The Effect of Basal Channels on Oceanic Ice-Shelf Melting

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1 INTRODUCTION

The mass budget of Petermann Glacier (Fig. 1), which is one of the largest and most influential glaciers in northern Greenland[1], is dominated by oceanic melting (80%)[2]. Petermann Glacier's ice tongue has four deep basal channels, aligned with glacier flow[2], whose importance on the stability of the ice shelf remains open; with proposed impacts including an increase in mechanical instability[2] and a reduction in basal melting, leading to an increase in ice-shelf stability[3].

We have used MITgcm to model the cavity beneath a pre-2010 Petermann-style idealised ice shelf[2,4]. The domain is a north-south orientated rectangle, 100 km by 20 km by 900 m deep. The ice shelf extends 70 km from the southern boundary and thins from 600 m at the grounding line to 60 m at the ice front. Sinusoidal longitudinal channels are introduced across the entire width of the ice shelf base (Fig 2).

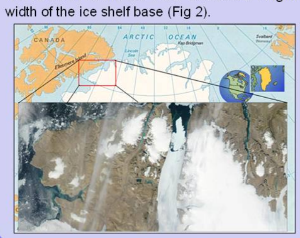

Figure 1) Location of Petermann Glacier.

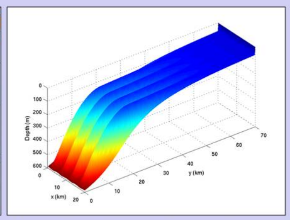

Figure 2) Model draft map of Petermann Glacier

2 BASAL MELTING

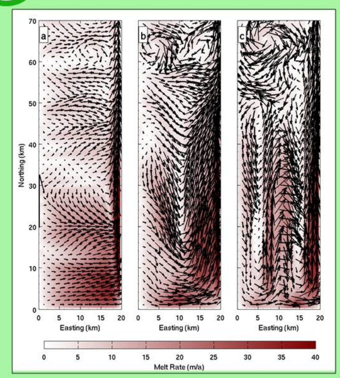

Figure 3. Modelled mixed-layer velocities for the a) 0-, b) 1- and c) 2-channel cases overlain on basal melt rates (m/a).

Figure 3 shows that as channels are introduced, the mixed-layer flow changes from a Coriolis-generated boundary current to geostrophic returning currents confined within the channels.

The location of strongest melt also changes from underneath the eastern boundary current to in the channels near the grounding line and on their right-hand slopes. As the number of channels is increased further, the mean melt rate decreases (Fig. 4a).

To a good approximation the melt rate is proportional to the thermal driving (T-Tb) and frictional velocity (u*)[5,6]. Figure 4b shows that the variation in u* explains the variation in melt rate seen in Figure 4b.

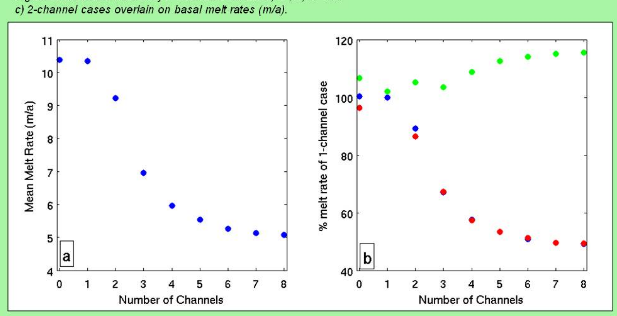

Figure 4. a) Mean melt rates. b) predicted melt rates as a % of 1-channel case. Blue dots are modelled melts, red dots are varying u and green dots are varying (t-tb).*

3 CHANNEL EFFECT

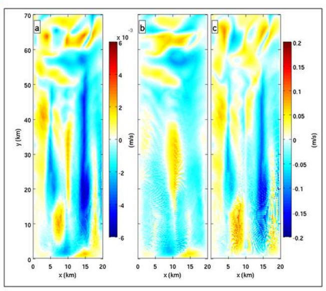

Figure 5. Difference in a) u, b) u_m and c) v_m between the 1- and 2- channel case. A negative value indicates a decrease going from 1- to 2- channels.*

The decrease in u* can be explained by the decrease in v_m (Fig. 5). The mixed layer is in geostrophic flow, so one would imagine the reduction in v_m is due to a change in across shelf basal gradients, however Figure 6 shows the basal gradients to be similar between the 1- and 2- channel cases, meaning this is not the case.

