# Estimating the Heat Production and Distribution across Ice-Stream Shear Margins Using Surface Velocities

*Nicholas Holschuh*, David Lilien, Knut Christianson*

*Correspondence can be sent to holschuh@uw.edu

[C41C-1251]

A copy of this poster can be found here:

UNIVERSITY of WASHINGTON

## The Research Questions:

1) For realistic ice stream configurations, does lateral shear in ice stream margins significantly elevate local ice temperatures?

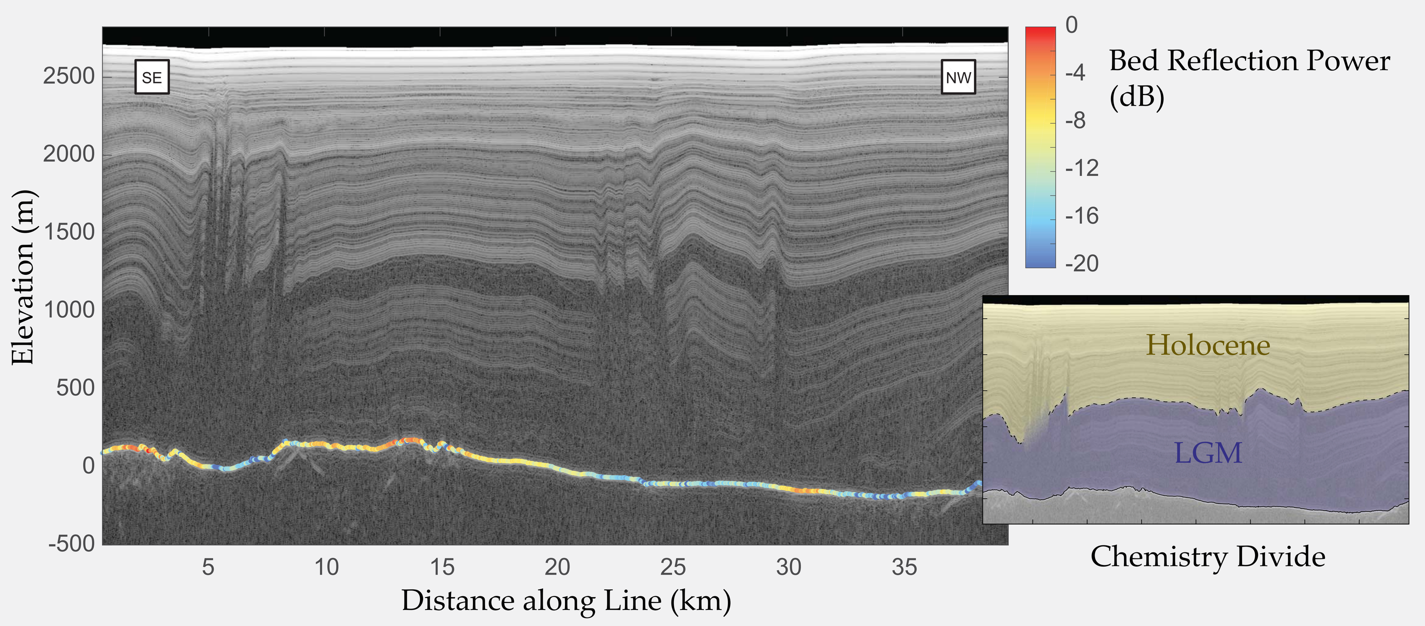
2) Do radar inferred temperatures agree with models of heat production in ice stream shear margins? If so, can models be used to separate the effects of temperature and basal hydrology in radar data to constrain substrate properties?

