Stable channelized subglacial drainage beneath Thwaites Glacier, West Antarctica

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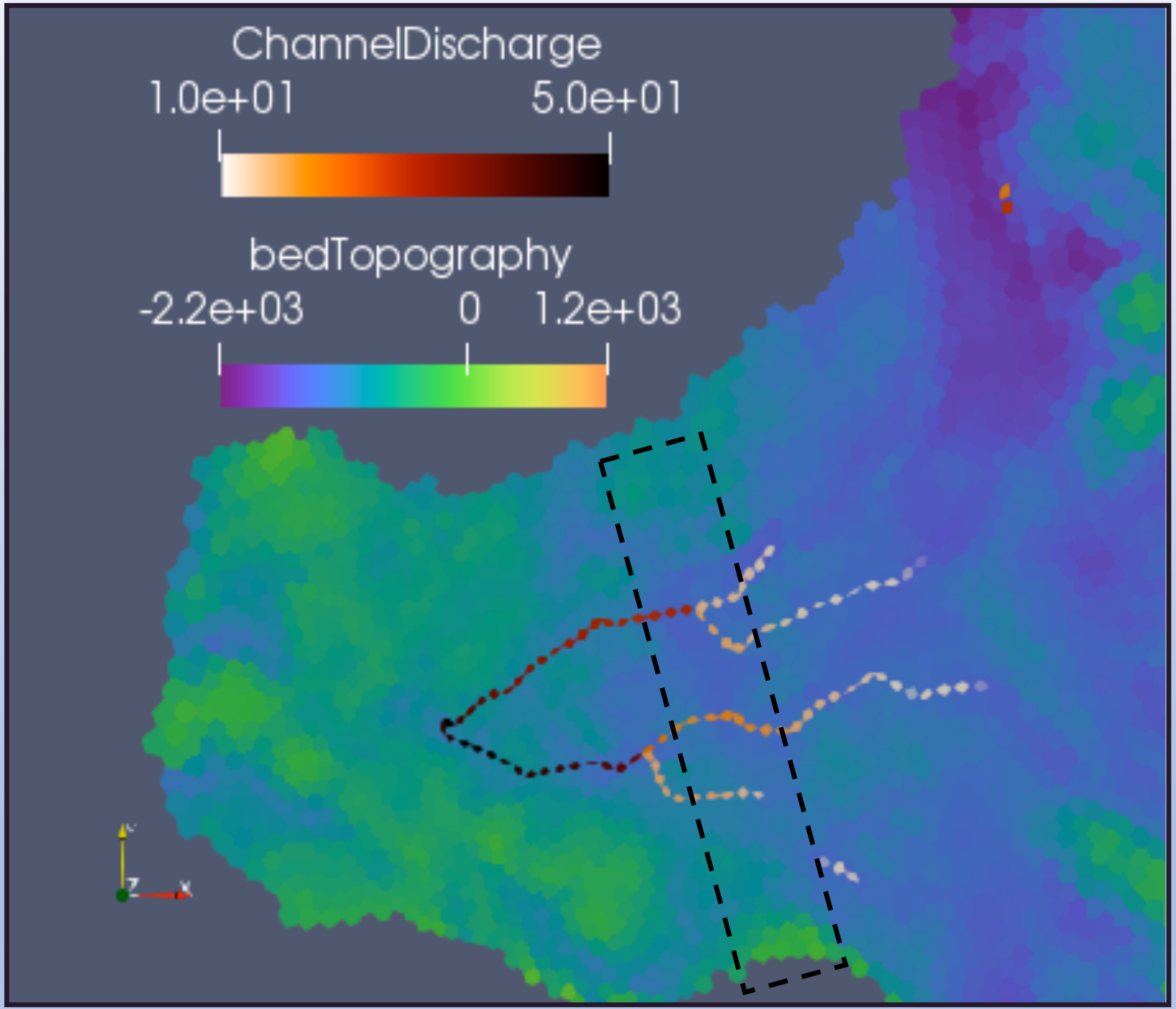
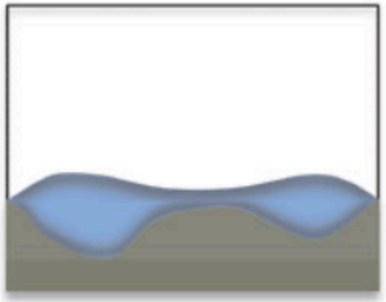


