Modeling the Thermal Balance Between Groundwater Springs and River Ice

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ABSTRACT

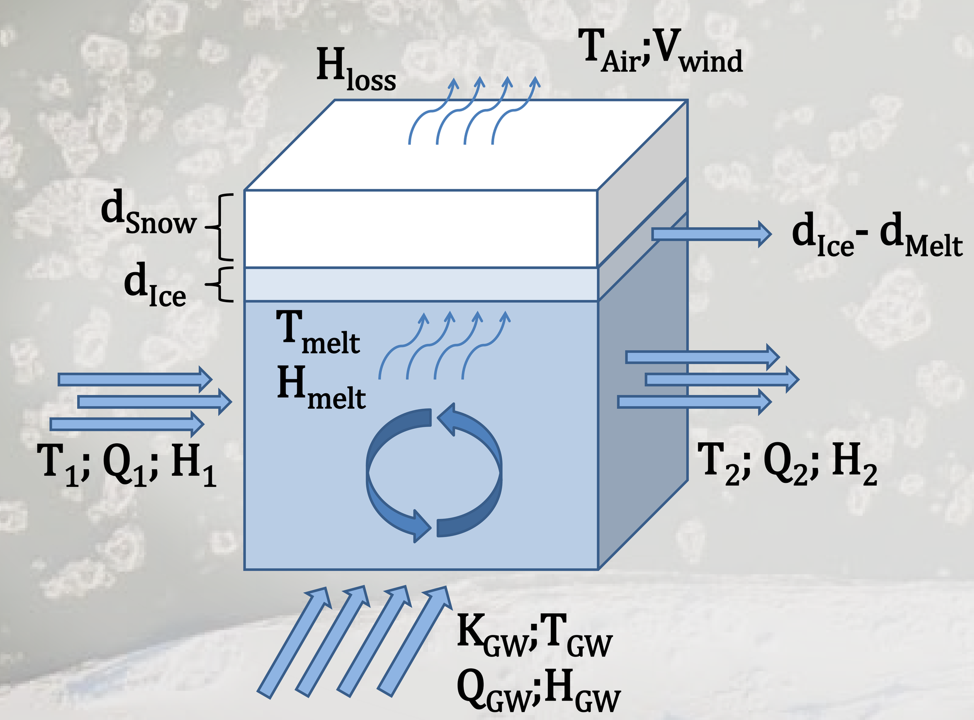
We modeled the thermal balance between groundwater discharge and ice-free areas in the Tanana River near Fairbanks, Alaska, a region that is characterized by discontinuous permafrost. Under degrading permafrost conditions, these areas have been hypothesized to have increased winter discharge due to increasing contributions from groundwater flow. In the winter, interior Alaskan rivers are fed almost entirely by groundwater, which also serves as an external source of heat energy to the system. Several reaches of the river fed by groundwater springs remain ice-free or have dangerously thin ice throughout the winter despite air temperatures that dip below -40° C. These areas are dangerous for winter travelers who regularly use Alaskan rivers for wintertime travel.

Our model allows us to explore the relationship between seasonal groundwater flows and ice thickness under changing atmospheric conditions. Our model results explore how local and regional changes in groundwater flow can affect ice thickness by addressing two primary research questions: 1) What physical factors influence seasonal ice dynamics on the Tanana River? 2) How is the thermal balance maintained between changing groundwater flow and cold air temperatures?

Our results indicate that under field conditions with our measured upwelling rate, heat flux due to upwelling may degrade river ice at up to 17 mm/day, but the potential ice melt is reduced by increased air temperature and water depth, but increased by increased hydraulic conductivity, groundwater upwelling, ice thickness, or snow depth.

Increased air temperatures associated with climate change is expected to increase upwelling rates, decrease the temperature gradient, increase snow depths, and decrease ice thickness. Estimated future changes estimate that potential ice melt rates may increase by up to 18% under an altered climate. These results provide additional evidence that changing hydrologic conditions may affect inhabitants of northern latitudes under potential hydrologic scenarios in a changing climate.