## Radar Theory

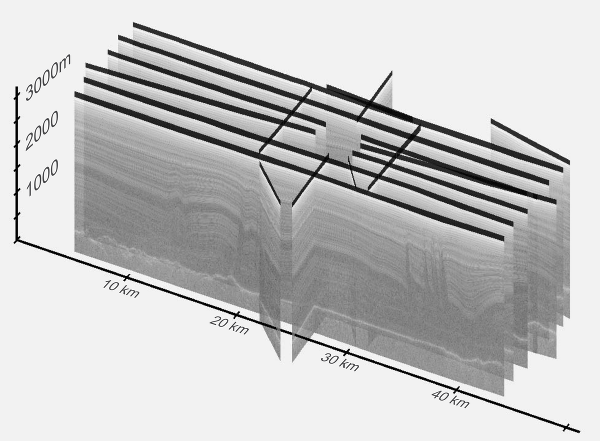
Radar imagery are commonly used to measure the ice sheet structure and subsurface geometry in Antarctica and Greenland. These data have the potential to inform our understanding of many glaciological variables of interest, as electrical properties that affect the propagation and reflection of electromagnetic waves co-vary with physical properties of the ice and substrate that affect ice flow. **Ice conductivity**, which controls radar wave absorption during propagation, **varies as a function of its chemistry and temperature** according to an Arrhenius relationship (MacGregor et al., 2007):

$$\sigma = \sigma_{ice} \exp\left[\frac{E_{pure}}{k}\left(\frac{1}{T_r} - \frac{1}{T}\right)\right] + \sum \sigma_{ion} \exp\left[\frac{E_{ion}}{k}\left(\frac{1}{T_r} - \frac{1}{T}\right)\right]$$

This implies that well calibrated radar data could be used to infer ice temperature. In this study, we use radar data together with ice flow models to better understand the extent of thermal weakening in ice stream shear margins.

