The Cryosphere Discuss.,
https://doi.org/10.5194/tc-2017-242-RC3, 2018

The Cryosphere Discussions

Interactive comment on "Basal drag of Fleming Glacier, Antarctica, Part B: implications of evolution from 2008 to 2015" *by* Chen Zhao et al.

Anonymous Referee #3

Received and published: 12 March 2018

GENERAL COMMENTS

Main question in the abstract: Is the observed acceleration of the flow and thinning of the glacier due to increased ocean warming and/or marine ice sheet instability?

Method: Infer basal shear stress from observations and calculate a steady state temperature field using a Stokes ice sheet model for 2008 and 2015.

Results: Reduction in magnitude and increase in area of low basal shear stress near the 1996 grounding line and reduction in height above flotation between 2008 and 2015 suggest the grounding line has retreated for Fleming Glacier, southern branch of Fleming Glacier and Prospect Glacier.

A band of higher basal shear stress parallel to the 1996 grounding line at 2008 sug-

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Discussion paper

gests that Fleming Glacier was still grounded at that time.

Subglacial water may be generated from high basal frictional heating upstream of Fleming Glacier. Frictional heating has increased between 2008 and 2015 over a rise between two deep bedrock basins.

Comments: I don't think the main question can be answered from instantaneous time slices of the ice flow. The authors need to do forward experiments with various ocean forcing such as different basal melt rates or vertical melting at the calving front. Alternatively, the authors need to pose a different question.

The band of high basal shear stress may not be physical realistic. The model error reported in their companion paper is relatively high in this area.

Interesting idea: The authors propose that basal water generated from high basal frictional heating upstream draining towards the front, triggered grounding line retreat of Fleming Glacier. This mechanism is an alternative to the usual ocean forcing explanation. Mass loss could significantly increase, due to marine instability, if the grounding line retreated over a bedrock rise into the second deeper basin. The highest frictional basal heating in 2015 is located over the rise, which may be a potential trigger for the grounding line retreat.

Manuscript in general: The font is too small and the text is not double spaced, which made reviewing the paper tricky. Picking out the references was particularly difficult give the font size and text spacing. Some of figures are too small.

SPECIFIC COMMENTS

Ocean forcing: It seems reasonable to suggest that increased melting at the vertical face of the front of FGL due to incursions of CDW may have affected the pressure boundary condition at the front sufficiently to remove the high band of basal shear stress. However, I don't think your results shed any new light on what has been suggested in the other references you use about ocean basal melting. Forward timedependent modelling experiments are needed to test these theories and here's an example for Larsen B of how you can extend the work you have done for this paper. Vieli et al 2007 Causes of pre-collapse changes of the Larsen B ice shelf: Numerical modelling and assimilation of satellite observations. Earth and Planetary Science Letters. https://doi.org/10.1016/j.epsl.2007.04.050

Grounding line retreat: The results for 2015 of low basal shear stress and low height above buoyancy confirm the findings of Friedl et al 2017 that Fleming Glacier's grounding line has retreated. The results for PGL are different to FGL: Driving stress appears to be much higher for PGL in 2015. Temperature homologous near the 1996 grounding line appears much lower in 2015 suggesting that the glacier may have become frozen to the bed?

Is the band of high basal stress at the front of FGL physically realistic? The authors attempt to address this question in the paragraph beginning on line 209. Part A shows that the misfit between the modelled and observed speed is high, where the modelled speed is too fast, and the surface slope is also higher here than over the region of low shear stress. The driving stress is not obviously high given the relatively high surface slope. What concerns me is your model appears unable to model the front. What about rheology of the ice near the front? Perhaps the standard A is not appropriate here. Part A shows a large vertical shear at the front where the basal speed is much smaller than the surface. Is the ice stiffer at the front? Vieli et al 2006 Numerical modelling and data assimilation of the Larsen B ice shelf, Antarctic Peninsula, Phil. Trans. R. Soc. A, 364, 1815–1839, doi:10.1098/rsta.2006.1800 solved the inversion problem for effective viscosity. Modelling a front is difficult! What about the direction of the flow? Is there a difference is the modelled flow direction and the observed direction? Is there a change in flow direction between 2008 and 2015 as the ice moves over the sticky band and becomes ungrounded. Also, could ice melange at the front FGL affect the boundary condition?