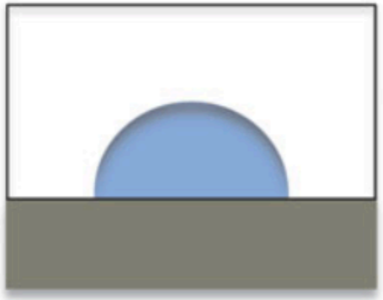
Subglacial Hydrology Theory

Subglacial Hydrology of Thwaites Glacier

Two Types of Drainage:



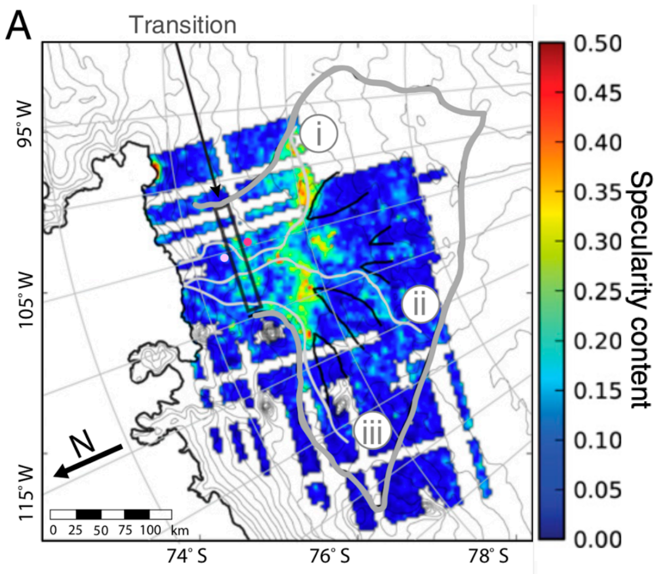
Distributed Drainage: Highly pressurized and spatially distributed network water-filled cavities. Distributed drainage lubricates large swaths of the glacier bed, and is prevalent when discharge is low.



Channelized Drainage: Localized conduits transporting large volumes of water that form from turbulent melting of the overlying ice. Channels efficiently remove water from the bed and increase basal friction. Channels only exist when discharge is high.

Flowers (2015)

It is uncertain whether there is sufficient meltwater beneath West Antarctica to form stable channels; however recent radar specularity observations suggest the Thwaites Glacier catchment may be large enough to form channels near the glacier terminus.



Schroeder et al. (2013)

High radar specularity can be a proxy for the presence of distributed drainage. The lack of specularity near the terminus suggests a transition to channelized drainage.

MPAS-Albany Ice Model (MALI)

We use a DOE-developed, 2-D subglacial hydrology and ice-dynamics model, MALI, to asses the likelihood that stable channelized flow exists beneath Thwaites Glacier.

General Model Framework:

Distributed Discharge:

$$\boldsymbol{q} = -k_q W^{\alpha_1} |\nabla\phi|^{\alpha_2 - 2} \nabla\phi$$

Where k_q is the distributed conductivity, and W is the distributed system water thickness:

$$\frac{\partial W}{\partial t} = c_s |\boldsymbol{u}_\mathrm{b}| (W_\mathrm{r} - W) - c_\mathrm{cd} A_\mathrm{b} N^3 W$$

C_s and W_r are free parameters representing bed roughness and maximum bed bump height.

Channelized Discharge:

$$\boldsymbol{Q} = -k_Q S^{\alpha_1} |\nabla\phi|^{\alpha_2 - 2} \nabla\phi$$

Where k_Q is the channelized conductivity, and S is the channel cross-sectional area:

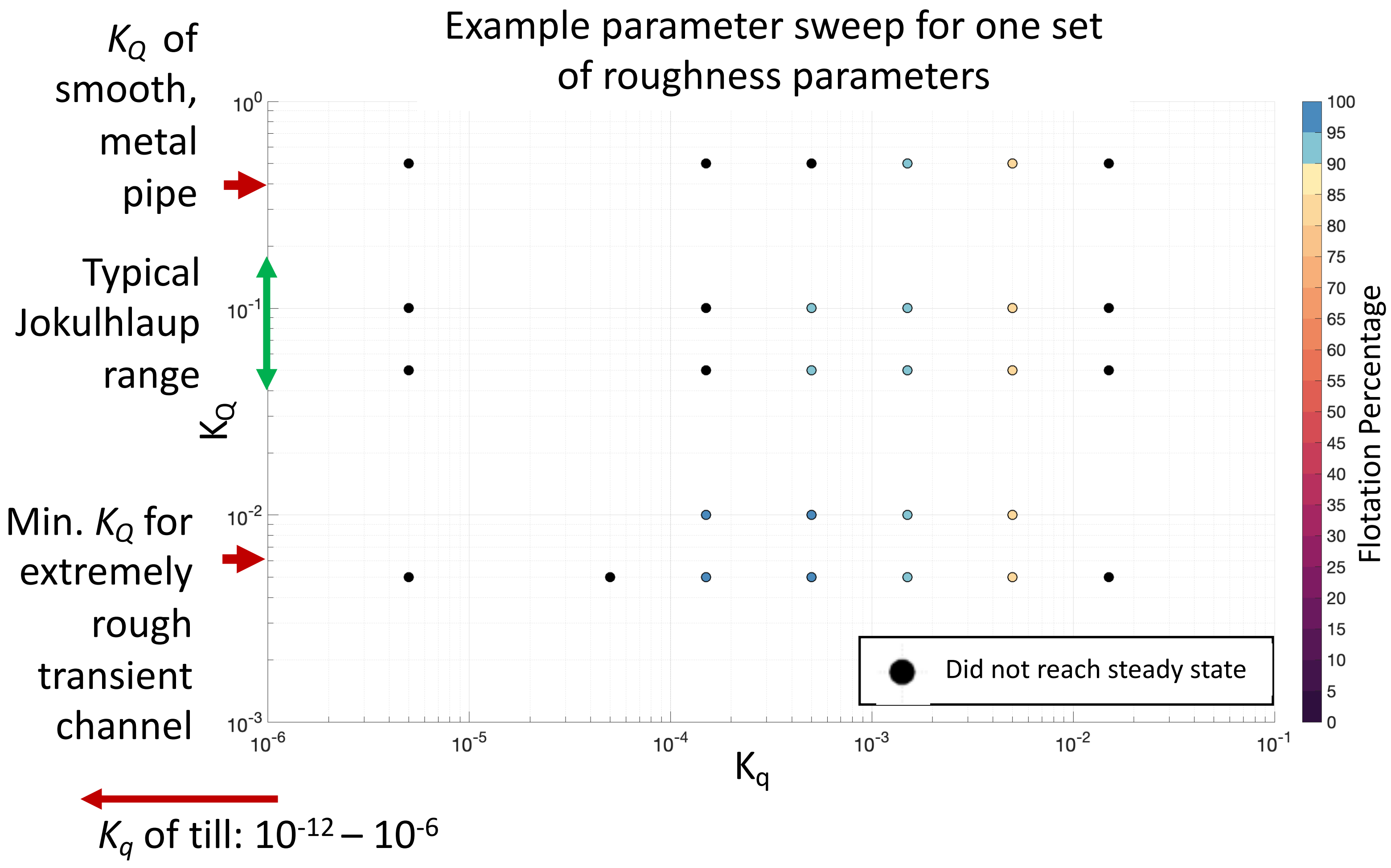
$$\frac{\mathrm{d}S}{\mathrm{d}t} = \frac{1}{\rho L}(\Xi - \Pi) - c_\mathrm{cc} A_\mathrm{b} N^3 S$$

Melt opening

Creep closure

Parameter Sweep

- The model has four free parameters:
    1. Distributed hydrologic conductivity (Kq)
    2. Channelized hydrologic conductivity (K_Q)
    3. Bed roughness (C_s)
    4. Maximum bed bump height (W_r)
- For a given set of bed roughness parameters, we tested the full range of realistic combinations of K_q and K_Q
- Runs must reach steady state and have an average flotation percentage >90 %
- 113 total model simulations across a range of realistic choices.

