Understanding Ice Temperature in Ice Streams in Antarctica and Greenland

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Background

Ice reaches the sea in the Antarctic and Greenland ice sheets by flowing downhill through ice streams, or rivers of ice, until it either melts or reaches the ocean. This then ultimately leads to sea level rise. As ice travels from high elevations to low elevations, colder temperatures get carried down.

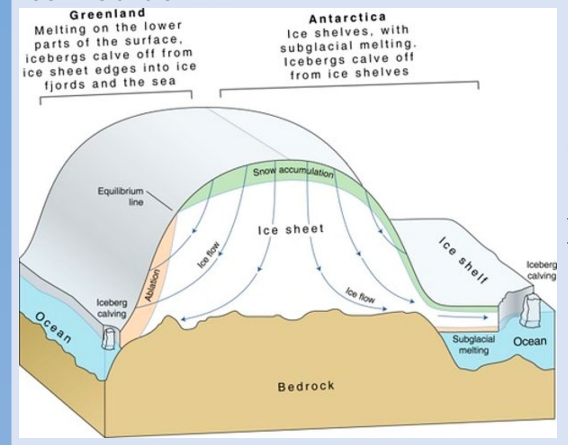
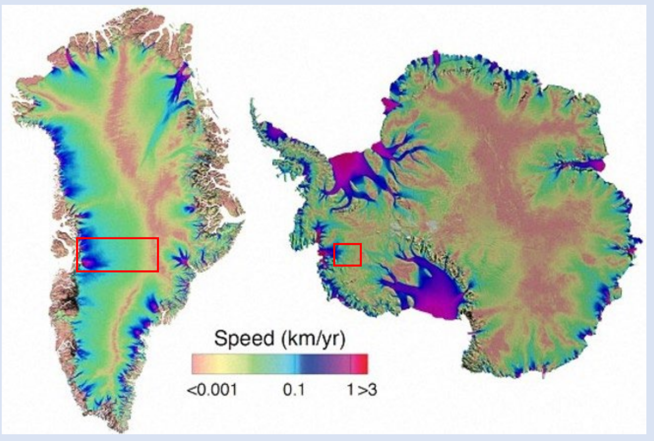


Figure 1[1] Shows the differences between an ice sheet and an ice shelf while also depicting ice flow. Snow accumulates at the top, the ice flows downhill through the ablation zone where ice melts until it reaches the ocean where either it has fully melted or breaks off.

Inside of ice, temperatures most dominantly flow vertically by the following mechanisms: diffusion(spreading out), advection(following the ice flow field), and melting caused by the heat released from the Earth below the ice. Longitudinal temperature flow, which follows the same direction as ice stream flow, has been under-appreciated in some recent studies due to its presumed 'negligibility'. The issue though, is that there is a large deviation when comparing temperature predictions to measured temperatures that could be a result of not accounting for the longitudinal temperature flow correctly. It is important to understand this temperature flow due to its relationship with ice flow and how these affect rising sea levels.

Figure 2[2] Represents the ice flow lines in Antarctica and Greenland showing where ice velocity is strongest.



Methods

We use surface temperature(T_s), accumulation($\dot{a}$), ice thickness(H), and velocity(u^*) data to graph certain drainage basins of interest in Antarctica and Greenland. We can gather specific data points to parameterize heat flow through ice streams. Then, the following formula from previous work is used[4,5],

$$\Lambda = \frac{2H^2}{\alpha T_s} u \frac{\partial T}{\partial x}$$

where the heat flow parameter(Λ) is dependent on how fast the ice flows and the along-flow temperature gradient ($\frac{\partial T}{\partial x}$). The internal temperature gradient depends on climate and ice geometry variables, and can be approximated as,

$$\frac{\partial T}{\partial x} = \frac{\partial T_s}{\partial x} + \tau \left(\frac{1}{H}\frac{\partial H}{\partial x} - \frac{1}{\dot{a}}\frac{\partial \dot{a}}{\partial x} \right)$$

We use linear regression to calculate along flow gradients for surface temperature(T_s), accumulation($\dot{a}$), ice thickness(H).