The reduction in v_m is due to the addition of 'no flow' areas under the ice shelf (channel keels and crests), which are areas of minimal flow and hence melt. As more channels are added, the number of these areas increases, meaning a reduction in mean melt.

For narrower channels, the viscosity does not allow the horizontal shear of the returning circulation, with an overturning circulation replacing it. This changed melting locations to the channel crests (Fig. 7), meaning that the inclusion of more 'no-flow' regions has little effect.

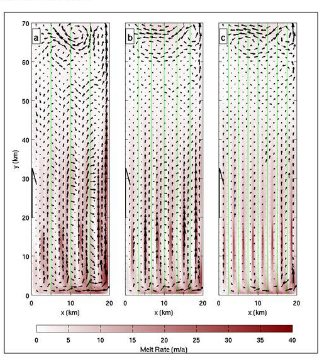

Figure 7. Modelled mixed-layer velocities for the a) 4-, b) 6- and c) 8-channel cases overlain on basal melt rates (m/a). Green lines represent keels between channels.

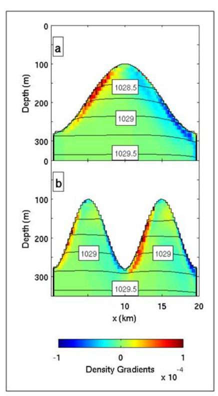

Figure 6. Density (contours) and across shelf gradients (colour) 20km from grounding line, for 1- (a) and 2-channels (b)

4 SUMMARY

- The introduction of channels changes the mixed-layer circulation from a Coriolis-generated boundary current to geostrophic returning currents in each channel.
- Channels cause the areas of strongest melt to change from against the eastern boundary to near the grounding line in the channels and on the channel's right-hand slopes.
- As the number of channels increases, the mean melt rate reduces. For a small number of wider channels this sensitivity is high, but for a greater number of smaller channels this sensitivity drops.
- For a small number of channels this sensitivity is due to the inclusion of more 'no-flow' regions underneath the ice shelf.
- As further channels are introduced, the circulation within the channels changes to an overturning circulation. The addition of further areas of 'no-flow' have a smaller effect on mean melt rate, reducing the sensitivity to the number of channels.
- This stabilising effect is a potential explanation as to why basal channels are observed in warm-water ice shelves around Greenland and Antarctica. If the channels stabilise ice shelves, ice shelves with channels are more likely to persist, and a 'survivor bias' makes them more likely to be observed.

5 REFERENCES

1. Rignot, E, Gogineni, S, Joughin, I, and Krabill, W, (2001) Contribution to the glaciology of northern Greenland from satellite radar interferometry, *Journal of Geophysical Research*, 106, 34007-34020
2. Rignot, E., and K. Steffen (2008), Channelized bottom melting and stability of floating ice shelves, *Geophys. Res. Lett.*, 35, doi:10.1029/2007GL031765
3. Gladish, CV, Holland, DM, Holland, PR, and Price, S (2012), Ice-shelf basal channels in a coupled ice/ocean model, *Journey of Glaciology* 58 (212), 1227-1244.
4. Johnson, HL, Munchow, A, Falkner KK, and Melling, J, (2011), Ocean circulation and properties in Petermann Fjord, Greenland, *Journal of Geophysical Research*, 116, doi:10.1029/2010JC006519
5. Holland, DM, and Jenkins, A, (1999) Modelling Thermodynamic Ice-Ocean Interactions at the Base of and Ice Shelf, *J.Phys. Oceanogr.*, 29, 1787-1800
6. Holland, PR, Jenkins, A, and Holland, DM, (2008) The Response of Ice Shelf Basal Melting to Variations in Ocean Temperature, *Journal of Climate, 21, 2558-2572*