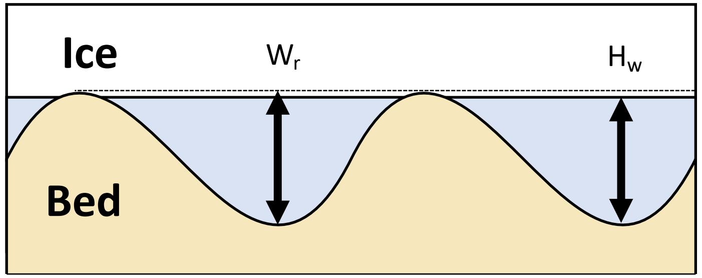


Model Comparison to Radar Specularity

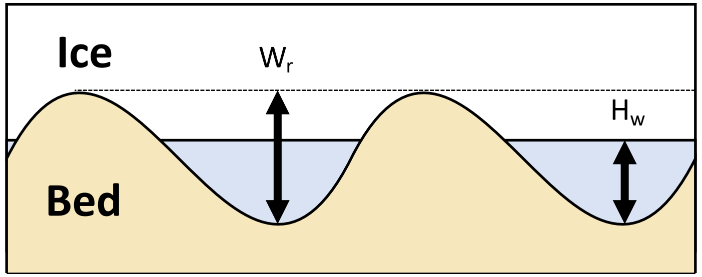
We compare each of our steady state runs with previously-observed radar specularity to determine the most realistic simulations.

Radar specularity is high when reflecting off of a flat surface, such a sheet of water or a distributed drainage system. This condition is met in our model when water thickness is close to the maximum bump height.

Water Thickness Ratio: $R_{WT} = W_r / H_w$



Highly specular

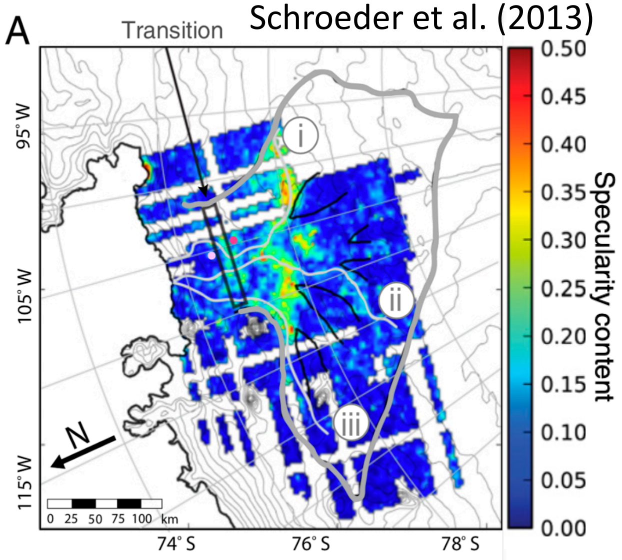


Not specular

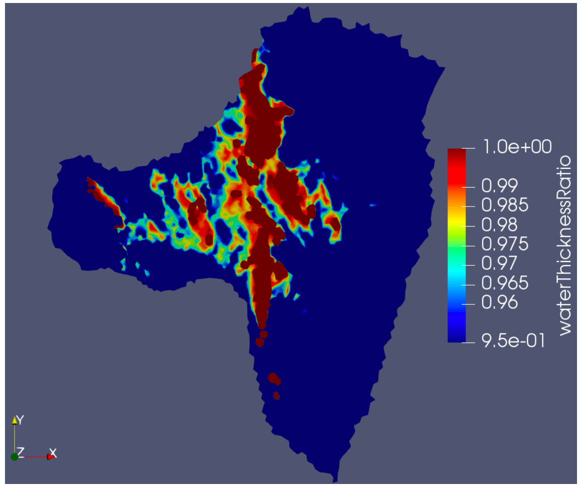
Water thickness ratios from each simulation are compared to radar specularity. “Realistic” simulations share both a strong correlation and similar spatial pattern to radar specularity.

Observed Radar Specularity

Schroeder et al. (2013)



