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Modelling the impact of polygonal soil structures on the thermal state of permafrost in Northern Siberia

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Permafrost characterizes almost 25 % of the northern hemispheric land area and its thermal stability strongly controls various ecosystem processes such as hydrology or the carbon budget. Patterned ground structures are a typical feature of the periglacial landscapes, which involve highly heterogeneous surface and subsurface properties. Spatial differences in the surface cover, soil constitution, and water content imply spatial variations in the surface energy balance and the soil heat transport processes. In addition, variations in micro-topography can lead to very distinct variations in snow cover which strongly determines the ground heat flux during winter. Hence, surface and subsurface heterogeneities are key elements for the understanding of the surface energy balance and the thermal state of the ground of permafrost landscapes. This study focuses on the typical polygonal tundra landscape at a study site in the Lena River Delta in northern Siberia. The landscape at the study site consists of polygons mostly characterized by low centres with wet conditions or little ponds and elevated rims with comparatively dry soils on a scale of several metres to tens of metres.

An established permafrost model is extended to two dimensions (2D) in order to account for spatial heterogeneities and lateral heat transport. The model is based on a finite-differences scheme including conductive heat transfer and phase changes of water. A surface energy balance model is coupled to the soil model and variations of the snow cover are represented as a surface layer of dynamical height. Applying cylindrical coordinates in the simulation allows to represent the three dimensional system of the polygonal structures that usually show approximately radial symmetry.The numerical accuracy of the model is verified for special cases where analytical solutions of the heat transport problem with phase change are available. The model is extensively evaluated with field observations at a the study site in the Lena Delta, Northern Siberia, which include spatially distributed soil profiles at different positions in a tundra polygon and long-term energy balance measurements.

A “best fit” model configuration is inferred and used to investigate the influence of the polygonal structure on the soil-atmosphere heat transfer and the thermal state of permafrost. This includes the quantification of the lateral heat flow processes inside the polygon as well as the sensitivity of the system to changes in the governing parameters and environmental conditions.