Permafrost Degradation Leaves Us On Thin Ice

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ABSTRACT

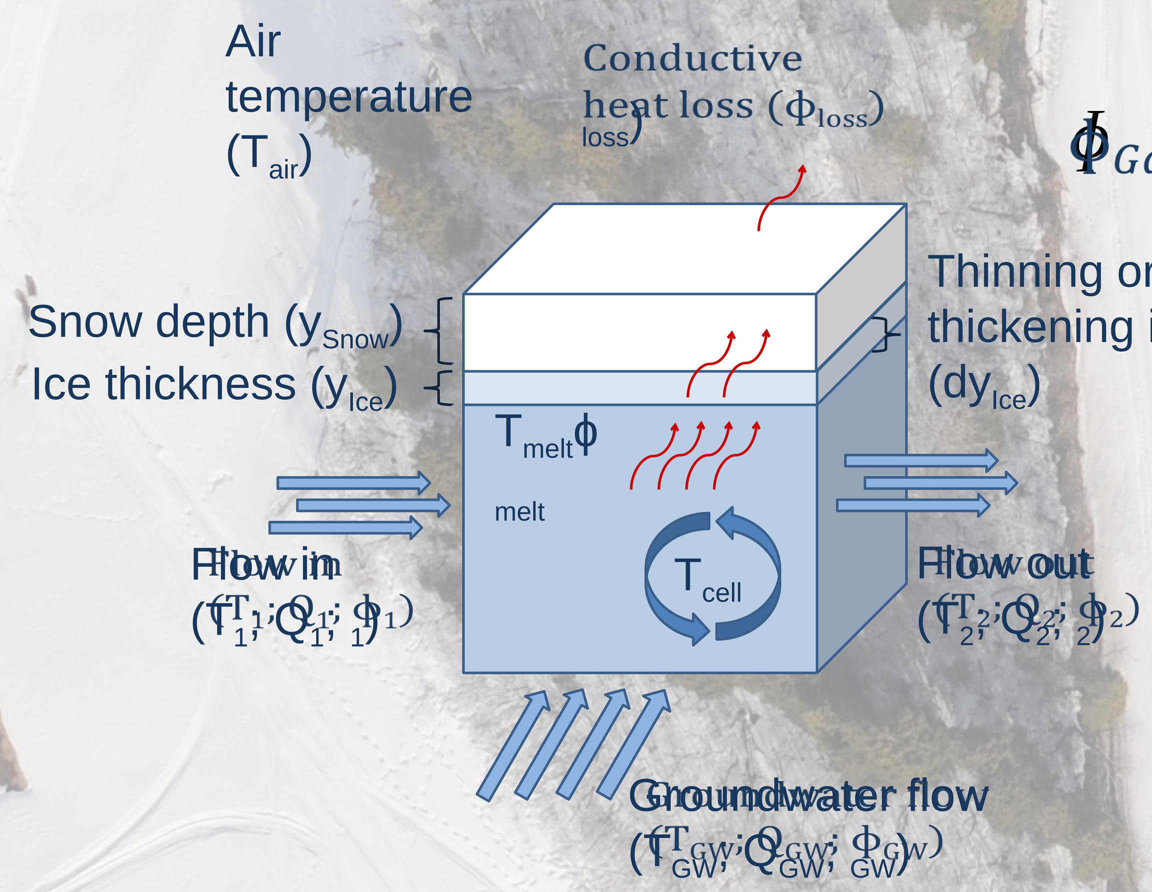
The Tanana River flows through interior Alaska, a region characterized by discontinuous permafrost. Studies link degrading permafrost to increased winter river discharge due to increasing groundwater input. In winter, interior Alaskan rivers are exclusively fed by groundwater, which serves as an external source of heat. In fact, some portions of rivers fed by groundwater maintain thin ice throughout the winter, or remain altogether ice-free, despite very cold air temperatures. These ice conditions represent a significant danger to winter travellers who use rivers for wintertime travel, particularly in this largely roadless area.

We developed a physically-based, numeric model to explore how fluctuations in groundwater discharge control ice thickness on the Tanana River. The model allows us to examine how changes in groundwater flow affect ice dynamics by addressing two questions: 1) What are the dominant factors controlling seasonal ice dynamics on the Tanana River? 2) What are the rates of change in ice thickness resulting from observed and projected changes in these factors?

Conclusions

Ice melt is amplified by increased hydraulic gradients, increased groundwater upwelling, increased air temperature, increased groundwater temperature, increased water depth, or increased snow depth. A warming climate in regions with discontinuous permafrost is expected to increase groundwater input into rivers, decrease the temperature gradient between the atmosphere and the ice/water interface, and increase snow depths. All these changes contribute to faster ice melt, decreased ice thickness, and thus more hazardous conditions for winter travellers. The model illustrates the physical mechanisms that corroborate reports from Alaskans about ice conditions that have become more dangerous in