Basal frictional heating and subglacial water: Could the region of low basal shear stress near the front simply be due to subglacial water from upstream pooling in the bedrock basin, e.g. FGL in 2008? Could the region be partially grounded? The temperature homologous is high, which prevents the water from refreezing. I think the role of subglacial water could be explained more in the literature review. Paragraph beginning 85: You don't explain what the feedback mechanism is. As I understand it, Schoof (2010) talks about the importance of variability of basal water on flow dynamics, with flow accelerating due to a short-lived increase in basal water, but then the flow slows if the basal water stays high. Is that happening here? You have high basal frictional melting in 2015, which you say is speeding up the flow, but figure 3 in Friedl et al 2017 shows that the ice speed of FGL decreased between 2011-2015.

Figure 1 shows that the ice front for PGL and sFGL has calved between 2008 and 2016, with some advance in the southern part of the bay. Could calving event(s) explain the speed up and lowering of the surface of the streams? Also, from figure 1, PGL has an ice shelf, are you applying the normal stress, hydrostatic pressure boundary condition at the 1996 grounding line or at the real front?

Bedrock plots: The way the bedrock is plotted is a bit inconsistent and unclear. Figure 1 c clearly shows where bedrock is above or below sea level with a white colour band around 0, but the bed elevation colour in figure 4 c and d looks like most of the bedrock is either below or at sea level and figure 2 b is too small. It would be useful to see where the retrograde and prograde slope are.

Figures 3,4,5: useful to have a third column of figures showing the difference between the first two columns.

Line 158: The Linear sliding law is fine for the inverse problem because τ remains unchanged, if a higher power of u is used, only the coefficient C would change. However, for a forward run a linear law may be inappropriate.

Please define basal frictional heating in your method section.

Figure 2 is too small and/or too detailed. A difference plot of surface elevation may be more informative.

Figure 3: The patterns in c and d seem to be influenced by the computational mesh. Have you investigated mesh resolution by halving or doubling element sizes?

The ratio of basal shear stress to driving stress: I'm not sure what figure 3 c and d are showing or why a low value means the ice may be close to flotation. Figure 4 c and d: Would showing the potential gradient be more informative? I can't see labels on the contours of hydraulic potential.

Figure 5: Height above buoyancy appears to be negative south of the main stream of FGL (and south of PGL). Is the bedrock above sea level there?

Discussion section: Is a maximum melt rate of 1 m/a enough to generate a plume of high enough velocity to entrain incursions of CDW to enhance basal melting beneath the floating ice? You can calculate the flux of subglacial water for each year by τbub/Lii x area that feeds the grounding line based on the hydraulic potential (or its gradient).

Line 395: Could you explain the positive feedbacks.

Estimating the time scale for the ice to unground from the rise between basins leaving the ice stream vulnerable of marine instability in the upstream basin is good, but I'm not sure you can say height above buoyancy is a measure of potential mass loss.

TECHNICAL CORRECTIONS

Line 46: abbreviation 'GL' is not defined.

Line 88: Not sure the sentence is helpful. Might be better to delete it.

Section 2.2: Is Hmc part of a dataset from Morlighem or have you combined two dataset yourself?

Lines 132, 151: Part 1 or Part A

Line 145: Is the basal frictional heating calculated from output from the inverse problem and used as an input into the heat equation?

184: I don't think N needs a numbered equation because it isn't used.

Line 222: northern and eastern. It might be helpful to add an arrow indicating North on one of the figures.

Lines 367, 420: Friedl et al 2017 gave an estimated grounding line for 2014.

Figure 1: sFGL is not marked on the figure.

Figure 3: It is difficult to work out where the plotted regions exist in relation to figures 1 and 2. Orientation is given in figure 5 but would be more useful on figure 3.

Figure 3: Cannot see cyan contour on printed paper.

Figure 4: I can't distinguish between red and magenta contours.

Line 529: Case is wrong for Schafer.

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