Investigating basal thaw as a potential driver of ice flow acceleration in Antarctica

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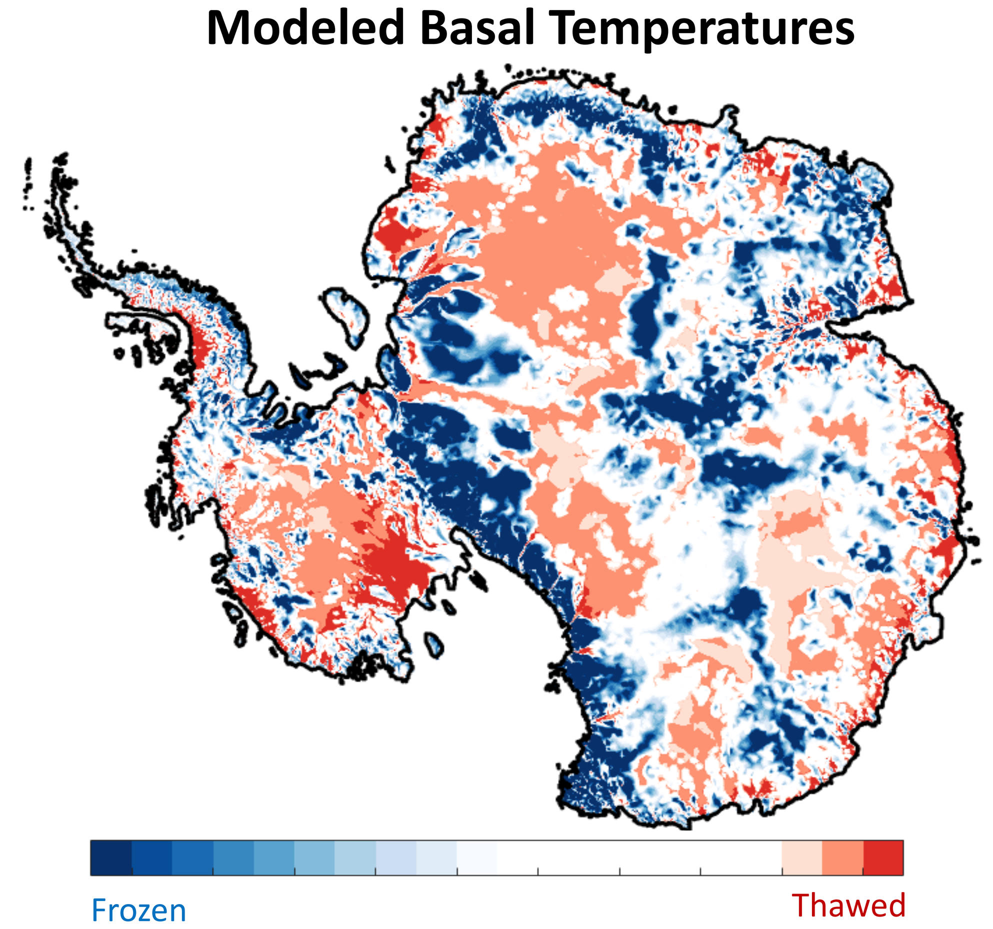
The rate of basal sliding depends on the temperature at the ice-bed interface [1][2]. Frozen-bed regions are characterized by high basal traction and no sliding leading to reduced ice flow compared to regions with thawed beds. In Antarctica, some frozen-bed regions separate fast-flowing glaciers and ice streams [3]. Others separate inland catchments with thawed beds from the grounding zone of marine ice-sheet sectors [4]. We use the Ice Sheet System Model (ISSM) [5] to simulate the thawing of frozen bed regions and assess Antarctica's sensitivity to changes in basal thermal regime.

1. Basal thaw enhances the slipperiness of the bed. This is represented by increased sliding, reduced basal friction, and higher radar bed reflectivity.