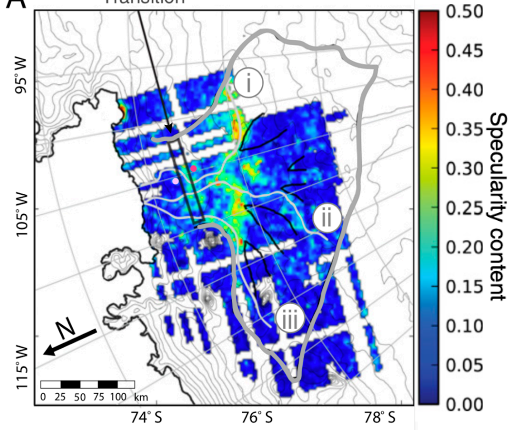
Modeled Water Thickness Ratio



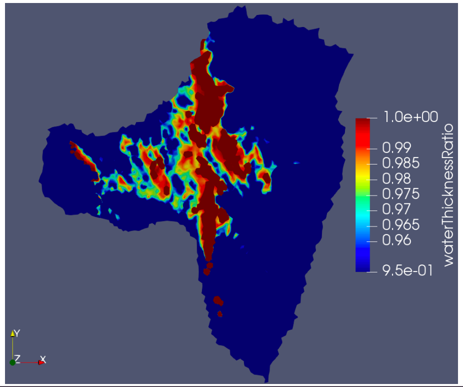
Model Comparison to Radar Specularity

Observed Radar Specularity

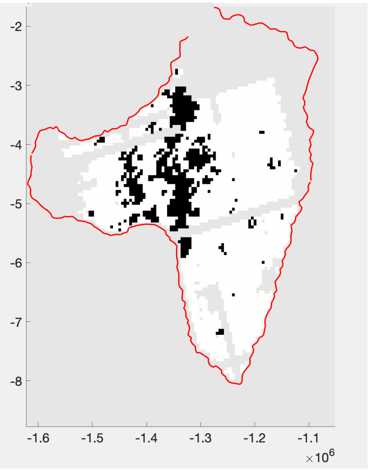
Schroeder et al. (2013)

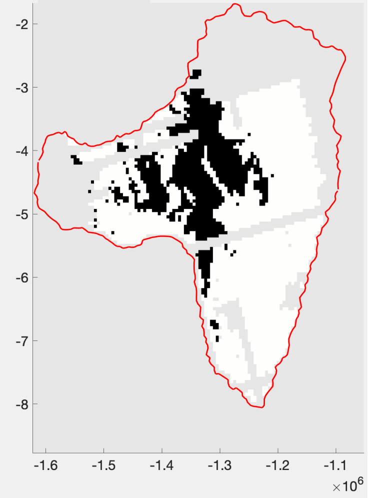


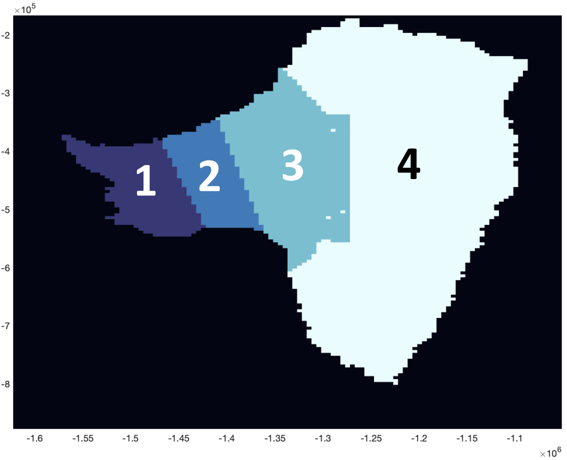
Modeled Water Thickness Ratio



To compare between observations and the model, we create binary masks of high specularity and high R_{WT}

