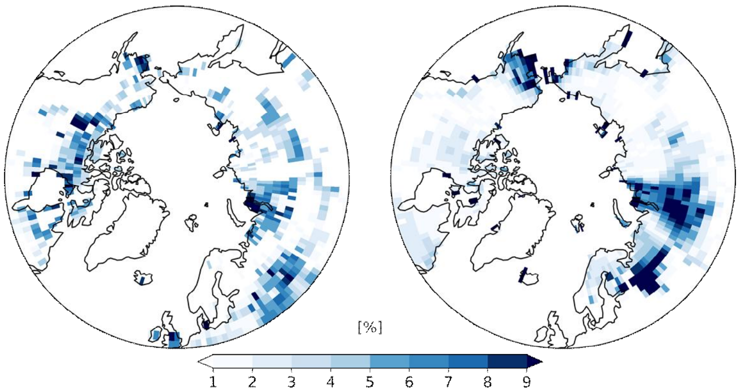

Figure 2: Simulated wetland/ inundated fraction: Estimated with the TOPMODEL approach (left) and estimated using the WEED scheme (right).

3 Thaw depth

Thaw depths determine how much of the soil carbon in permafrost-affected regions becomes available for decomposition, making them one of the key variables to determine the future greenhouse gas release from arctic soils. Here, we managed to substantially lower the simulated thaw depths (Fig. 3) making them much more comparable to observed thaw depths (Fig. 4).

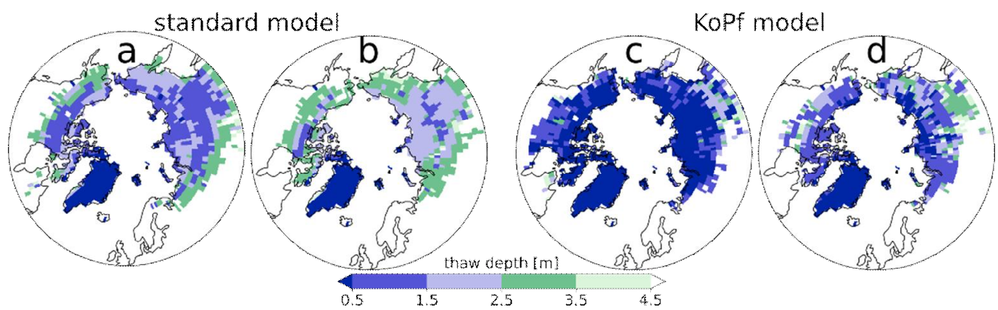

Figure 3: Simulated annual maximum thaw depth simulated with the MPI-ESM. a) Shows the 1990-2010 minimum simulated with the MPI-ESM standard version. b) same as a but for the 1990-2010 maximum. c) same as a but for the model version developed in the KoPf project. d) same as b but for the KoPf model version.

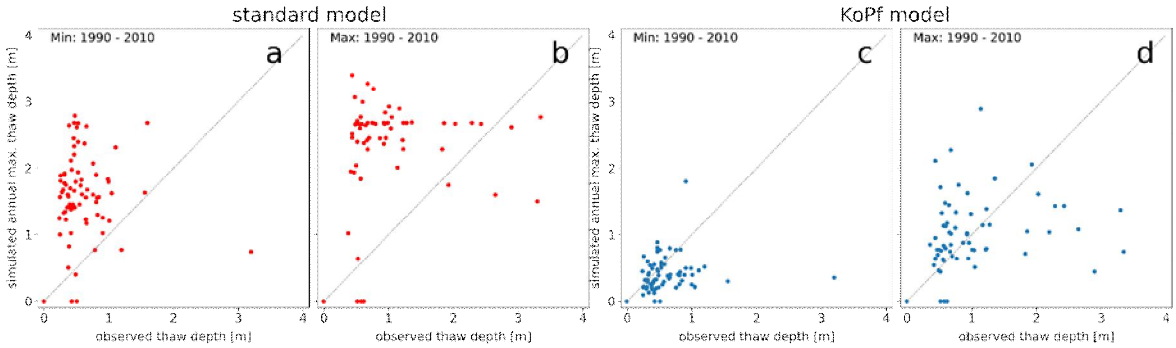

Figure 4: Comparison between simulated and observed thaw depths. The sub plots show the same model versions as in Fig. 3, again with the 1990-2010 minumum (a,c) and maximum (b,d). The observations constitute measurements at stations of the „Circumpolar Active Layer Monitoring Network“ (Brown, 1998).

Simulations

With the model developed in the KoPf project we are able to adequately represent land surface processes in high latitudes, allowing to study the behaviour of permafrost-affected soils in simulations with prescribed atmospheric conditions. Here, we found that that the CO2 fluxes increase substantially with increasing surface temperatures but decrease similarly when surface temperatures decrease again (Fig. 5). However the methane emissions behave very differently, showing only a small increase with rising temperatures, becoming potentially negative when the temperature forcing is reversed.

A paper describing these findings in detail is in preparation, to be submitted by the end of this year.

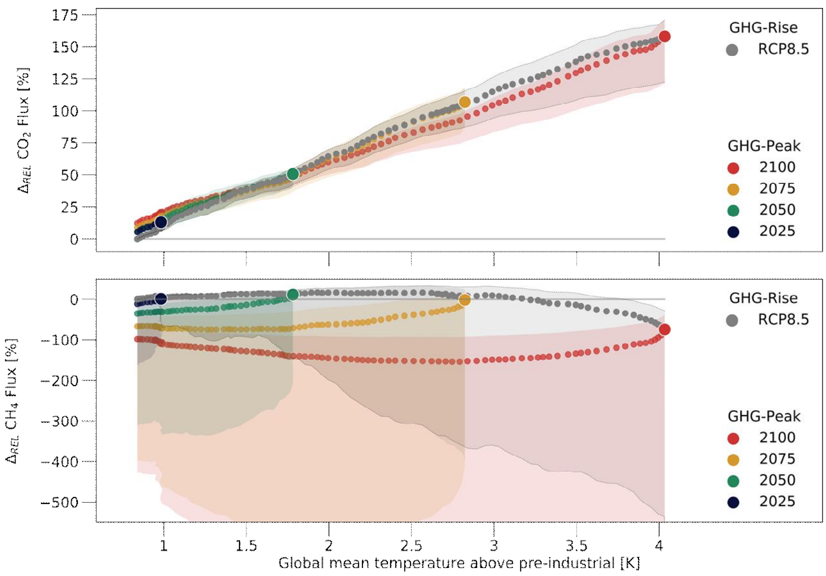

Figure 5: a) Simulated changes in soil CO2 fluxes from permafrost affected soils relative to changes in global mean temperature. b) same as a but for the soil CH4 flux. Grey dots indicate fluxes while temperatures decrease, while the coloured dots correspond to decreasing temperatures after a peak in the year 2025, 2050,2075 or 2100. The coloured areas indicate the spread across several simulations with different values for key parameters.

References:

Kleinen, T., V. Brovkin, and R. J. Schuldt. "A dynamic model of wetland extent and peat accumulation: results for the Holocene." Biogeosciences 9.1 (2012): 235-248.

Brown, J. 1998. Circumpolar Active-Layer Monitoring (CALM) Program: Description and data. In Circumpolar active-layer permafrost system, version 2.0. (ed.) M. Parsons and T. Zhang, (comp.) International Permafrost Association Standing Committee on Data Information and Communication. Boulder, CO: National Snow and Ice Center.