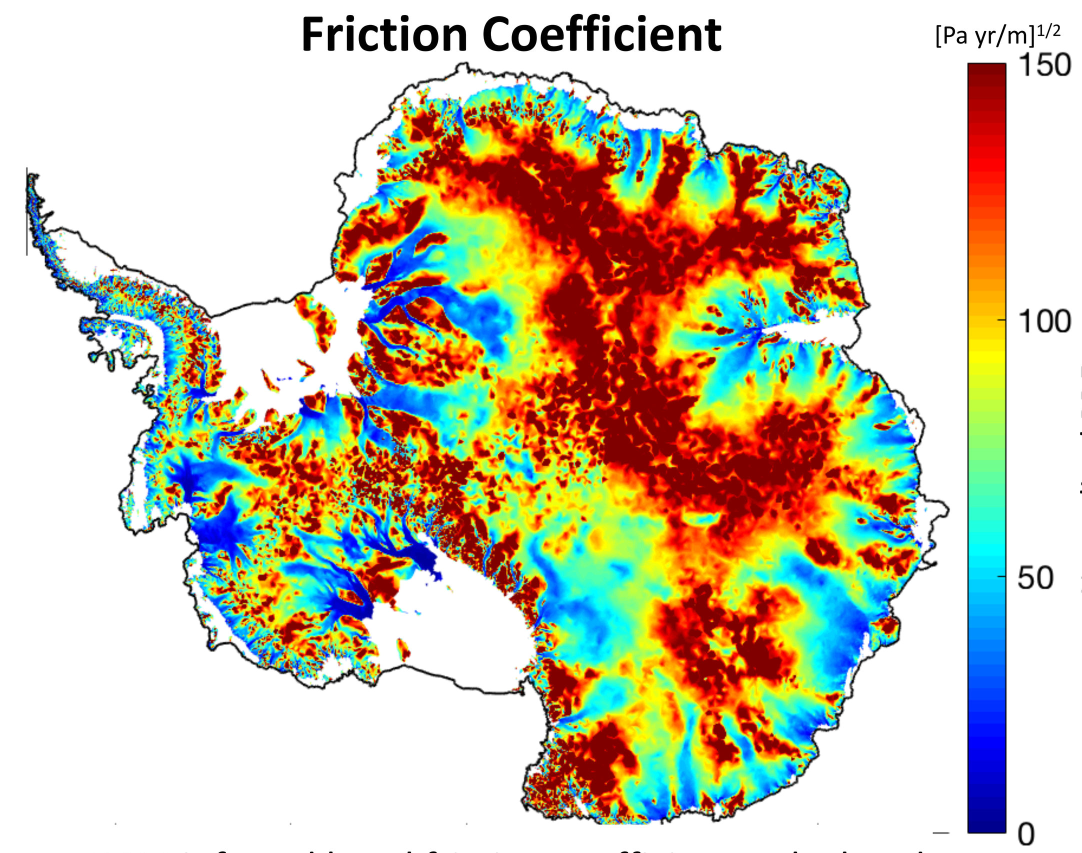
2. A change in ISSM inferred friction coefficient can be used as a proxy for a change in basal temperature.

Currently, large scale numerical ice sheet models are not capable of simulating the thermomechanical feedback when a region undergoes thawing. Instead, we model basal thawing by reducing the basal friction coefficient for all regions where the bed is just below freezing.