THE MODEL



$$\phi_{Gain} = \phi_1 + \phi_{GW} - \phi_2 - \phi_{loss} - \phi_{melt}$$

$$\phi = C_v Q (T - T_{Melt})$$

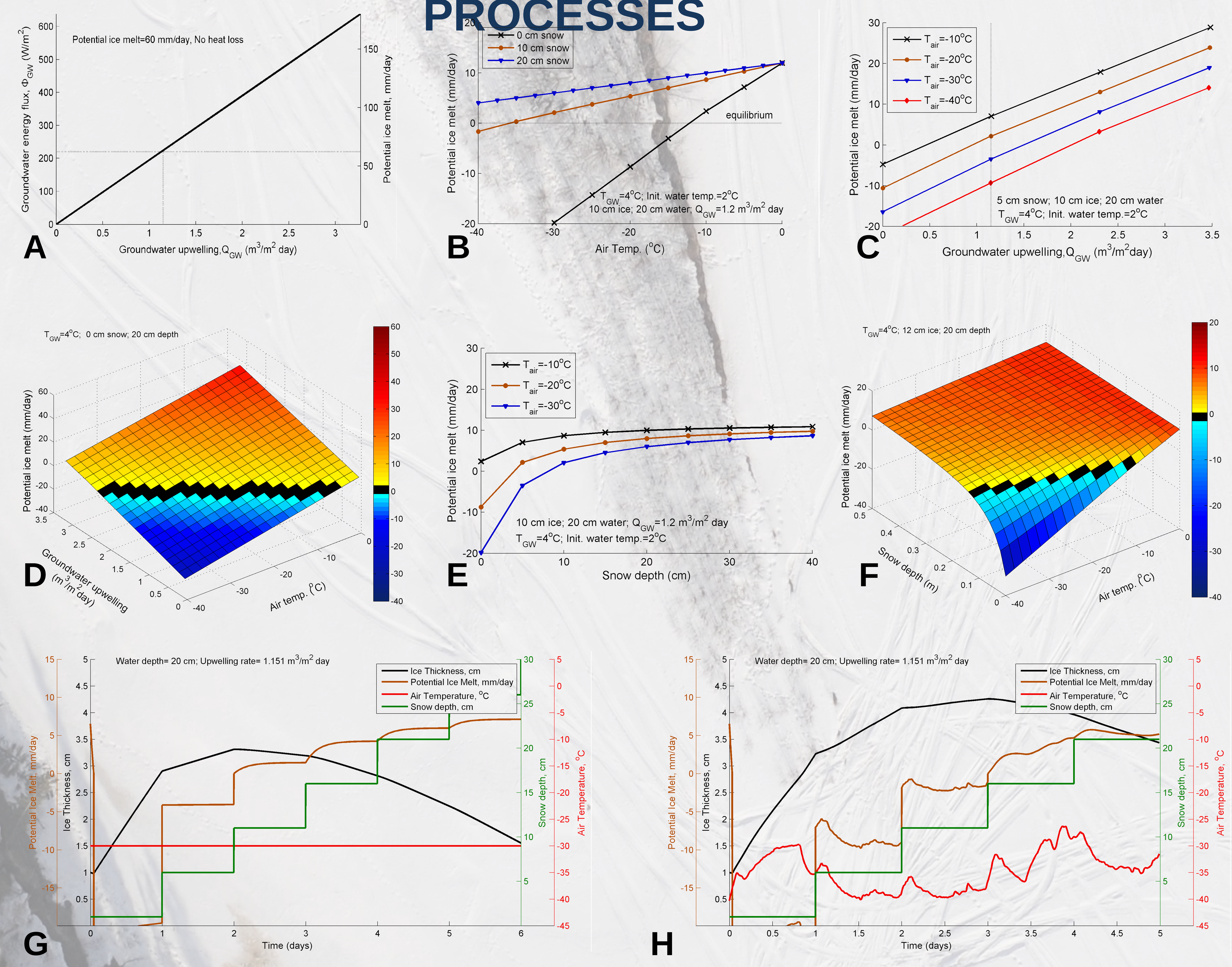
$$\phi_{loss} = \frac{T_{melt} - T_{air}}{\frac{y_{ice}}{k_{ice}} + \frac{y_{snow}}{k_{snow}}}$$

$$\phi_{Melt} + \phi_{Loss} = \alpha (T_{cell} - T_{Melt})$$

$$\frac{dy_{ice}}{dt} = \dot{y}_{melt} = \frac{\phi_{Melt}}{\lambda_{fusion} \rho_{ice}}$$

α= heat transfer coefficient

MODELED PROCESSES



RESULTS

Table 1. Sensitivity Analysis

Parameter	Units	Initial	Variability	Ice Melt Rate Sensitivity
Groundwater temp.	°C	4.0	+/- 30%	+/- 38%
GW upwelling rate	m/day	1.1	+/- 30%	+/- 38%
Water depth	cm	20	+/- 30%	+/- 34%
Snow depth	cm	25	+/- 30%	-13% to +8%
Air temp.	°C	-20	+/- 30%	+/- 11%
Heat transfer coef.		11.23	+/- 30%	-8% to +4%
Water column temp.	°C	2.0	+/- 30%	+/- 4%
GW horiz. flow	m/day	0.3	+/- 30%	-4% to +2%

*If snow depth of 2 cm is varied by +/- 30%, sensitivity ranges from -50% to +60%

Table 2. Climate Scenario Analysis

Parameter	Units	Historic climate scenario	Modern climate scenario	Future climate scenario
GW upwelling rate	m/day	.9 (-20%)	1.1	1.3 (+20%)
GW horiz. flow	m/day	0.3	0.3	0.3
Initial ice thickness	cm	10	10	10
Snow depth	cm	15	20	25
Air temp.	°C	-18	-15	-12
Initial water temp.	°C	2.0	2.0	2.0
Ice melt rate	mm/day	5.2	9.3	13.0
Complete ice melt	days	19.1	10.7	7.7
Change in ice melt	%	-44%	N/A	+40%