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Modelling high Arctic deep permafrost temperature sensitivity in Northeast Greenland based on experimental and field observations

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Permafrost affected areas in Greenland are expected to experience a marked temperature increase within decades. Most studies have considered near-surface permafrost sensitivity, whereas permafrost temperatures below the depths of zero annual amplitude is less studied despite being closely related to changes in near-surface conditions, such as changes in active layer thermal properties, soil moisture and snow depth. In this study, we measured the sensitivity of thermal conductivity (TC) to gravimetric water content (GWC) in frozen and thawed permafrost sediments from fine-sandy and gravelly deltaic and fine-sandy alluvial deposits in the Zackenberg valley, NE Greenland. We further calibrated a coupled heat and water transfer model, the "CoupModel", for one central delta sediment site with average snow depth and further forced it with meteorology from a nearby delta sediment site with a topographic snow accumulation. With the calibrated model, we simulated deep permafrost thermal dynamics in four 20-year scenarios with changes in surface temperature and active layer (AL) soil moisture: a) 3 °C warming and AL water table at 0.5 m depth; b) 3 °C warming and AL water table at 0.1 m depth; c) 6 °C warming and AL water table at 0.5 m depth and d) 6 °C warming and AL water table at 0.1 m depth.

Our results indicate that frozen sediments have higher TC than thawed sediments. All sediments show a positive linear relation between TC and soil moisture when frozen, and a logarithmic one when thawed. Gravelly delta sediments were highly sensitive, but never reached above 12 % GWC, indicating a field effect of water retention capacity. Alluvial sediments are less sensitive to soil moisture than deltaic (fine and coarse) sediments, indicating the importance of unfrozen water in frozen sediment. The deltaic site with snow accumulation had 1 °C higher mean annual ground temperature than the average snow depth site. Permafrost temperature at the depth of 18 m increased with 1.5 °C and 3.5 °C in the scenarios with 3 °C and 6 °C warming, respectively. Increasing the soil moisture had no important additional effect to warming, although an increase in thermal offset was indicated. We conclude that below-ground sediment properties affect the sensitivity of TC to GWC, that surface temperature changes can influence the deep permafrost within a short time scale, and that differences in snow depth affect surface temperatures. Sediment type and the type of precipitation should thus be considered when estimating future High Arctic deep permafrost sensitivity.