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Subsurface flow pathway dynamics in the active layer of coupled permafrost-hydrogeological systems under seasonal and annual temperature variability.

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There is a need for improved understanding of the mechanisms controlling subsurface solute transport in the active layer in order to better understand permafrost-hydrological-carbon feedbacks, in particular with regards to how dissolved carbon is transported in coupled surface and subsurface terrestrial arctic water systems under climate change. Studying solute transport in arctic systems is also relevant in the context of anthropogenic pollution which may increase due to increased activity in cold region environments. In this contribution subsurface solute transport subject to ground surface warming causing permafrost thaw and active layer change 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 timing of the start of increase in travel time depends on heterogeneity structure, combined with the rate of permafrost degradation that also depends on material thermal and hydrogeological properties. These 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 impact these change mechanisms have on solute and dissolved substance transport is further analysed by integrating pathway analysis with a Lagrangian approach, incorporating considerations for both dissolved organic and inorganic carbon releases. Further model development challenges are also highlighted and discussed, including coupling between subsurface and surface runoff, soil deformations, as well as site applications and larger system scales.