Project: **903**

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

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Report period: **2017-01-01 to 2017-12-31**

Project focus

During deglacial warming from the Last Glacial Maximum (LGM) to pre-industrial (PI) climate, the terrestrial vegetation was a strong sink of carbon through increased productivity stimulated by warmer temperatures and higher CO_2 levels. A key question concerns the role of terrestrial soils as a carbon source along the transition from the Glacial to the Holocene. Here, the MPI's Earth System Model (MPI-ESM) was used to investigate the soil organic carbon (SOC) stored in permafrost soils under glacial conditions, and the carbon dynamics under deglacial warming into the pre-industrial climate.

Model development and experiments

The soil carbon dynamics were investigated using the stand-alone (offline) configuration of the MPI-ESM's land surface model JSBACH in T31GR30 resolution, driven by a transient climate forcing for the period from the LGM to PI. The forcing was derived from a LGM time-slice experiment with MPIESM-1.2 in combination with a full transient glacial cycle experiment performed by the model of intermediate complexity CLIMBER2. JSBACH's standard permafrost physics was used with six additional soil layers that extend the soil column to a depth of 40m. The soil carbon dynamics were simulated with the YASSO model but, different to the standard model, a distinction is being made between active and passive SOC. The former is located within the active layer and exposed to conditions that allow decomposition, whereas the latter is located in perennially frozen parts of the soil, where no decomposition occurs. In addition to the passive SOC pools a soil carbon build-up module was implemented, which captures vertical transport processes that determine the vertical SOC distribution (Fig. 1).

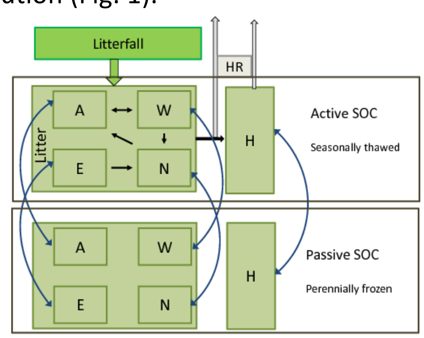

Figure 1: Extended soil carbon pool structure in JSBACH accounting for seasonally thawed and perennially frozen carbon (modified from Goll et al. 2014). In YASSO, soil organic matter is separated into groups of different chemical compounds (A,W,E: labile pools), an intermediate pool (N), and a slow humus pool (H). Carbon gain results from litter input, carbon loss from heterotrophic respiration (HR) in seasonally thawed pools. Changes in maximum seasonal thaw depth induce a transfer of carbon (blue arrows) from passive to active pools (warming), and vice versa (cooling).

Main Findings

We find that the northern hemisphere permafrost extent differs by roughly 4 million km^2 between LGM (24 million km^2) and PI (20.3 million km^2), with a smaller difference for the near-surface permafrost (within the upper three meters of the soil), i.e. 16.9 million km^2 for PI and 18 million km^2 for LGM.).

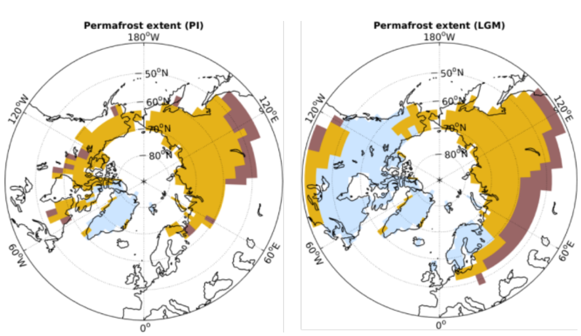

Figure 2: Ice sheet coverage and permafrost extent at PI and LGM. Yellow-brownish colours illustrate grid cells of simulated near-surface permafrost with active layers smaller than three meters, dark brownish areas describe permafrost with active layers deeper than 3 meters. Light bluish areas show prescribed ice sheet coverage. Data shown represent hundred year time averages.

Despite these comparatively small changes in total extent between the LGM and PI, our simulations show large-scale shifts in permafrost coverage, with permafrost disappearance in southerly regions, and permafrost aggregation in formerly ice-covered grid cells in North America (Fig. 2).