Modeled Basal Temperatures

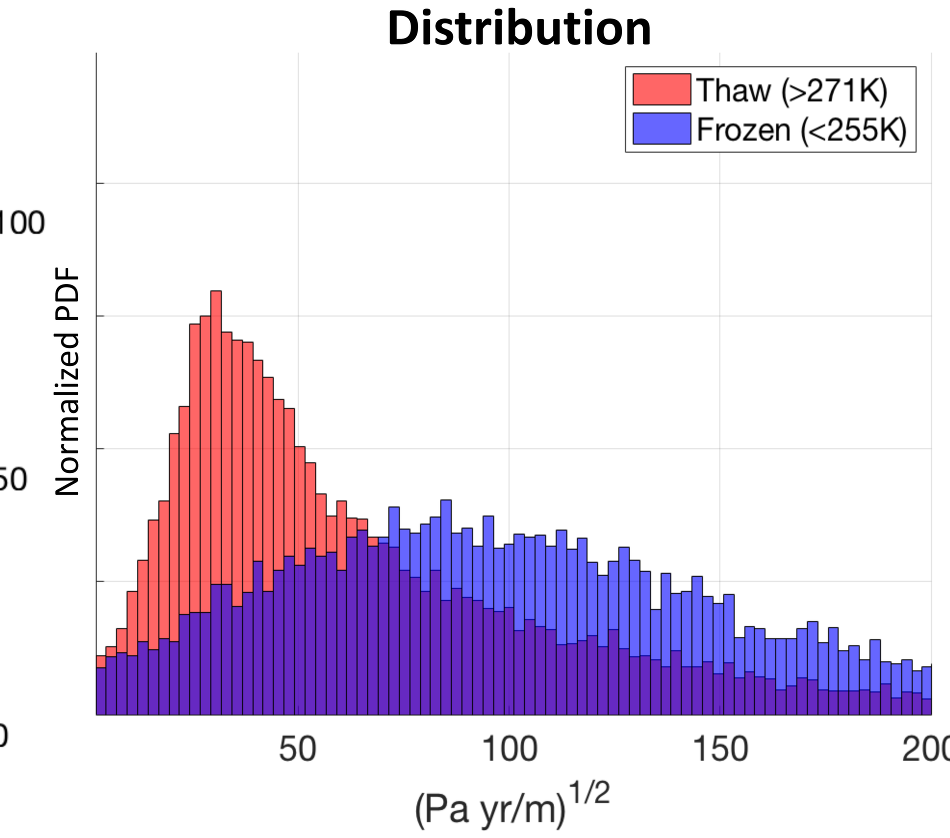


Friction Coefficient



ISSM inferred basal friction coefficient, calculated using an inversion to minimize the misfit between observed and modeled surface velocities [6]

Friction Coefficient Distribution



3. Proof of concept experiment for Thwaites Glacier

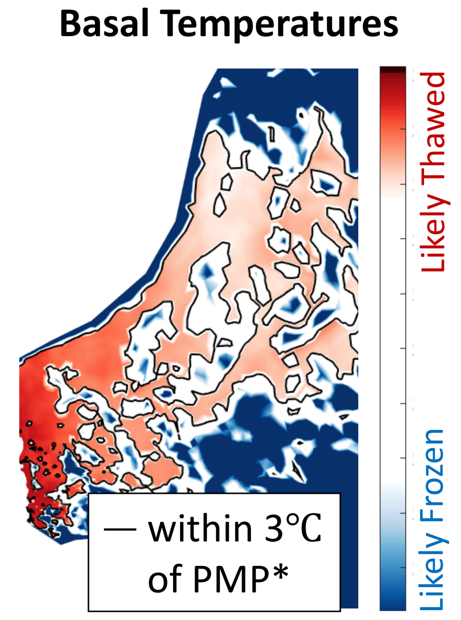
ISSM Set up:

Mesh
- Adaptive horizontal mesh ranging from 3-30 km.
- 5 vertical layers with quadratic interpolation (P1 x P2).

3D Thermomechanical Model Simulations
- Higher Order Stress Balance Model [7][8]
- Thermal Model (Enthalpy formulation [9])
- Transient Model

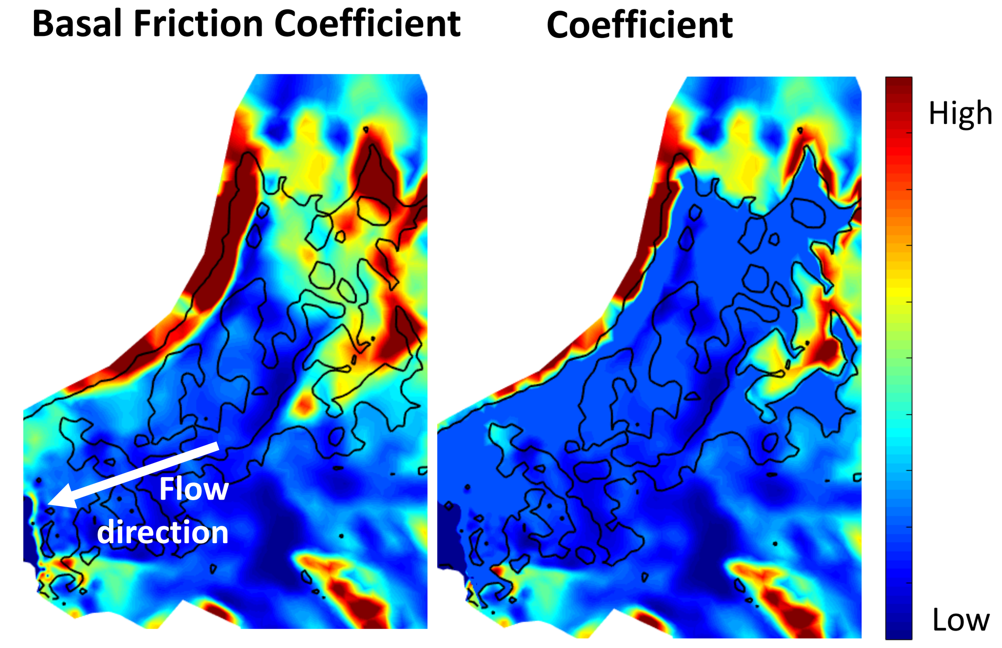
1. ISSM basal temperatures are used to highlight areas where the bed is just below freezing.