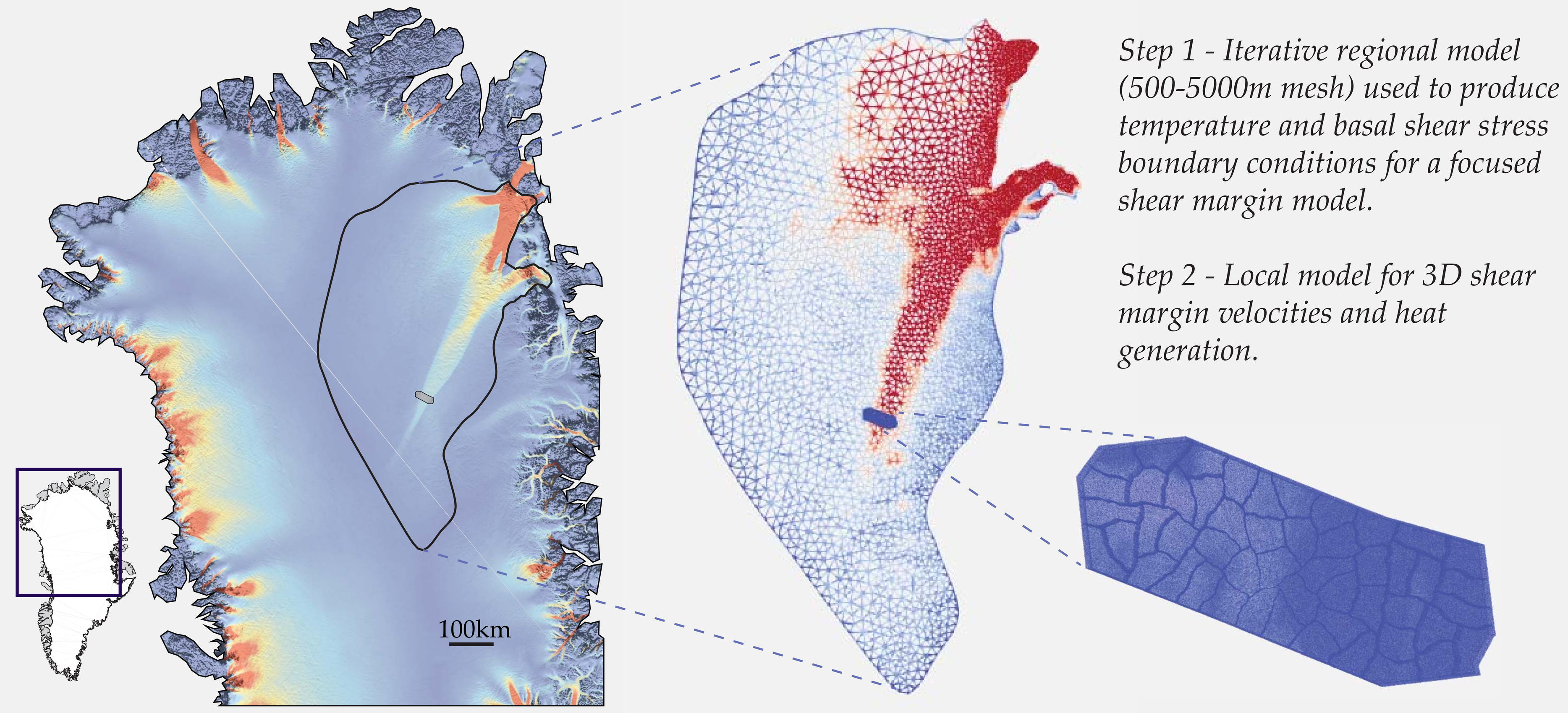



In 2012, a ground based radar survey was conducted across the shear margins of the Northeast Greenland Ice Stream. Early reflection amplitude interpretations attributed variability in bed reflection power to the distribution of subglacial water (Christianson et al., 2014), but **we believe a significant component of that signal is the result of temperature anomalies within the ice**.



## The Northeast Greenland Ice Stream

The future of the Northeast Greenland Ice Stream (NEGIS) will likely depend on the behavior at its margins. Previous studies of shear margin dynamics argue that feedbacks from thermal weakening localize shear, but this argument is largely based on analytical models that ignore the effects of cross-marginal flow on shear margin temperature. These models are inappropriate for NEGIS: flow is sub-parallel to the margin orientation on the northwest side, but oblique to the margin on the south side ( >15°). To evaluate whether or not heat dissipation due to cross-marginal flow prevents heat build-up in the NEGIS shear margins, **we implemented a higher-order thermomechanical model for ice flow in Northeast Greenland using Elmer/Ice.**




*Step 1 - Iterative regional model (500-5000m mesh) used to produce temperature and basal shear stress boundary conditions for a focused shear margin model.*

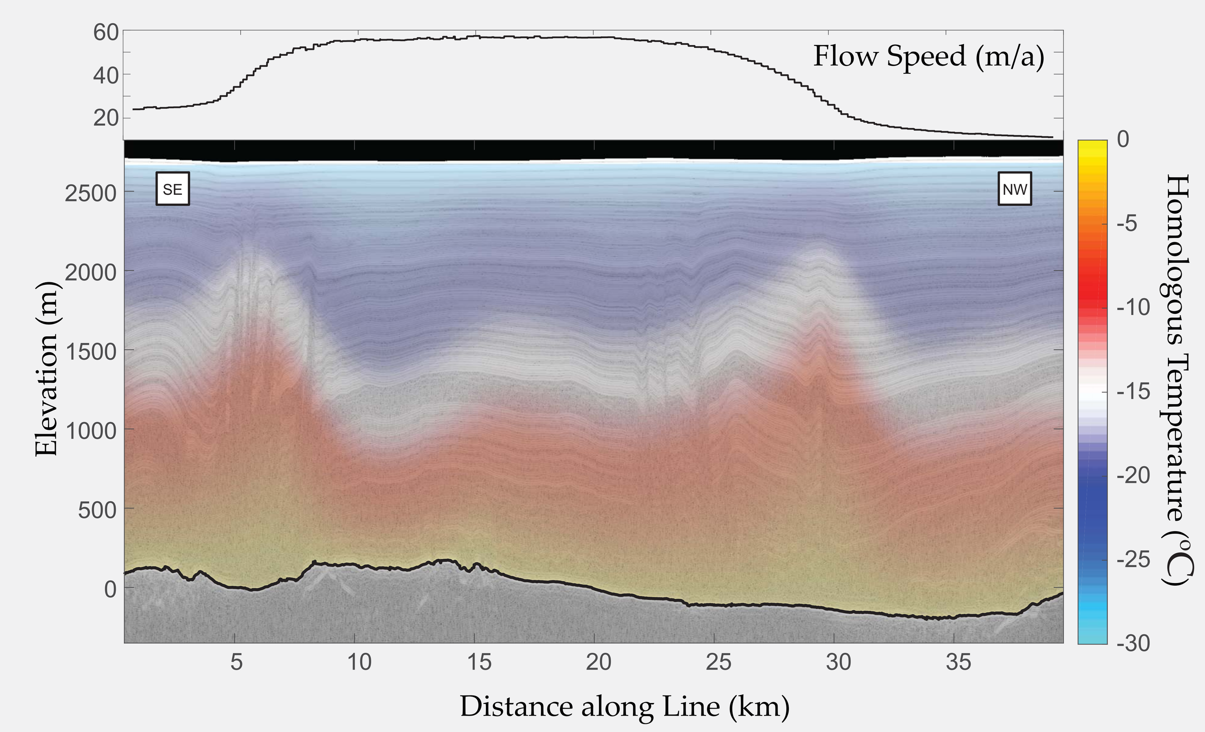
*Step 2 - Local model for 3D shear margin velocities and heat generation.*