The simulated SOC storage in the active layer (SOC_{AL}, Fig.3 left) also exhibits pronounced regional to continental-scale differences between PI and LGM. For PI the storage in North America is (much) higher than in Eurasia as a consequence of differences in vegetation productivity. Given low glacial vegetation productivity, many grid cells reveal low LGM soil carbon storages (below 5 kgC m^{-2}). However, in many regions the vertical transport of carbon into deeper soil layers, has led to pronounced increases in SOC in perennially frozen near-surface permafrost (SOC_{PF}, Fig. 3 right) and in the total SOC storage (above 15 kgC m^{-2}). For PI these regions with a high SOC_{PF} are located mainly along Siberia's coastline.

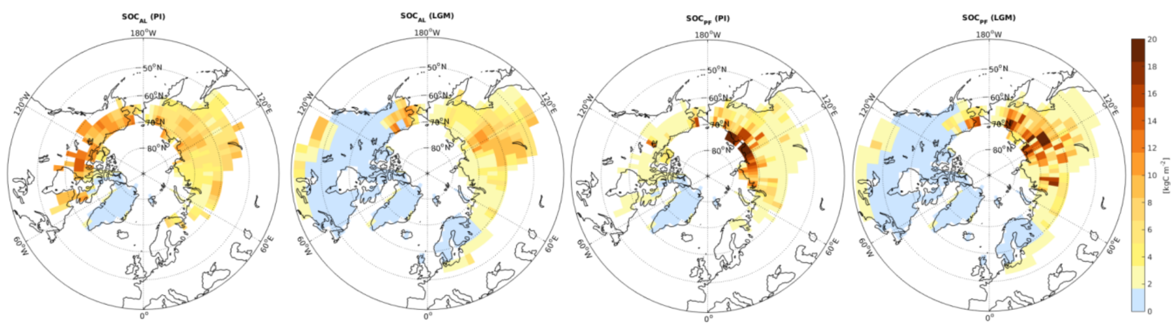

Figure 3: Seasonally thawed SOC in the active layer (SOC_{AL}) and perennially frozen SOC in near-surface permafrost (SOC_{PF}) at PI and LGM simulated by JSBACH. Light bluish areas show prescribed ice sheet coverage. Data shown represent hundred year time averages.

Besides a pronounced decline in northern hemisphere ice sheet coverage and large-scale shifts in permafrost extent, deglacial climate dynamics have affected permafrost carbon storage by increases in vegetation productivity through higher CO_2 levels (thus increasing litter input to the soils), and a prolonged and warmer growing season. In parallel, soil respiration rates have also increased by soil warming and carbon was transferred from perennially frozen to seasonally thawed soils through active layer deepening. As an aggregate effect of changing conditions between LGM and PI, the total SOC in near-surface permafrost increases by roughly 20 PgC, despite a decline in the overall permafrost extent (Fig. 4). The study is prepared for publication in Climate of the Past (T. Schneider von Deimling et al.,, Deglacial permafrost carbon dynamics in MPI-ESM, tbs).

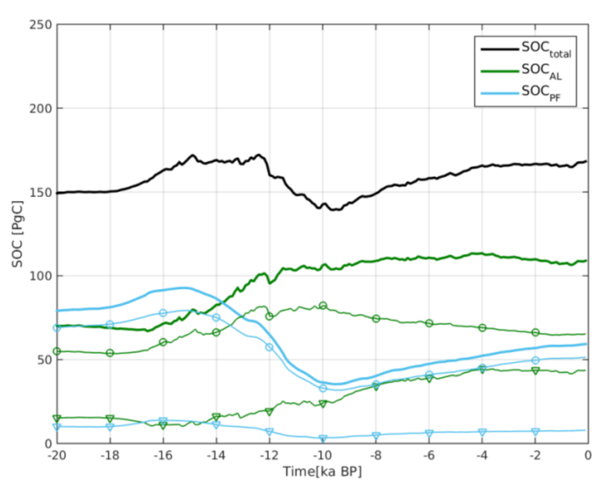

Figure 4: Deglacial evolution of seasonally thawed and perennially frozen SOC in near-surface permafrost from -20 ka BP to 0 BP. Total SOC (black line) is composed of seasonally thawed SOC (green lines) and perennially frozen SOC (blue lines). Contributions from North America (dash-dotted lines) and Eurasia (dashed lines) are shown separately. Data shown represent hundred year time averages.