Investigating impacts of basal channel formation and evolution on ocean melting in an embayed Antarctic ice shelf

Sienna Phillips

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Introduction: As global temperatures rise, the Antarctic ice sheet continues to exhibit significant thinning and retreat (Levermann et al., 2020). While several studies have highlighted the link between rising ocean temperatures and elevated ice shelf melting (Hoffman, Asay-Davis, Price, Fyke, & Perego, 2019; Holland, Jenkins, & Holland, 2008; Naughten et al., 2021; Jenkins et al., 2018), the geometry of the ice shelf can also influence melt rates. Figure 1. shows satellite imagery of Pine Island Glacier in West Antarctica where several longitudinal grooves can be seen. These indentations are deep channels incised into the underside of the ice shelf and are known to exist throughout the ice shelves of both East and West Antarctica (Alley, Scambos, Siegfried, & Fricker, 2016). The exact cause of these channels, as well as their overall impact on the ice shelf is unknown, however, one proposed mechanism for their formation is heterogeneity in the ice-draft (the part of the ice shelf below sea level). This variability in thickness results in the speed up of buoyant plumes which entrain underlying warm seawater and so melt rates are expected to increase along parts of the draft where steep slopes occur.

We aim to investigate this mechanism for channel formation and simulate two situations; one in which the ice draft is initially homogeneous, and another where we have introduced some heterogeneity into the initial conditions. We also intend to compare the melt rates of both situations as we expect the number of areas with steep basal gradients to affect both the magnitude and distribution of melt rates.

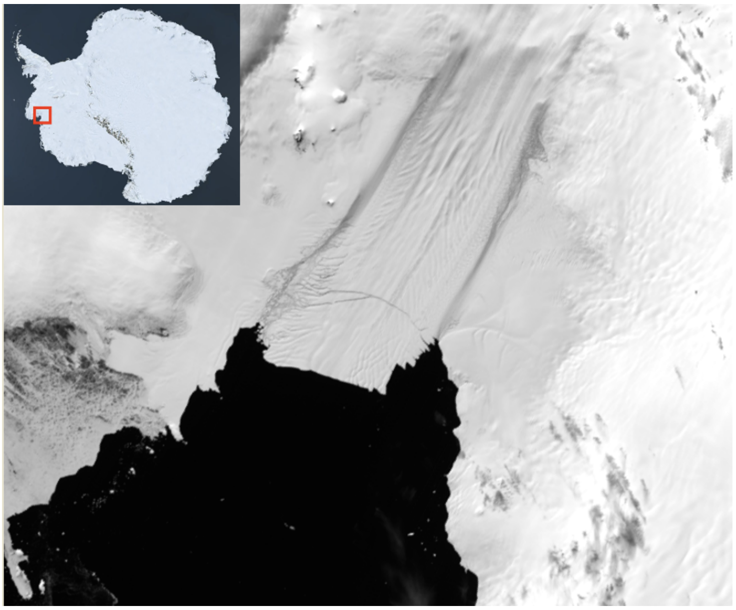

Figure 1: *Pine Island Glacier located in West Antarctica with clear indentations running in the along flow direction*

Methods: The domain compromises of a 3 dimensional, embayed ice shelf with dimensions of 50 km width and 80 km length, based on those of Pine Island. The shelf is embayed and so no slip boundary conditions are enforced on the lateral boundaries. The Shallow Shelf Approximation (SSA) is used as the equations for the conservation of mass and momentum, as implemented in the Ice-sheet and Sea-level System Model (ISSM; https://issm.jpl.nasa.gov). Glen's flow law is used to describe the ice viscosity with the Glen's flow law exponent, taken to be 3.

We ran the SSA for 140 years with homogeneous ice draft initial conditions until a steady state was reached and then introduced a plume model for a further 50 years. The plume model was introduced firstly on the steady state shelf with no further heterogeneity added to the ice-draft then later we ran the same 50 year plume model but introduced the following perturbation at the grounding line (the line where ice transitions from being grounded to floating) $\delta H = 200\left(cos(\frac{30\pi x}{Lx})\right)$, where L_x is the length of the domain (50 km).

