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Confining the evolution of ice-wedges in a warming climate

Jan Nitzbon (1,2,3), Léo Martin (2), Kjetil Schanke Aas (2), Moritz Langer (1,3), Sebastian Westermann (2), Julia Boike (1,3)

(1) Alfred Wegener Institute for Polar and Marine Research, Permafrost Research, Potsdam, Germany (jan.nitzbon@awi.de), (2) University of Oslo, Department of Geosciences, Oslo, Norway, (3) Humboldt-Universität zu Berlin, Geography Department, Berlin, Germany

Ice-wedges are the most common form of ground ice in the continuous permafrost zone and have been reported to degrade throughout the terrestrial Arctic. The degradation of ice-wedges is accompanied by interrelated changes to the hydrology, the biogeochemistry, and the energy balance of polygonal tundra landscapes. Recent studies have improved the understanding of ice-wedge dynamics under past and current climatic conditions by employing field measurements, remote sensing and numerical modelling techniques. However, the evolution of ice-wedges under future climatic conditions remains uncertain. This uncertainty affects estimations of the potential decomposition of organic carbon stored in permafrost soils, which is anyway poorly constrained for ice-rich permafrost landscapes that are prone to thermokarst activity.

We used the numerical permafrost model CryoGrid3 to project the future evolution of ice-wedges under different hydrologic conditions and future warming scenarios (RCP4.5 and RCP8.5). Our model explicitly takes into account lateral fluxes of heat, water, and snow between different topographic units of the polygonal landscape (centres, rims, and troughs). It furthermore simulates topographic changes resulting from melting of excess ground ice (i.e. thermokarst). Additionally, we simulated the lateral transport of organic and mineral sediment into the polygon troughs, a process which has been reported to act as a stabilizing mechanism.

Through our long-term simulations for a study site in the Lena River delta in Northern Siberia, we confined the future pathways of landscape evolution, ranging from the formation of thermokarst lakes underlain by taliks to well-drained plateaus of high-centered polygons. We analysed the dependence of those pathways on hydrologic and climatic conditions. Finally, the sensitivity of the landscape evolution to the geometry and the volume of wedge ice was investigated.

Altogether, our investigations highlight the wide range of possible landscape evolution pathways of polygonal tundra, thereby confining the possible implications for water, energy, and carbon fluxes in the course of permafrost degradation in a warming Arctic climate.