Despite significant cross-marginal flow, the modeled temperature field shows clear thermal anomalies within the shear margins. Elevated temperatures are spatially correlated with englacial structures, implying that deformation here is, at least in-part, affected by lower-viscosity ice at the streaming-flow transition.

Despite the differences in their dynamics, the magnitude of the thermal anomalies in the two margins are nearly equal. Several competing factors likely produce this result:

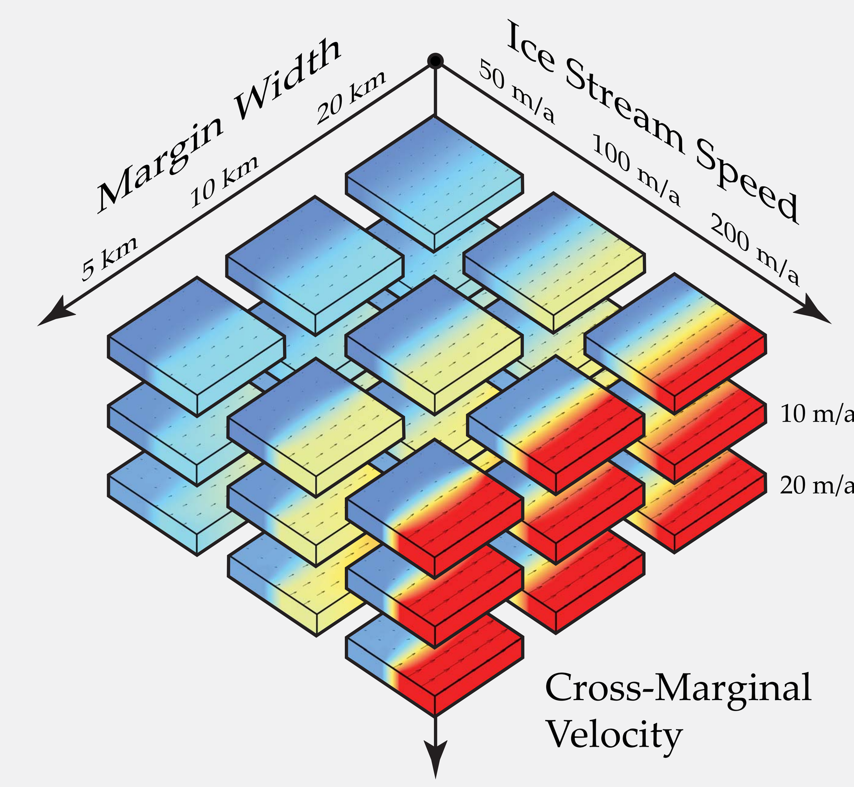
**SE Margin:**
Narrow shear zone with steep velocity gradient (+), smaller total velocity change (-), higher cross-marginal flow rate (-).