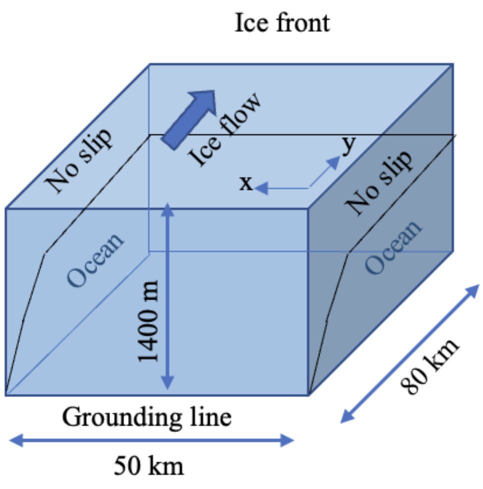

Figure 2: *Geometry of the embayed ice shelf model used in this project.*

Results:

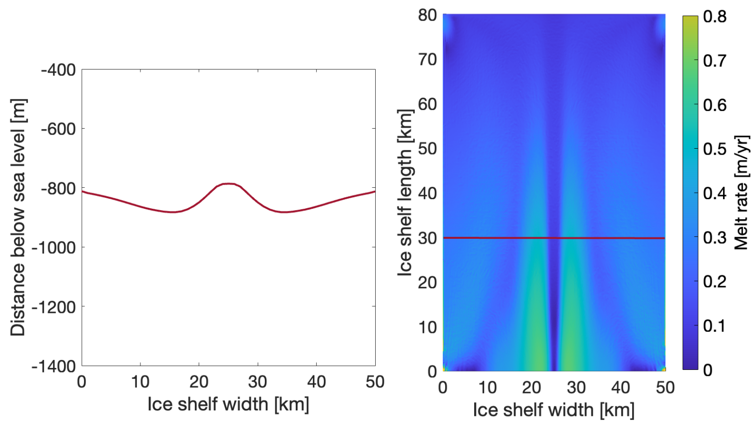

Figure 3: *Left:transect of the ice draft 30 km downstream of the grounding line showing clear transverse variability. Right: melt rates across entire shelf*

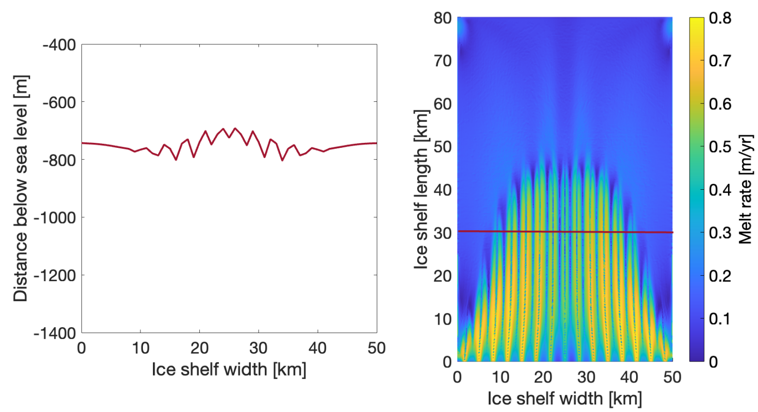

Figure 4: *Left: transect of ice draft 30 km from the grounding line showing the perturbations in thickness which have evolved into longitudinal channels. Right: melt rates across entire shelf.*

Discussion: Over the development of the steady state, natural heterogeneity in the ice-draft evolved, with one broad channel appearing. Figures 3 and 4 show the shape of the ice draft 30 km from the grounding line as well as the melt rates after the plume parameterisation has been run. Figure 3 shows that variability in the ice draft arises even before the perturbation is added. This is due to the velocity gradient across the shelf. The velocity is greatest along the centreline and decreases to zero on the lateral walls. One large channel is produced and we can see that the melt rates are indeed highest along the walls of this channel where the basal slopes are high. The plumes can travel faster along these walls and so we see melt rate increasing.
Figure 4 shows the impact of the perturbation added at the grounding line. The channels decrease in amplitude as the flow moves toward the ice front. The overall shape of the large channel seen without the perturbations is also maintained as can be seen in the transect. Melt rates are highest along the walls of the channels as expected where the variability in ice-draft is highest and overall, melt rates are higher than when no perturbations were added. This could be due to the greater number of steep basal slopes present in the ice-draft due to the channels created by the perturbations.
The values of the melt rates themselves in both cases are very low, we would expect them to be an order of magnitude greater. This is most likely due to the model not being coupled to an ocean model which would account for the broad, overturning ocean circulation beneath an ice shelf. We intend to couple such a model to the plume model to get more accurate melt rate values in the future. We also aim to assess the impact that basal channels may have on the structural integrity of the ice shelf.

Conclusions: We conclude that transverse variability caused both by lateral shear and the heterogeneity in ice thickness at the grounding line can lead to higher melt rates where steeper slopes are present. We look forward to further analysis of basal channels as well as their overall impact on the ice shelf stability.

Acknowledgments: Satellite data acquired for Figure 1 available at https://nsidc.org/data/NSIDC-0102/versions/2 and https://gisgeography.com/antarctica-map-satellite-image/

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