Basal Temperatures



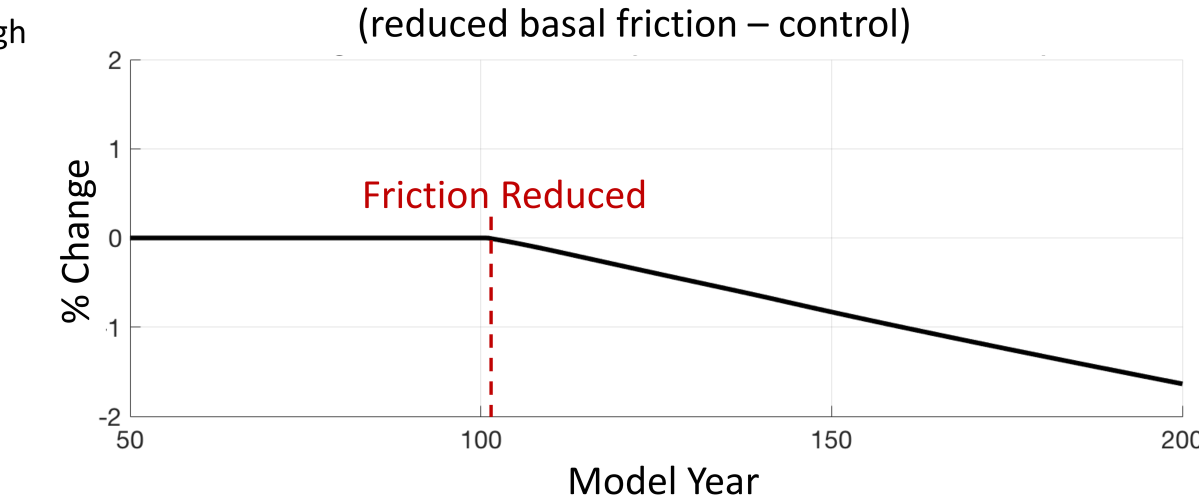
*PMP = Pressure Melting Point

2. In these frozen bed regions, the basal friction coefficient is reduced to the mean thawed friction value.



3. A transient model is run for hundreds of years to allow the ice sheet to respond to the friction perturbation

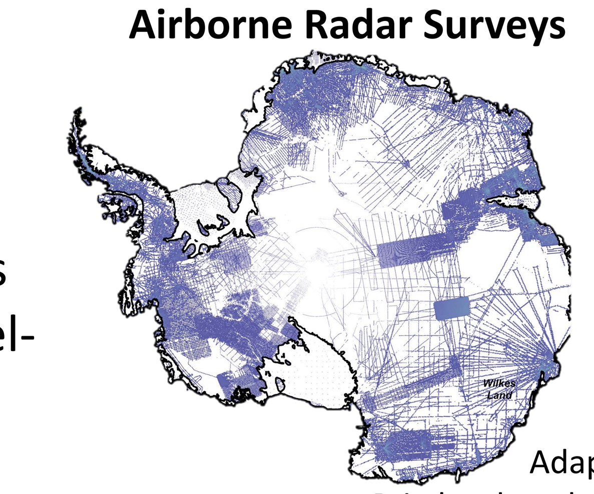
Change in Catchment Ice Volume
(reduced basal friction – control)