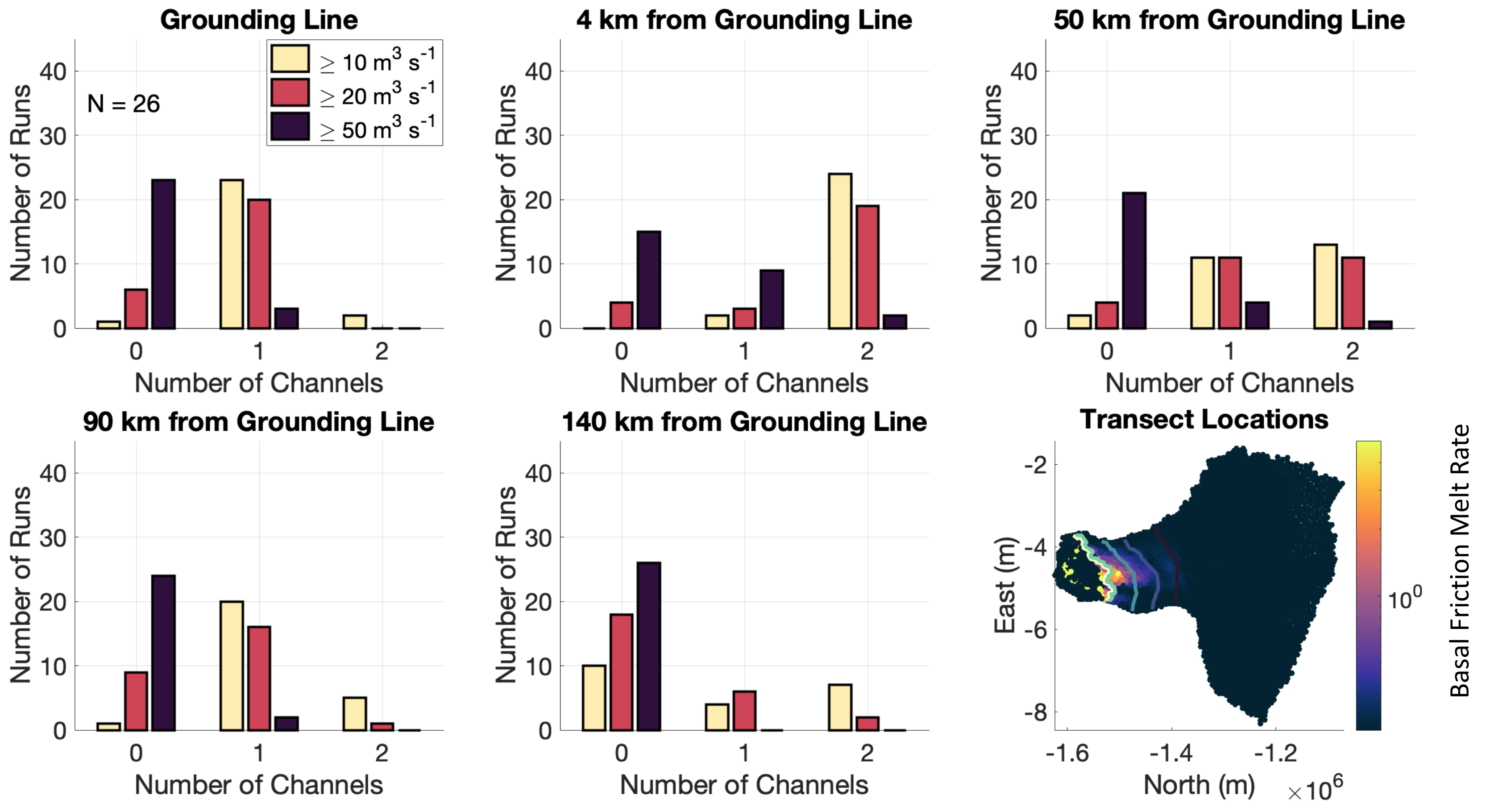






We then divide the domain into four regions: 1) a lower non-specular region, 2) the ”transition zone”, 3) a highly specular region, and 4) an upper non-specular region. Simulations are deemed “realistic” if the masks agree for the majority of grid points in each zone, and have an overall correlation coefficient of over 0.4.

Results



- 26 simulations met our *realistic* criteria.
  - All realistic runs developed channelized flow with 140 km of the grounding line (within the hypothesized channelized zone in Schroeder et al. (2013).
- Channel discharge and the number of channels increase toward the grounding line, likely a result of increased basal frictional melting near the terminus.
- Channel discharge exceeds 50 $m^3 s^{-1}$ near the grounding line for some realistic simulations.

Implications and Future Directions

- Our results indicate stable channelized drainage is probable beneath Thwaites Glacier, and likely occurs at other large glacier catchments in West Antarctica.
- Near-terminus channelization at Thwaites Glacier may act to stabilize ice dynamics by reducing water pressure and increasing basal friction. However, channels also form buoyant subglacial discharge plumes at the grounding line, which increase submarine melting and calving, and could potentially expedite retreat.
  - We are starting work coupling the ice dynamics and subglacial hydrology portions of MALI for Thwaites Glacier to determine how channelization affects long-term projections of retreat.
- Subglacial water can also be an importance source of iron and other nutrients to the otherwise iron-depleted Southern Ocean. Channelized drainage may create hotspots for nutrient export into the ocean, as well as allow nutrients to upwell from depth through entrainment into the subglacial discharge plume.