Permafrost-modulated arctic landscape evolution

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The mechanics of hydrologic and geomorphic processes in the arctic are modulated by temperature-dependent permafrost dynamics. When groundwater is frozen, permafrost adds a large amount of cohesion to the landscape and stabilizes it. As permafrost melts, a loss of cohesion is mechanistically linked to an increase in water flux: as the resistor to landscape evolution weakens, a driver for landscape evolution emerges. Modeling such a system would be possible within the CSDMS framework. In order to do this, we would need to understand heat inputs, heat distribution, the effect of that heat on the permafrost and melt/thaw processes, and the resulting hydrologic processes. Water flux and weakening of the substrate would lead to erosion and landscape evolution (though we ignore slumping for the simplest test case described here). Landscape change would then feed back into the melting processes by modifying the topography, which would direct groundwater flow paths and define the amount of solar radiation received per unit volume of material.

Doug Jerolmack and others are engaged in field work at the Baldwin Peninsula near Kotzebue, Northwest Alaska, on the Arctic Circle. There, they are collecting repeat topographic surveys of channel head cuts, channel long profiles, and channel cross-sectional profiles. This data set includes both north- and south- facing channel systems, with the channels on the south face evolving more quickly. Their data on the evolution of the channels with time can be linked to observations of insolation to ground-truth the models.

In list form, our modeling strategy is:

1. Topography (either prescribed starting topography or topography resulting from previous run of model)

2. Radiation model (from TopoFlow) → Heat flux to surface (as f(topography) due to aspect) → Thermal model via thermodynamics of water and sediment

3. Thermal model via thermodynamics of water and sediment → Temperature field and spatial distribution of ice and melt

4. Spatial distribution of ice and melt → groundwater flow model solution using specified hydraulic conductivity (or modeled, as a function of melt fraction)

5. Groundwater flow solution → Groundwater flow rate and direction at seepage face (TopoFlow) → Constitutive relation between water flux and erosion rate, calibrated to erosion survey data

6. Back to beginning and repeat