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Results

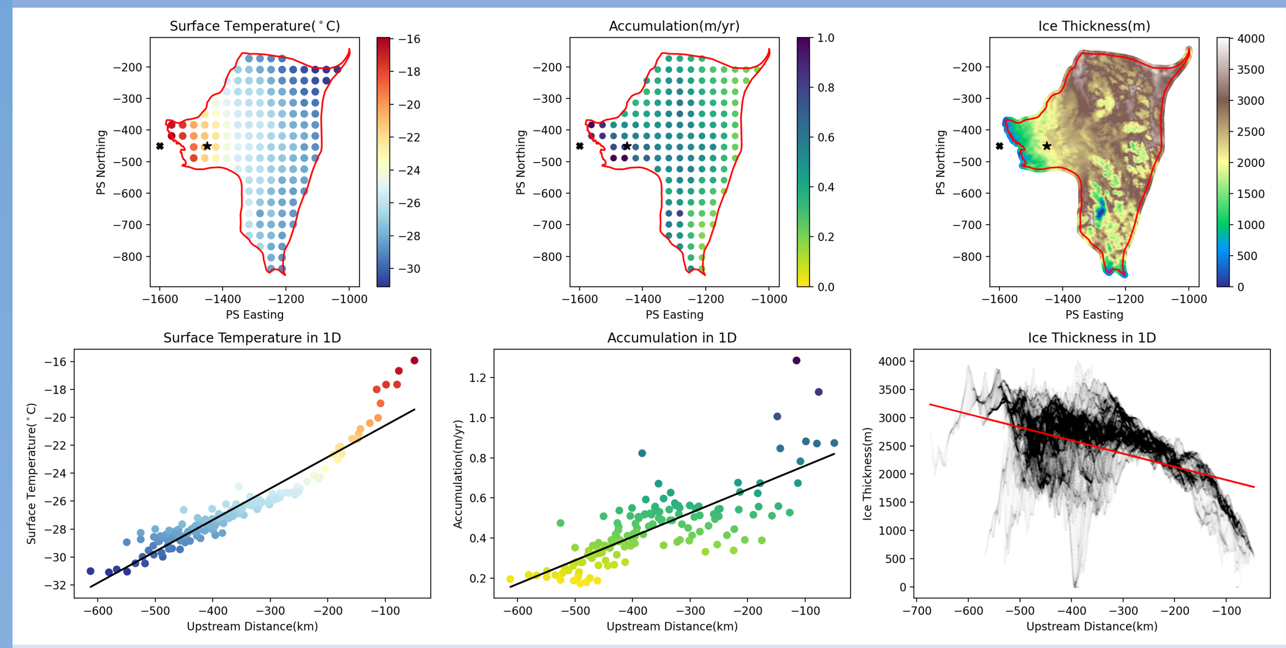


Figure 3 (Pictured above) Thwaites Glacier Graphs – Respective graphs for the contributing factors of internal glacial heat flow. The x marks the point used in calculating the upstream distance while the star marks the point used in calculating the equations presented in the methods tab.

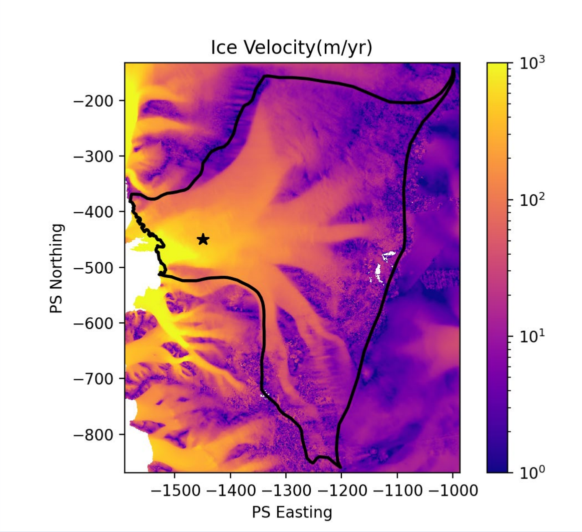


Figure 4 Thwaites Glacier Ice-Surface Velocities Graph – The glacial flow in Thwaites. Ice flows from right to left here, from the slow velocities at the ice divide toward the faster velocities going downhill and then ultimately into the ocean. These velocities are derived from satellite products[2].

Variable Names:	Surface Temperature	Accumulation	Ice Thickness	Surface Temperature Gradient	Accumulation Gradient	Thickness Gradient	Velocity	Internal Temperature Gradient	Heat Flow Parameter
Variables:	T_S	$\mathring{a}$	H	$\frac{\partial T_s}{\partial x}$	$\frac{\partial \mathring{a}}{\partial x}$	$\frac{\partial H}{\partial x}$	u*	$\frac{\partial T}{\partial x}$	Λ
Bindschadler	-28.6809	0.0672825	957.199	0.00245199	-0.000121281	-3.17777	400.567	0.00093469	0.6958192
Thwaites	-20.8364	0.847051	2172	0.0225629	0.00117936	-2.32938	369.286	0.020098129	97.759108
Jakobshavn	257.952	0.662545	2693	0.0272343	-0.000518338	-4.18388	293.256	0.026463031	12.692936

Table 1 Data and Calculations – Surface temperature, accumulation, and thickness data gotten from Bindschadler in the Siple Coast, Thwaites in West Antarctica, and Jakobshavn in West Greenland. Along with their respective gradients and final advection result, Λ.

