Response to the 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 #2
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We are grateful to Reviewer 2 for the positive and constructive suggestions to improve our paper. We have addressed the comments below. The line numbers in the responses are based on the revised manuscript without change track.

Please note that Mathieu Morlighem created the ice thickness data for the Fleming Glacier system using the mass conservation method, which is very important for most experiments done in this study. We do value his contribution to this paper, so we add him as the co-author in the revised text.

In the revised companion paper (Zhao et al., companion paper), we implemented a new sensitivity test to the enhancement factor (E). It reveals that the optimal value of E = 1.0 should be chosen as the enhancement factor in the CONTROL experiment. Accordingly, we re-ran all the simulations in this study with E = 1.0, and the high basal shear stress band near the ice front in 2008 has decreased into high basal shear spots, which are suspected of being artefacts of the inversion process and are discussed below. We modified the text and figures accordingly. All other result and interpretations are not qualitatively changed from the original manuscript.

General comments

This paper, using diagnostic inverse modeling of basal conditions, discusses the possible causes of the retreat of Fleming glacier observed between 2008 to 2015. In particular, the potential acceleration induced by the production of water by frictional heating at the base of the glacier is discussed. This paper is well written, even if some sentences are too long and some figures can be improved. I have made below some suggestions that I believe could improve the manuscript.

Specific comments

line 62: nearly twice or more than twice?

"More than twice" is more suitable here. Modified.

line 95: I don't really see where in Gladstone et al. (2017) inverse methods are used?

The reference is deleted here.

line 123: define what is bed_zc

bed_zc, has been defined using Eq. (1). To clarify it better, we modified the sentence into "The bedrock data, bed_zc (Fig. 2b), …" (Line 136)

line 127: S2008 is not the "surface DEM in 2008" but the "surface elevation in 2008".

We modified it into "where S_{2008} is the surface elevation in 2008 combined from two DEM products as discussed in Zhao et al. (companion paper),… " (Line 140-141).

line 134: (on the same line) The "2008 velocity" should be "The 2008 velocity

dataset"

Modified.

line 155: the assumption that all the ice is grounded is for the inverse method? May be you can specify already here that floating ice will be deduced as the place where basal stress is lower than a threshold? It is not clear all along the manuscript if there is still a floating part or not on Fleming glacier and it would help if it could be mentioned more clearly in the introduction.

Yes, the assumption that all the ice is grounded is for the inverse method. The floating ice will be deduced where basal shear stress is lower than a threshold. To clarify this, we added a sentence "This assumption might be incorrect for the main branch of the FG, and we evaluate it based on the deduced floating area where the inferred basal shear stress is lower than a threshold, which is discussed in Sect. 4.1." (Line 172-175).

In the introduction, we declared that the ice front position in Apr 2008 (dark blue line in Figs. 1b and 1c, Wendt et al. (2010)) has almost coincided with the 1996 grounding line position (Line 62). For this study, we assume that all the ice is grounded and the ice front position is same as the 1996 ice front position, which is added in Line 171-172.

line 175: it should be mentioned that Eq. (4) is valid under the assumption of N = 0

Thanks for the suggestion. We added one sentence after this equation (Line 208-210). "Here we assume that the water pressure in the subglacial hydrologic system is given by the ice overburden pressure, which is equivalent to assuming that the effective pressure at the bed, N, is zero (Shreve, 1972)"

line 186: here it should be mentioned that Eq. (6) is derived under the assumption of a perfect connectivity of the basal hydrology system with the ocean

Thanks for the suggestion. We did say that we used a simpler hydrostatic balance. In order not to get tangled up with the interior hydraulic modeling, we add a sentence to qualify this "This expression for Z_* assumes a perfect connectivity of the basal hydrology system with the ocean. This is appropriate for the present study where we are exploring the degree of grounding of the fast flowing regions of the FG over the downstream basin." (Line 217-220).

line 192: C is not a vector (not in bold)

Modified.

line 380: The increase of the amount of melt water should be quantified by integrating the frictional heating over the bedrock. But it should be also discussed that more melt doesn't necessarily induce an acceleration of the glacier as the basal hydrology system is evolving dynamically to adjust this surplus of water. The link of basal sliding with basal water should be clarified, and specifically is should be mentioned that the important variable is not the amount of water but its pressure. And this later quantity is not evaluated in the present work.