THE MODEL

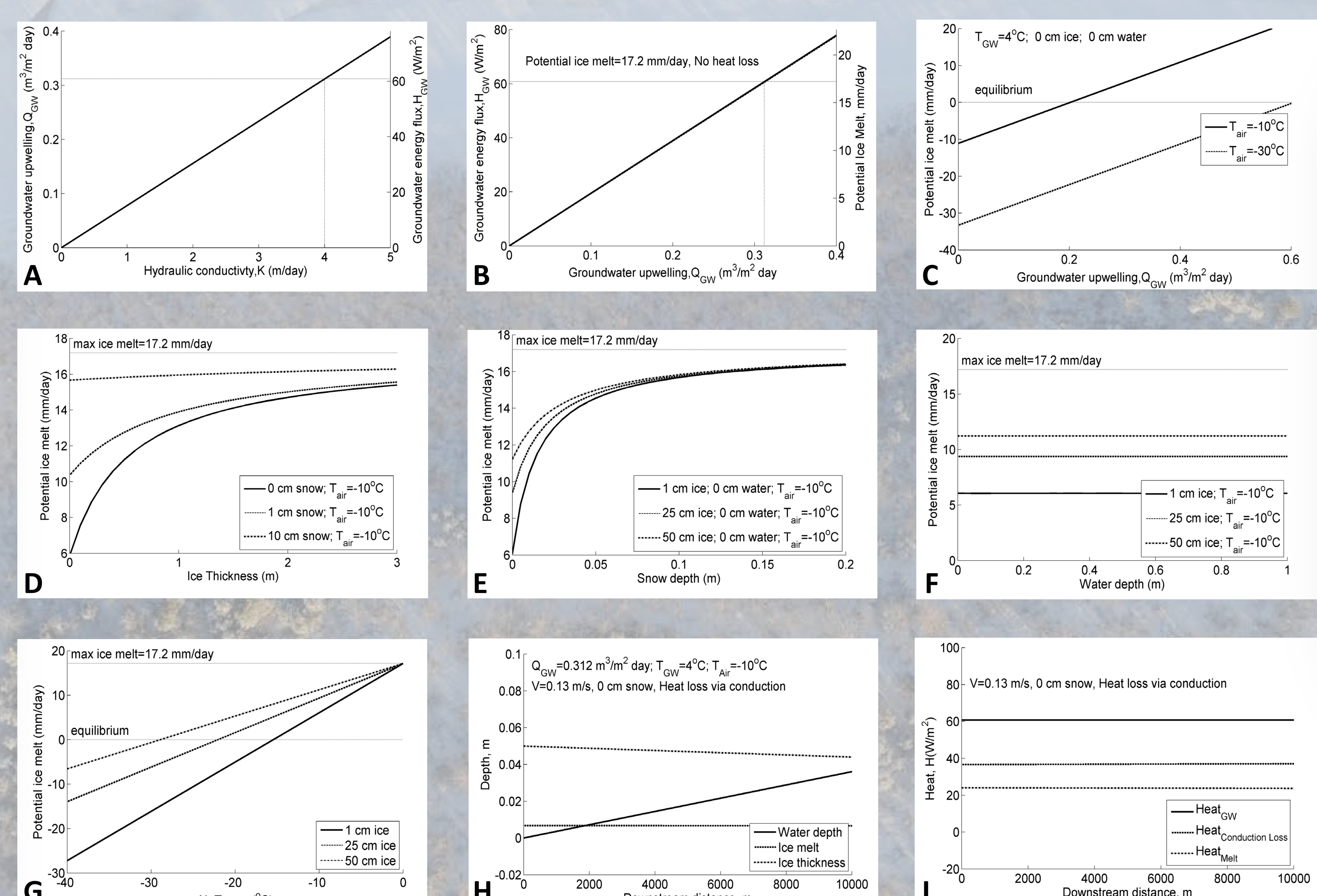


$$H_{loss} = \frac{T_{melt} - T_{air}}{\frac{d_{ice}}{k_{ice}} + \frac{d_{wind}}{k_{snow}} + \frac{1}{10+V_{wind}}}$$

$$H_{GW} = \rho_{H_2O} Q_{GW} C_{p,\,H_2O} (T_{GW} - T_{melt})$$

$$d_{melt} = \frac{H_{GW} + H_1 - H_2 - H_{loss}}{\lambda_{fusion}\,\rho_{ice}}$$

MODELED PROCESSES



RESULTS

↑ • Hydraulic conductivity • Upwelling rate • Ice thickness • Snow depth • Air temp. ⇒ ↑ Ice Melt Rate

↑ • Water depth ⇒ ↓ Ice Melt Rate

Table 1. Sensitivity Analysis for dominant factors affecting potential ice melt

Parameter	Increase	Change in Ice Melt
Hydraulic cond.	+10%	+25%
Upwelling rate	+10%	+25%
Ice thickness	+10%	+1%
Snow depth	+10%	+2%
Air temperature	+10%	+8%
Water depth	+10%	+0%*

CONCLUSIONS

As an experiment, we developed a warming climate scenario to see how potential ice melt might be affected. In the scenario, air temperature increased from -10 to -4 ˚C, snow depth by +10%, ice thickness by +1%, and the hydraulic head by +15%. Under this scenario the potential ice melt increased by 18% from 14.6 mm/day to 17.3 mm/day. If these conditions persisted for 2 weeks in the spring, an additional 38 cm of ice would be melted under an altered climate. These types of changes could have serious impacts on northern communities that rely upon intact ice in Alaskan rivers for winter travel.

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