Project: **1236**
Project title: **Q-ARCTIC**
Principal investigator: **Victor Brovkin**
Report period: **2022-11-01 to 2023-10-31**

Summary

Within the reporting period, a strong focus was on model development (specifically permafrost processes) as well as tuning of the ICON Earth System Model (Ruby version) to allow for the application of our model in a scientific study. Furthermore, complementary small-scale processes were studied to investigate the validity of the global model assumptions.

Model process development and infrastructure

In order to allow for a more realistic representation of arctic land surfaces, a number of processes had to be implemented:

- Surface water ponding on flat surface which allow for the formation of wetlands and small ponds. For this processes, parts of the WEED (WEtland Extent Dynamics) scheme were ported into ICON-LAND.
- Lateral water and energy exchange within the surface water and soil column of individual tiles in each grid cell. This included work on model infrastructure to make the tile states accessible to each other as well as implementing rules to define the connection order and transport pathways between the tiles.
- Revision of the surface runoff scheme because the currently used ARNO Scheme's idea is to represent full catchments rather than small parts of a single catchment. The new HydroTile scheme represents the latter and therefore surface runoff needs to be computed taking infiltration capacity and local slope into account.
- Snow drift between tiles which are considered to be close together, e.g. small depressions and the surrounding areas in flat permafrost landscapes.
- preparation of new model boundary data to prescribe cover fractions for our new tiles based on datasets of compound topographical index (Marthews et al., 20015,) and the Boreal lake and wetland dataset (Olefeldt et al., 2021)

For now, these new features are considered experimental. Therefore, they are not yet merged into the ICON main development branch, but are first subject to evaluations done in a number of studies.

Investigation of permafrost cloud feedback using ICON-ESM

The above described model development allowed us to investigate the effect that a thaw-induced drying of the northern permafrost zone may have on global climate. Using 7 100-year, fully coupled simulations with ICON-ESM we could demonstrate the existence of a hydrological feedback by which permafrost degradation amplifies climate change. The warming-induced thawing of the ground increases the hydraulic connectivity, resulting in a drying of the landscapes and a reduction in evapotranspiration. This diminishes the summertime cloud cover which, in turn, increases the shortwave radiation absorbed by the surface, hence, temperatures and the rate of permafrost degradation. For the end-of-the-century atmospheric greenhouse gas concentrations of a high-emission scenario, the climate effects of such a permafrost cloud feedback could be of the same order of magnitude as those of the permafrost carbon feedback,

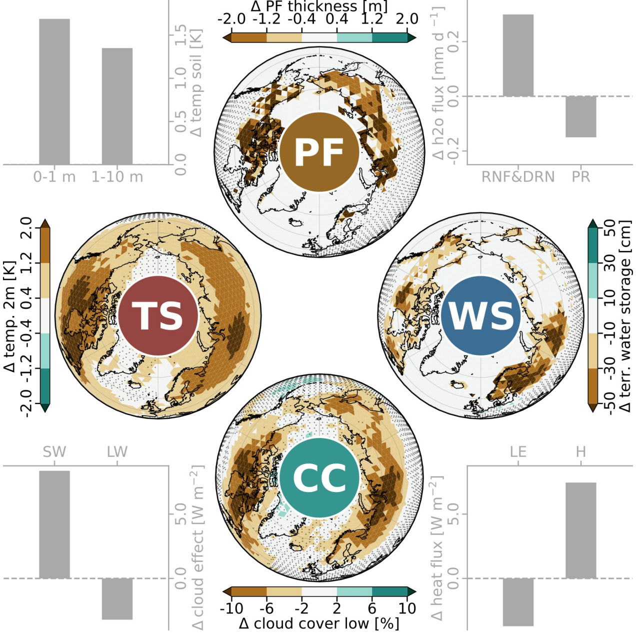

Figure 1 Permafrost cloud feedback in ICON-ESM simulations. Shown are the impacts of a thaw-induced increase in hydraulic connectivity on: Surface runoff & drainage (RNF&DRN) and precipitation (PR) [top right], terrestrial water storage [middle right], latent (LE) and sensible heat flux (H) [bottom right], low cloud cover fraction [center bottom], shortwave (SW) and longwave (LW) cloud effects [bottom left], near-surface air temperature (temp. 2m) [middle left], soil temperatures for depths of 0 m to 1 m and 1 m to 10 m [top left], and annual minimum permafrost thickness (PF thickness) [top center].