The amount of melt water has been quantified based on the Eq. S1 in the Sect. S2 and shown in Fig. S4 in the supplementary material. We present the distribution of the basal melt water along with a 2015-2008 difference plot rather than presenting the integrated total. This approach demonstrates the patterns and regions of important differences, which would not be apparent in an integrated quantity. Also, the

integrated basal melt would be sensitive to the region of integration. We mentioned this in Line 468-471.

We have clarified the positive feedback mechanism in Sect. 4.2 (Line 295-301). "Since the reduction of effective pressure is the key process to enhance sliding, this positive feedback is dependent on a positive feedback of melt water generation to water pressure. This dependence can break down when there is sufficient basal water to generate efficient drainage channels (Schoof, 2010). However, such efficient channelization in the subglacial hydrologic system is typically associated with seasonal surface meltwater pulses reaching the bed (Dunse et al., 2012), a process that is not expected to occur for Fleming Glacier (Rignot et al., 2005)."

For the subglacial water pressure, it is not possible to evaluate this quantity without a hydrology model, which is beyond the scope of this study.

line 430: Can the buttressing exerted by the pining band in 2008 be quantified in a more rigorous way? A complementary experience would be to remove this band of high friction (by setting no friction there) and to see how the velocity field is modified upstream. This would directly quantify the increase of velocity induced by an instantaneous loss of the pining band. The difference between this velocity field and the 2015 one would indicate places where a decrease of basal shear stress is necessary to explain the 2015 velocity field.

We integrated the basal shear stress (~3.42e11 N) for the frontal sticky spots in 2008 (where the Taob>0.01 MPa shown in Fig. S3). We have clarified this in Line 232.

We have tried some sensitivity tests to different ice front positions and ice front ocean-pressure boundary conditions in the companion paper (Zhao et al., companion paper). Those experiments have a similar effect to modifying basal shear stress near the ice front. The results show that those changes didn't impact on the velocity very far upstream. So this unpinning on its own is unlikely to have caused the speed up, but it could be a trigger for basal feedbacks to kick in.

line 528: Schaëfer is not spelled correctly

Modified.

Caption Fig. 1: inset (c) should be located in (b) and in (c) the front position in

2008 and 2016 should be added to visualise a potential ice-shelf?

Modified and added.

Fig. 3: the grounding line in 2014 seems to have a different form than the one of Friedl et al. (2017) in their Fig. 6?

Fig. 3 is generated with Paraview. To add the grounding line of 2014 in Paraview, we have to generate the mesh with the grounding line of 2014. A typical element size in this region is ~200-300 m. The only difference between the grounding line in Fig. 3 and the original shapefile is mapping it to nodes on the Elmer mesh, therefore the differences are always less than one element size. The mesh size and the refinement affected the location of grounding line. So the difference is never more than 300 m (an element's width), and it would not affect the analysis in this paper.

References

Dunse, T., Schuler, T. V., Hagen, J. O., and Reijmer, C. H.: Seasonal speed-up of two outlet glaciers of Austfonna, Svalbard, inferred from continuous GPS measurements, The Cryosphere, 6, 453-466, 2012.
Rignot, E., Casassa, G., Gogineni, S., Kanagaratnam, P., Krabill, W., Pritchard, H., Rivera, A., Thomas, R., Turner, J., and Vaughan, D.: Recent ice loss from the Fleming and other glaciers, Wordie Bay, West Antarctic Peninsula, Geophysical Research Letters, 32, 2005.
Schoof, C.: Ice-sheet acceleration driven by melt supply variability, Nature, 468, 803-806, 2010.
Shreve, R.: Movement of water in glaciers, Journal of Glaciology, 11, 205-214, 1972.
Wendt, J., Rivera, A., Wendt, A., Bown, F., Zamora, R., Casassa, G., and Bravo, C.: Recent ice-surface-elevation changes of Fleming Glacier in response to the removal of the Wordie Ice Shelf, Antarctic Peninsula, Annals of Glaciology, 51, 97-102, 2010.
Zhao, C., Gladstone, R., Zwinger, T., Warner, R., and King, M. A.: Basal friction of Fleming Glacier, Antarctica, Part A: sensitivity of inversion to temperature and bedrock uncertainty, The Cryosphere, companion paper. companion paper.