4. Investigating the vulnerability of frozen regions identified by radar

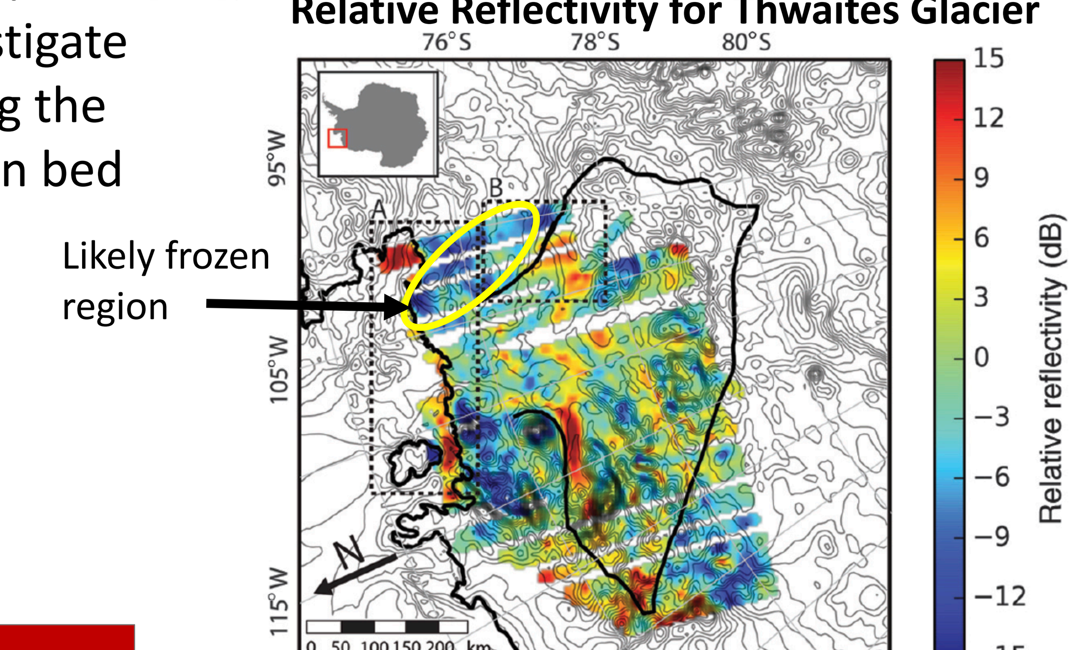
- Radar bed reflectivity is sensitivity to the subglacial environment, including the bed thermal state [10][11][12][13].
- Radar sounding surveys cover much of Antarctica. We perform reflectivity analysis on select radar flight lines to provide model-independent identification and characterization of frozen bed regions (following the technique of [10]).
- We use ISSM to investigate the impact of thawing the radar identified frozen bed regions.

Airborne Radar Surveys



Adapted from Pritchard et al. 2014 [14]

Relative Reflectivity for Thwaites Glacier



From Schroeder et al. 2016 [10]

Key Points

- Model results show a bimodal distribution of friction coefficient between the frozen and thawed bed regions (section 2).
- We model the effect of thawing regions where the bed is just below freezing by reducing the friction coefficient to a value that's characteristic of a thawed bed (section 3).
- We use radar reflectivity to constrain regions where the bed is just below freezing since these observations are independent of the modeled bed thermal state (section 4).
- Our simulations suggest that basal thaw is a mechanism that could contribute to widespread retreat and global sea level rise.

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Acknowledgements

We acknowledge the contribution from the NASA JPL/UCI ISSM team for developing the numerical ice sheet model applied in this study.

References

[1] Mantelli et al. 2019 [2] Seroussi et al., 2013, [3] Joughin et al., 2009. [4] Pattyn, 2010. [5] Larour et al., 2012, [6] Morlighem et al 2013, [7] Blatter, 1995, [8] Pattyn, 2003, [9] Aschwanden et al., 2012, [10] Schroeder et al., 2016, [11] Peters et al., 2005, [12] MacGregor et al., 2016, [13] Matsouka et al., 2012, [14] Pritchard et al., 2014.