Response to the Interactive comment on

"Basal drag of Fleming Glacier, Antarctica, Part A: sensitivity of inversion to temperature and bedrock uncertainty"

by Chen Zhao et al.

Anonymous Referee #1
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We are grateful to Reviewer 1 for the positive and constructive suggestions to improve our paper. We have addressed all comments below. The line numbers in the responses are based on the revised manuscript.

Please note that Mathieu Morlighem created the ice thickness data for the Fleming Glacier system using 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 response to the reviewer 2's question about our choice of enhancement factor, we implemented a new sensitivity test. This was more thorough than our original test, and with a more up-to-date setup. And in fact, it reveals that our original choice was not optimal. So we added the sensitivity tests for various E values (0.5, 1.0, 2.0, 4.0) in Sect. 3.6 and Sect. 4.2, and the optimal value of 1.0 was chosen as the E in the CONTROL experiment. We redid all the simulations and modified the text and figures accordingly. Our conclusions have not changed.

General comments

This paper presents results from a series of Elmer/Ice simulations of the Wordie Ice Shelf-Fleming Glacier system in West Antarctica. It aims to demonstrate the sensitivity of model inversion to englacial temperature, bedrock topography and ice front boundary, as well as provide a realistic basal shear stress field. It uses a similar multi-step inversion process to Gladstone et al. (2014), where surface relaxation is followed by an inversion for basal friction coefficient (C); then a steady-state temperature simulation using this C and velocity; and another inversion using the steady-state temperature. This process is applied iteratively in three cycles, which they show helps remove the dependence on the initial temperature distribution. They argue this is particularly important to Fleming Glacier given the sensitivity of the system to englacial temperatures, due to the dominance of internal deformation over basal sliding. Using one of the initial temperature distributions, they run the inversion process several more times, testing the sensitivity of the inverted basal traction coefficient to bed geometry (e.g. bedmap2 versus mass-conserved), and the ice front boundary condition.

Overall this manuscript is well structured and clearly written, although some of the description of figures and discussion of results are fairly laborious and may benefit from being reduced in length. The conclusions are clearly supported by the results presented. I recommend this manuscript is published in The Cryosphere, provided the authors address the following comments.

Specific comments

Line 47: "especially for small-scale glaciers." Not sure this is relevant, or are there papers that show greater sensitivity of small- over large-scales systems?

To our knowledge, no study has shown that. We removed “especially for small-scale glaciers”.

Line 45 – 50: These two sentences appear to be contradicting each other – firstly you say that these uncertain quantities pose a challenge for modelling basal shear stress, and then you say they are not important (to that particular ice cap). I wonder if it’s worth holding off on discussing the results of the Vestfonna studies until the discussion.

The first sentence is a general statement for most glaciers, which we quote Vaughan and Arthern (2007). But, the Vestfonna Ice Cap is mentioned as a case showing the less sensitivity to the basal topography, which is contrasting to what we find for the Fleming Glacier in this study. The Fleming Glacier is the main focus of this paper, but we think it is good to mention the Vestfonna here.

Line 132: Why do you make this assumption? I know it is discussed further on that the ice shelf is effectively only 1.5 km long by 2008, but before knowing this, this statement seems strange, especially given that an ice shelf is mentioned previously.

We did not have a clear way to provide the ice thickness for a short fringing ice shelf left, which is detected from the DEM data in Jan 2008 (we clarify this in Sect. 2.1 and Fig. S1). This small ice shelf disappeared in Apr 2008, as shown in Fig. 1c. To discuss the sensitivity to different ice front position, we expanded remarks in Sect. 3.6 and Sect. 4.3, and relevant results and discussions have been added to the text.

Line 163: What is your justification for using a linear sliding law?

Different sliding laws in inverse modeling will not change the inversed basal shear stress distribution, and it will just lead to different basal friction coefficients based on different sliding law. In diagnostic studies that invert to find the basal shear stress which gives the best agreement with observed surface velocities, the choice of sliding “law” is not relevant provided that the required stress can be generated by adjustments of the parameters in the sliding law – in this case the coefficient C. The inversion procedure modifies C to modify stress – adjusting the momentum balance. That solution of the Stokes equation provides an updated estimate of basal velocity – which enters the next cycle of the inversion search. The question does remain whether this is physically suitable relationship to apply when the system is evolving, but this is not relevant here. So we adopted the simplest sliding law here following Gagliardini et al. (2013); Gillet-Chaulet et al. (2012). We clarified this in the text (Line 190).

Line 263: What do you mean by “imposed by a neigboring glacier”?