**NW Margin:**
Wider shear zone (-), higher total acceleration (+), minimal cross-marginal flow (-).

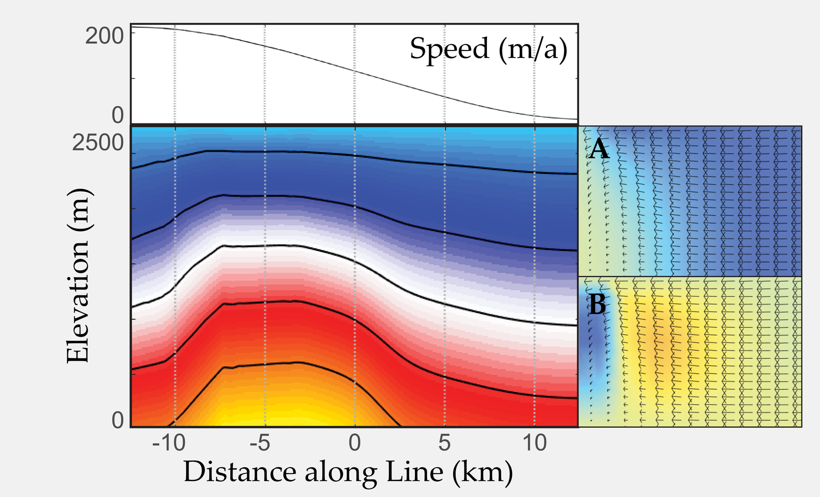



## Idealized Models

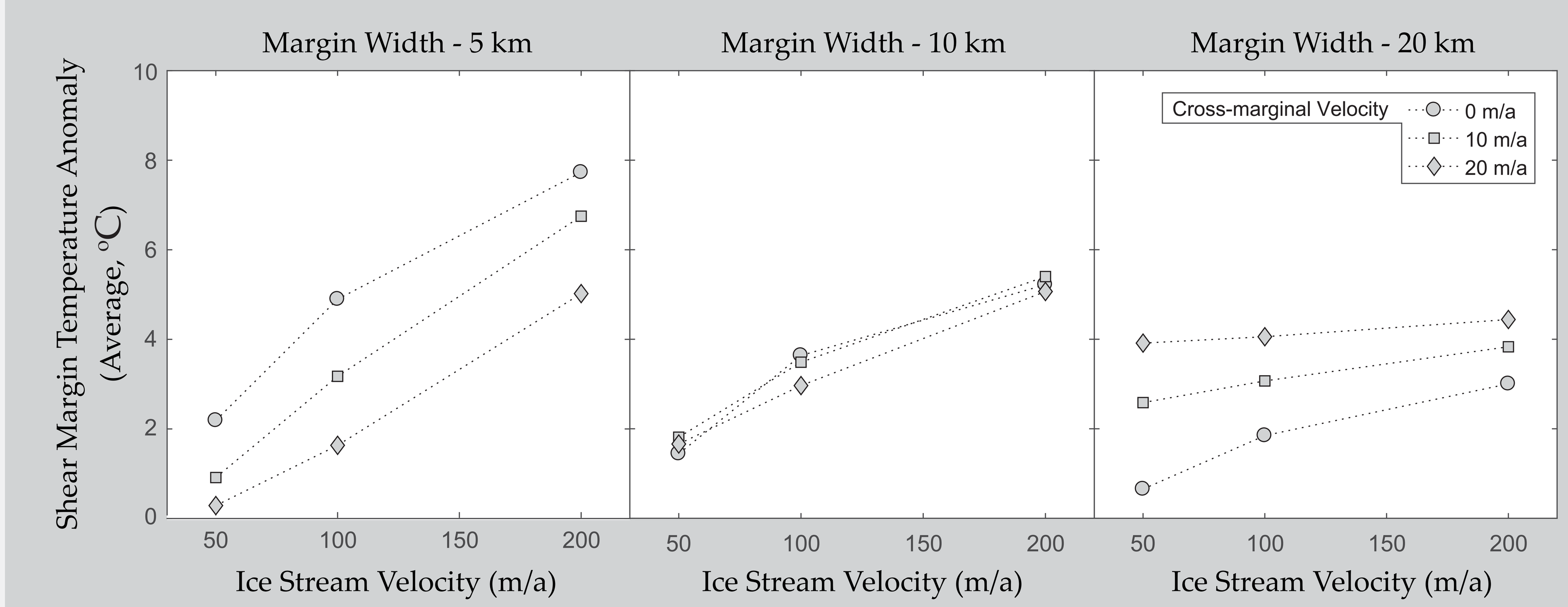
To investigate the parameters contributing to ice temperature in the Northeast Greenland Ice Stream shear margins, we performed a series of diagnostic modeling experiments, systematically varying the shear margin width (1), total ice stream speed (2), and cross-marginal flow speed to isolate their contributions to the temperature field. These were performed on a 25 km x 25 km square domain, with shear margins either 5, 10, or 20 km wide. The total velocity gradient was varied from 50 to 200 m/a, and the cross-marginal velocity ranged from 0 to 20 m/a.



