Development of perennial thaw zones in boreal hillslopes enhances potential mobilization of permafrost carbon

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Background:. Permafrost thaw substantially alters subsurface flow in boreal regions, including formation of a perennial thaw zone (PTZ) in areas where depth of thaw exceeds depth of seasonal frost. Changes in subsurface flow influences the magnitude, seasonality, and chemical composition of streamflow, particularly changes in carbon, nitrogen, and mercury.

Methods: An enhanced version of the USGA numerical code, SUTRA, was used to examine active layer dynamics, PTZ development, and fluid-flow and energy transport, and results were analyzed to quantify seasonal shifts in groundwater flux attributed to warming and thawing.

Results:

- PTZ development is sensitive to organic layer thickness and near-surface factors that mediate heat exchange at the atmosphere/ground-surface interface.
- PTZ evolution and groundwater discharge are greatest in spring and fall.
- PTZs serve as a detectable precursor to accelerated permafrost degradation.
- Timing of increased baseflow and flowpath depths are significant for evaluating dissolved organic carbon (DOC), total dissolved nitrogen (TDN), and mercury mobilization as well as for the transport of mineral weathering products.

Significance: This study provides important contextual insight on a fundamental thermo-hydrologic process that can enhance terrestrial-to-aquatic transfer of permafrost carbon, nitrogen, and mercury previously sequestered in thawing watersheds.

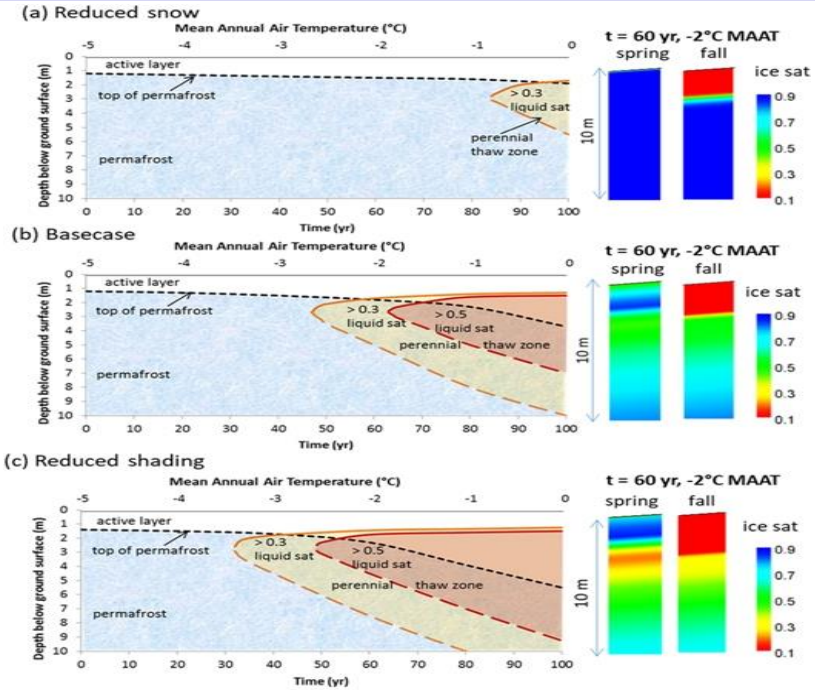

Figure: Mid-hillslope model results that display evolution of PTZ development, contoured at 0.3 and 0.5 perennial liquid saturation levels (solid contour = top; dashed contour = bottom), compared with permafrost top (black dashed line) for (a) reduced snow, (b) basecase, and (c) reduced shading cases. Model results through time (at left) were generated by analyzing the annual temperature and ice saturation cycles with depth at a mid-slope distance (vertical slice 50 m from the hill top) to identify the cryotically-defined top of permafrost and the vertical location of perennial liquid saturation thresholds. Ice saturation results (at right) represent seasonal snapshots at *t* = 60 years.