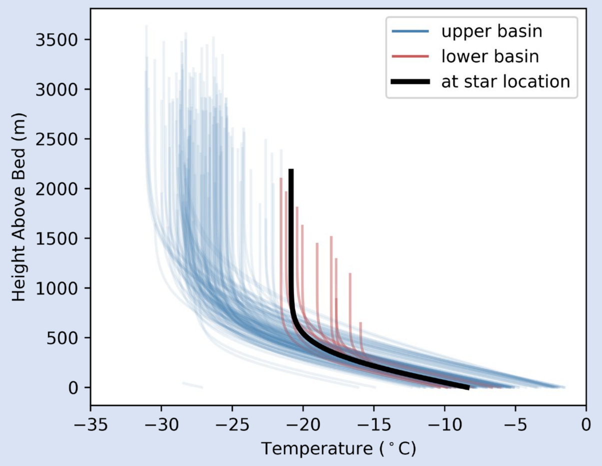


Figure 5 Thwaites Temperature Profile - Modeled temperature profiles at distinct points throughout the Thwaites Glacier basin. Temperature profiles are steady state, calculated with the Robin (1955) solution, so along-flow advection is not included as a heat-transfer process here. The solid black line is the model solution at the selected point within the main trunk of Thwaites Glacier, the blue lines are upstream of that point, and the red lines are downstream of that point.

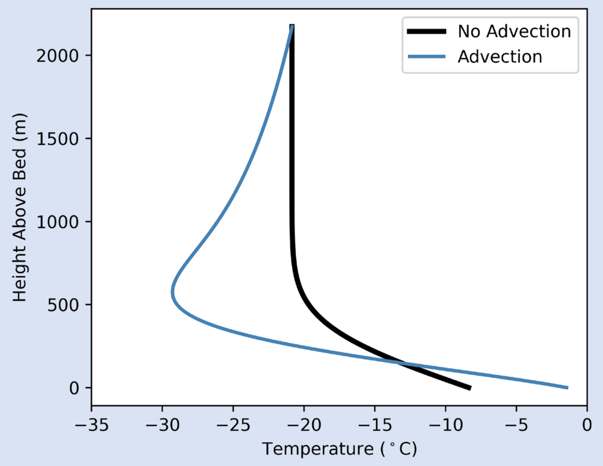
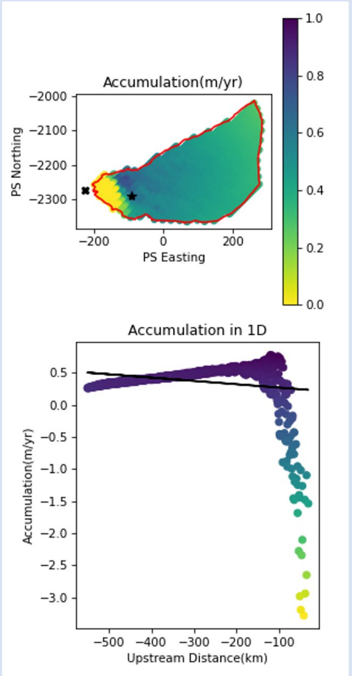


Figure 6 Thwaites Numerical Temperature Profile - Modeled temperature profiles at the selected point within the main trunk of Thwaites Glacier. The black line is again the steady-state Robin (1955) solution, the same as in Figure 5. The blue line is a numerical solution which incorporates along-flow advection using the climate variables and gradients calculated in the table above.

Discussion



- The data used for this analysis comes from a model named RACMO(Regional Atmospheric Climate Model) which is a physics-based model that is grounded in observations by various meteorological stations and other data sources throughout Antarctica/Greenland[6]. While it is a great product, it is problematic in certain areas (particularly for some variables on the Siple Coast) due to its limited measured data.
- The accumulation pattern throughout a drainage basin can have a strong influence on the net temperature gradient. In Greenland, we see that strong summer melting leads to net ablation (negative mass balance) along the western margin of the ice sheet. In this case, the linear regression is no longer a representative approximation of the data although the physical process of downstream advection is still important[7].

Conclusion & Future Work

Conclusion:

- Ice advection transports cold ice from high elevation along ice flow, cooling ice-stream temperature.
- Along-flow advection is strongest where ice flows the fastest.
- There are different margin effects in Greenland due to the summer melting at the edges.

Future Work:

- Expand the research with more basins all across Greenland and Antarctica.
- Including alpine glacier environments and comparing them to other areas.
- Compare the heat flow process and magnitude of advection observed to other heat transfer processes like heat production by friction in an ice stream shear margin.

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