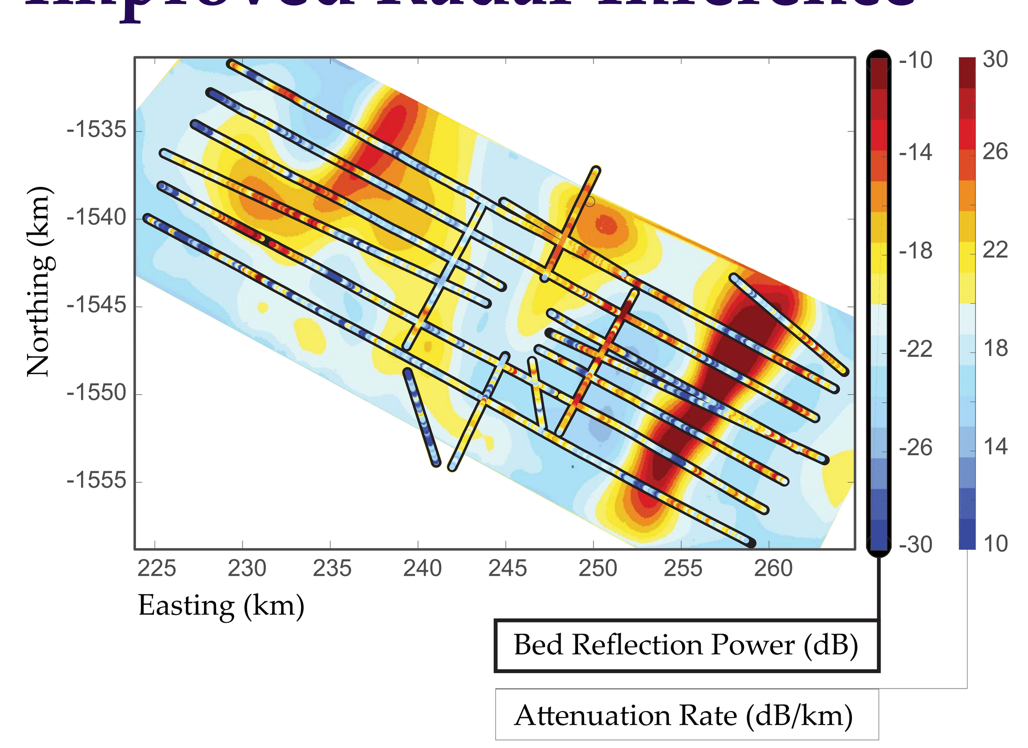

An example model result is provided to the right [20km wide margin, 200 m/a ice stream speed, 20 m/a cross-marginal flow]. Cross-marginal flow concentrates heat on the inside edge of the margin, with local convergence (shown in the horizontal velocities plotted in panel A/B) defining the location of maximum temperature. For each model run, we compare peak shear margin temperatures to the temperature profile within streaming flow. In this example, the temperature is elevated ~4°C within the margin.