underscoring the importance of the region as a climate-change hotspot. We also found a significant global-scale warming for the end-of-the-century concentrations of a middle-of-the-road scenario, while for the concentrations of a sustainable emission-pathway, the feedback still exerts a significant influence on the northern-hemisphere.The study was submitted to Nature and is currently under revision.

Large Eddy Simulations over degrading Arctic permafrost

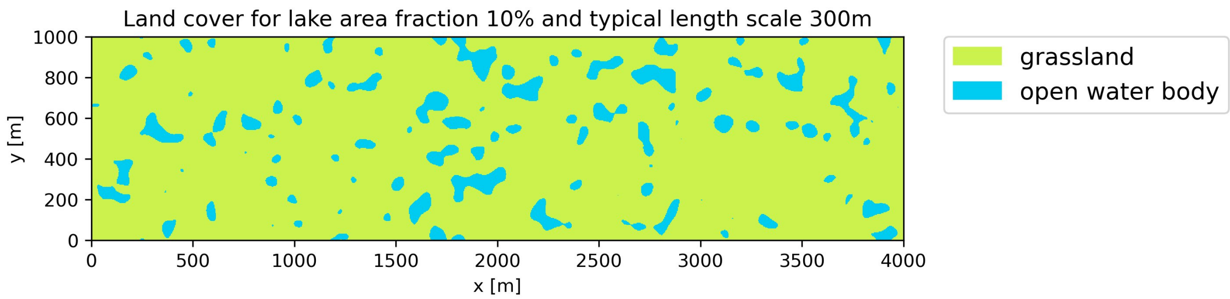

Figure 2 Random land cover map as input for LES.

In order to study small-scale processes of permafrost degradation the EULAG research model was utilized to perform Large Eddy Simulations (LES) of the atmospheric boundary layer (ABL). We developed and implemented a stochastic model to generate random tundra landscapes consisting of two land-cover types: grass land and open water bodies.

From simulations with JSBACH, typical sensible heat fluxes and roughness lengths for the generated landscapes (see Figure 2) were used to force the ABL. A snapshot of such a simulation is shown in Figure 3. We conducted many sensitivity experiments altering the statistical parameters of the landscape like lake areal fraction and the average distance between lakes which provide us with a measure of the surface heterogeneity. These experiments help us to understand the role of surface heterogeneity in the Earth System Model.

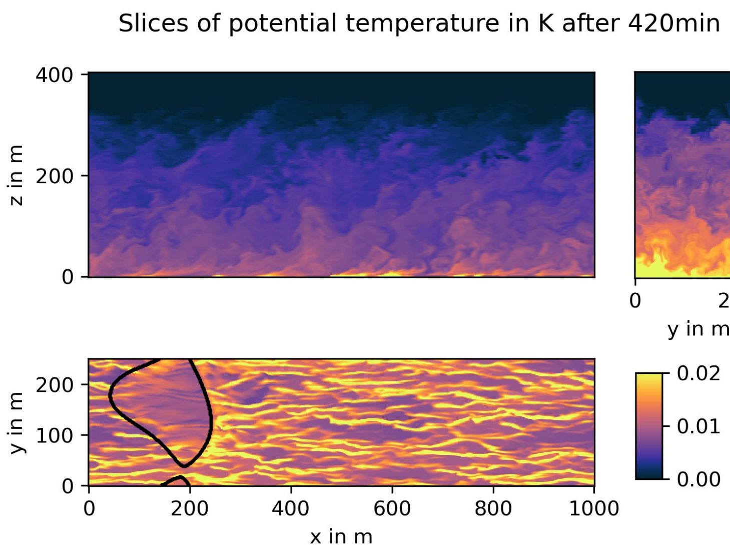

Figure 3 Simulation results of the ABL over the random landscape.