We made a hypothesis that the ice front of the Fleming Glacier had a continuation of the advancing glacier by exerting a normal stress on the ice front. Here we modified into “imposed by a hypothetical undeforming continuation of the advancing glacier”.

Line 274 – 277: This seems out of place here, and the related discussion in Section 4.3 is not obvious.

Now that we have adopted the E of 1.0 as the CONTROL setup, we find that the surface lowering near the ice front during the surface relaxation was <25 m in each cycle. But we still need to know whether the small changes in surface elevation at the ice front will affect the basal friction deduced from inversion, which is discussed in Sect. 4.4. So we modified this sentence to a separate paragraph and modified the relevant discussions in Sect. 4.4 (Line 333-337).

Line 334: add ", than CONTROL" to end of sentence? The similarity between BEDZC and BEDMC compared to CONTROL seems unsurprisingly, i.e. the two surfaces are more similar than the two thicknesses.

We added ", compared with CONTROL".

Line 352: Possibly worth mentioning Sun et al. (2014) here as another study that demonstrates the sensitivity of grounding line dynamics to bedrock topography.

Added.

Line 356 – 357: This seems unsurprising seeing as BEDZC makes use of surface (and mass conserved thickness?) from 2008, the same year as the velocity observations.

Yes, we agree. To clarify this, we clarified this in Line 438-440) "Both BEDMC and BEDZC use the 2008 surface DEM and this improvement over the Bedmap2 surface DEM in CONTROL appears significant, even before turning to the matter of ice thickness. "

Line 387 – 88: Why doesn't altering the sea level affect the grounding line position?

We ran all the experiments with the grounding line fixed. The sea level adjustments are meant as a convenient tool for altering the force applied at the ice front, including the influence of uncertainties in ice thickness (and hence bed depth) at the ice front/grounding line. We have clarified this in Line 302-304.

Note that the height above buoyancy calculations for 2008 in the companion paper (Zhao et al., companion paper) indicate that the glacier – as described by our datasets – would have remained grounded at the ice front for all but the largest sea level forcing.

Line 420 – 422: Not sure "spreading" is the right word: spreading in which direction?

By "spreading" we meant longitudinal extensional flow. We modified this sentence into "The lowered surface at the ice front in experiments IFBC1 and CONTROL is apparently the consequence of rapid deformation due to its own weight (longitudinal extension with locally high vertical shear) of an ice cliff, which is over 100 m higher than the control sea level. " (Line 526-529).

Technical corrections

Line 21 – 23: unnecessary repetition of "temperature-dependent" deformation, combine to one sentence

Modified.

Line 67: add comma at end of line

Added.

Line 108: Here FG is used for Fleming Glacier, whereas previously FGL is used. I suggest you use FG consistently (to me GL is grounding line).

Modified "FGL" into "FG" in whole text.

Line 184: Inconsistent use of basal sliding/drag/friction coefficient, as well as inconsistent use of boldface C. Discuss results in the present tense

Modified all these terms "basal sliding/drag/friction coefficient" into "basal friction coefficient". The font in equations is unchangeable so we could just make sure all the *C* in the main text shares the same font. We have adjusted the tenses used in the paper for consistency.

Line 295: remove quotations from CONTROL"

Deleted

Line 353: "most accurate", rather than "best"?

Modified into "more accurate"

Line 403 – 410: remove quotations from simulation names, e.g. "IFBC3".

Deleted

Figure 8: Could the 1500 m/yr contour be included in the other plots too, to help with comparisons?

Added

References

Gagliardini, O., Zwinger, T., Gillet-Chaulet, F., Durand, G., Favier, L., de Fleurian, B., Greve, R., Malinen, M., Martín, C., Råback, P., Ruokolainen, J., Sacchettini, M., Schäfer, M., Seddik, H., and Thies, J.: Capabilities and performance of Elmer/Ice, a new-generation ice sheet model, Geosci. Model Dev., 6, 1299-1318, 2013.

Gillet-Chaulet, F., Gagliardini, O., Seddik, H., Nodet, M., Durand, G., Ritz, C., Zwinger, T., Greve, R., and Vaughan, D. G.: Greenland ice sheet contribution to sea-level rise from a new-generation ice-sheet model, The Cryosphere, 6, 1561-1576, 2012.

Vaughan, D. G. and Arthern, R.: Why Is It Hard to Predict the Future of Ice Sheets?, Science, 315, 1503-1504, 2007.

Zhao, C., Gladstone, R., Zwinger, T., Warner, R., and King, M. A.: Basal friction of Fleming Glacier, Antarctica, Part B: implications of evolution from 2008 to 2015, The Cryosphere, companion paper. companion paper.