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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 #1**

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General comments

This paper presents some interesting results suggesting that glacier-bed interactions have an important role in the dramatic speedup of Fleming Glacier, Antarctica from 2008-2015. Recent work by Walker and Gardner posited that abnormally warm ocean temperatures in Marguerite Bay over this time period caused the observed changes in the glaciers that fed the former Wordie Ice Shelf. Friedl et al. 2017 used a combination of several remote sensing data sets to show that large areas near the terminus of Fleming Glacier ungrounded between 2008-2015. These data sets showed that Fleming Glacier lies on a retrograde bed slope, and thus is susceptible to runaway retreat via marine ice sheet instability. Zhao et al. argue that both of these explanations leave out a key factor, the interaction of the glacier and its bed. The authors used inverse



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methods to estimate the basal shear stress under Fleming Glacier in 2008 and 2015. This analysis revealed a band of high basal shear stress near the terminus in 2008 that is no longer present in 2015. They argue that the retreat of the glacier off of this region of high basal friction may also be a factor in the subsequent speedup.

The large changes that Fleming Glacier exhibited make it a valuable test case for understanding glacier change in Antarctica. The authors' results suggest that glacier-bed interactions are an important factor, in addition to ocean melting and geometric instability, in understanding the recent behavior of the glaciers that fed the former Wordie Ice Shelf. While I recommend publication, the work could be improved on a number of fronts. Drawing conclusions about the physics of glacier-bed interactions from the results of inverse methods can be difficult because, as the authors acknowledge, any one feature could be an artifact. Many of the arguments made in the paper are speculative and I think this should be made clearer. Suppose that the high-basal shear band they claim to find at the terminus of Fleming Glacier in 2008 were merely an artifact – what would that mean for the physics?

Specific comments

First, I think the abstract could be improved by (1) cutting many of the details that are covered in the discussion section and (2) giving a clearer statement about what this paper adds to the existing knowledge. The main precedents that the authors draw from are Walker and Gardner 2017 and Friedl et al. 2017. What do these two papers conclude, and how do the authors' conclusions agree with or depart from them? For example, both the present work and Friedl et al. 2017 argue that the speedup and thinning of Fleming Glacier is a consequence of ongoing marine ice sheet instability. However, the authors argue that subglacial hydrological effects may have also initiated the retreat off of a stable bedrock high, while Friedl et al. point solely to ocean warming. To my knowledge, this work and the companion paper are the first to use inverse methods to estimate the basal shear stress of this particular site at high resolution, as opposed to low-resolution estimations for all of Antarctica. This information, which





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ideally would be front-and-center in the abstract, is partly obscured by details that will be addressed in the discussion section anyway. In any case, this problem is more one of presentation and not of actual content.

At several points, the authors pose the question of whether either ocean warming or basal processes are the "dominant" causes of the observed changes (see lines 84, 411). The question of which process is dominant assumes that the two are additive, but if instead the relationship is causative, this question ceases to be meaningful. In the discussion section, the authors suggest that hydrological effects could destabilize the high-friction band, resulting in speedup, thinning, and ungrounding. In this scenario, hydrology-induced speedup and ungrounding create conditions where the ocean can then melt the ice shelf from underneath. One could also imagine a scenario in which ocean melting comes first and hydrological effects second. For example, ocean melting could push the glacier terminus off of a highly resistive bedrock bump, and the glacier begins to speed up and thin. The reduced overburden pressure then changes the overall hydraulic potential. The authors' hypothesis that hydrology might have initiated the recent changes is still significant and worth considering. Nonetheless, the paper's intent might be clearer by changing questions about which process is dominant to questions about which one came first. Finally, the authors suggest that coupled ice sheet-ocean modeling could help determine which case is more likely. This point could be expanded on further. For example, a coupled model using pre-2006 values of ocean heat flux that does exhibit a hydrology-induced destabilization would show that oceanic forcing is not necessary to explain observations.

The text gives conflicting statements about the authors' degree of confidence in the veracity of their conclusions. For example, in line 314 the authors assert that the disappearance of the high friction band near the calving front is a "likely" trigger for the subsequent retreat, but at other points they equivocate about whether this feature is real or merely an artifact. A lack of complete certainty about this resistive band is entirely reasonable but the paper would be improved if it were more consistent in what kind of assertions are made.

A numerical experiment could shed some more light on whether the resistive band near the terminus is real or not. The methods section describes inferring the basal friction using the 2008 ice thickness and the 2015 velocity to examine whether the result is sensitive to the geometry. In this vein, the authors could compute a velocity using the 2015 basal friction and the 2008 thickness. How well does this computed velocity agree with observations, weighted by the error variances? Is the misfit worse than that of the velocity computed using both the 2008 thickness and basal friction? If so, by how much? The presence of a resistive band at the terminus would be doubtful if a basal friction field without this feature can explain the 2008 data just as well as a basal friction field with this feature.

Technical corrections

17-21: Flip the order of the sentences starting with "To explore the mechanism underlying these changes..." and "Recent observational studies..."

23-28: Giving too much justification in the abstract obscures your overall point, this could be moved to the discussion.

66-69: "As a marine-type glacier system..." Rephrase or break up into 2 sentences.

73-74: "None of these past studies have modelled the glacier system and hence these hypotheses are untested." This suggests that modelling is the only way to really test these hypothesis. It's better to just say that the precise nature of the feedbacks hasn't been established and that you will test them using models.

88-90: "Changes in basal shear stress..." Rephrase this sentence.

162-165: "To explore their relative impacts..." While this experiment is a good sanity check, the result isn't essential to making your point and this could be relegated to a supplement.

294-296: Make this "The change in area", and "additional evidence supporting the hypothesis of rapid grounding line retreat".

313-315: Could the basal resistance band at the front be an artifact of neglecting back-stress at the terminus from melange or sea ice?

324-327: Overly long sentence, break up into 2 sentences.

326-327: "...as in the rapid retreat of Jakobshavn Isbrae in West Greenland (Steiger et al., 2017)." There were other factors in the retreat of Jakobshavn, see Motyka et al. 2011 and Holland et al. 2008.

336-340: Run-on sentence, break up into 2 or 3 sentences.

400-402: "...hard to say how much forcing would be needed to push the grounding line into it." Rephrase.

414: Change "simulate" to "estimate".

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