Plotted below are the thermal anomalies from each experiment. The dominant control on heat production is the ice stream speed. When annual cross-marginal flow exceeds the margin width, it results in a significant decrease in heat build-up within the shear margin.

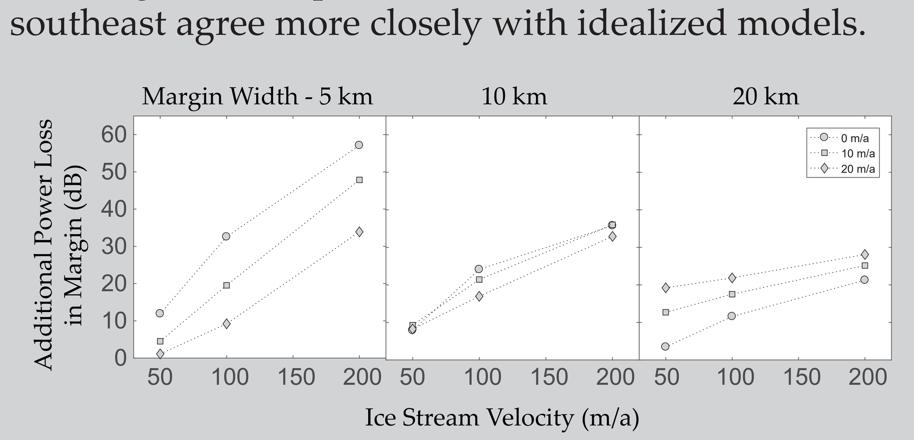



## Improved Radar Inference




The radar data show spatial agreement with modeled temperatures in the southeast margin, but the magnitude of the modeled temperature would predict greater power losses there. The northwest margin shows an inverse relationship between temperature and reflectivity.

The magnitude of power losses (~10dB) observed in the southeast agree more closely with idealized models.




## The Conclusions:

1) Thermal weakening likely plays a role in ice dynamics near the onset of the Northeast Greenland Ice Stream, where our modeled temperature field is characterized by positive thermal anomalies (~4-6°C), collocated with englacial structures imaged with ice penetrating radar.

2) Cross-marginal flow controls heat retention within ice sheet shear margins, dissipating heat most effectively in narrow margins, and inducing variability in marginal thermal anomalies on the order of 50% of the total signal.

3) Observed reductions in bed reflection power in the southeast margin (~10-15 dB) are consistent with the spatial pattern (but not the magnitude) of model predicted temperatures. The northwest margin disagrees in both pattern and magnitude, requiring a complex basal hydrology to explain the radar data.

4) Idealized models of shear margin thermal anomalies provide a more realistic match to the radar observations. Our future work is focused on rectifying that disagreement (which likely results from the basal shear stress inversion).

## Acknowledgments

N. Holschuh and K. Christianson received funding for this project through NSF grants PLR 1503907 and OPP 1643353, as well as NASA grant NNX16AM01G. Support for data collection was provided by Pennsylvania State University and the Center for Remote Sensing of Ice Sheets

## References

MacGregor, J. a., Winebrenner, D.P., Conway, H.B., Matsuoka, K., Mayewski, P.A., and Clow, G.D., 2007, Modeling englacial radar attenuation at Siple Dome, West Antarctica, using ice chemistry and temperature data: Journal of Geophysical Research, v. 112, p. 1–14.

Christianson, K., Peters, L.E., Alley, R.B., Anandakrishnan, S., Jacobel, R.W., Riverman, K.L., Muto, A., and Keisling, B.A., 2014, Dilatant till facilitates ice-stream flow in northeast Greenland: Earth and Planetary Science Letters, v. 401, p. 57–69, doi: 10.1016/j.epsl.2014.05.060.