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Solute transport modelling in a coupled water and heat flow system applied to cold regions hydrogeology

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In cold regions, flow in the unsaturated zone is highly dynamic with seasonal variability and changes in temperature, moisture, and heat and water fluxes, all of which affect ground freeze-thaw processes and influence transport of inert and reactive waterborne substances. In arctic permafrost environments, near-surface groundwater flow is further restricted to a relatively shallow and seasonally variable active layer, confined by perennially frozen ground below. The active layer is typically partially saturated with ice, liquid water and air, and is strongly dependent on seasonal temperature fluctuations, thermal forcing and infiltration patterns.

Here there is a need for improved understanding of the mechanisms controlling subsurface solute transport in the partially saturated active layer zone. Studying solute transport in cold regions is relevant to improve the understanding of how natural and anthropogenic pollution may change as activities in arctic and sub-arctic regions increase. It is also particularly relevant for understanding how dissolved carbon is transported in coupled surface and subsurface hydrological systems under climate change, in order to better understand the permafrost-hydrological-carbon climate feedback.

In this contribution subsurface solute transport under surface warming and degrading permafrost conditions is studied using a physically based model of coupled cryotic and hydrogeological flow processes combined with a particle tracking method. Changes in subsurface water flows and solute transport travel times are analysed for different modelled geological configurations during a 100-year warming period. Results show that for all simulated cases, the minimum and mean travel times increase non-linearly with warming irrespective of geological configuration and heterogeneity structure. The travel time changes are shown to depend on combined warming effects of increase in pathway length due to deepening of the active layer, reduced transport velocities due to a shift from horizontal saturated groundwater flow near the surface to vertical water percolation deeper into the subsurface, and pathway length increase and temporary immobilization caused by cryosuction-induced seasonal freeze cycles. The possible impacts these change mechanisms may have on attenuation of solute and dissolved substance transport is further highlighted and discussed.