Sensitivity of the Ross Ice Shelf to environmental and glaciological controls
-Response to reviewers-

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We would like to thank the two anonymous reviewers and the editor for their further positive and constructive comments. We address their remarks below point by point.

1 Reviewer #1

1.1 Major Comments

- In the first round of reviews for this manuscript, I expressed a concern about the use of a linear sliding law, and I suggested that the authors needed to perform additional analysis to demonstrate that their results are robust to the choice of sliding law prior to publication. The authors responded to my concern by repeating their experiment with a Weertman sliding law in addition to the Budd law that they originally used. I appreciate the effort that the authors have gone through to run an additional set of sensitivity experiments, which is more than the extra analysis that I requested originally. However, the new experiment doesn't actually address my concern. My concern was specifically with respect to the nonlinearity of the sliding law. That is, I was concerned that they were using a value of the sliding exponent of m=1.

The slip exponent used in this manuscript for the Weertman experiment was a value of m = 3. We are sorry for not stating this more clearly in the revised manuscript. Therefore, we satisfy your concern regarding the use of the sliding exponent of m = 1. This has been clarified in the methodology and limitations section of the manuscript.

1.2 Minor Comments

- Figure 1: replace 'ice surface thickness' with 'ice thickness'. Change 'polarstereographic" → "polar sterographic". In addition, the formatting of the degree symbol in -71^{o} needs to be fixed

Done.

- L70-73: "The basal friction is based on a Budd friction law (Budd et al., 1979), in which basal drag is directly proportional to sliding velocity. This friction law may not be valid under some sectors of our model domain such as the Siple Coast. Therefore, we performed additional experiments to test the sensitivity of our results to the Budd friction law (Figure A3) by using a Weertman friction law instead". As I stated in my major comment, this is where you need to state what value of the sliding exponent you used in the Weertman law. Replacing a linear Budd law with a linear Weertman law does not change the fact that "basal drag is directly proportional to sliding velocity". If you did, in fact, use a nonlinear Weertman law, then my major concern could be satisfied by simply stating the value of the slip exponent here.

The slip exponent for the Weertman Sliding law of m = 3 has been stated here.

- Figure 5: I believe that the units are wrong in the caption. Sensitivity should be m/(parameter units), which in the case of surface and basal mass balance would be m/(m/s).

Units have been changed to m/(m/s).

- Again, the Weertman law does not really present anything independent of the Budd law if the Weertman law also used a linear relationship between basal stress and basal slip. If the Weertman law used a value of the exponent other than m=1 then that fact needs to be stated here.

The Weertman Sliding law used an exponent of m = 3 and this has been clarified in this section.

- Figure A1. Thanks for including these maps, they are helpful for putting the results in context.

No problem, thanks for suggesting them!

- Figure A2. Thanks for including this figure as well. However, I think you should double-check the units of the plot. You have a color scale from 0 to 1000, with no units labeled. If this is supposed to be units of Pa, then the maximum is way too low, but if this is supposed to be kPa, then the maximum is way too high. The spatial pattern in the map looks reasonable but you should really double-check the units and the magnitudes here.

The units are in kPa and the magnitude has been checked (now 0 to 200 kPa). The figure has been replotted. Thank you for pointing this out!

- Figure A3. The units label for plot (a) implies that you used a value of m=3 in the Weertman law, which would satisfy my major concern described above. However, I can't be sure that you have labeled them correctly, because the units labels for plots (c) and (d) are wrong. Those labels should be m/(m/s).

The units have been changed for plots (c) and (d).

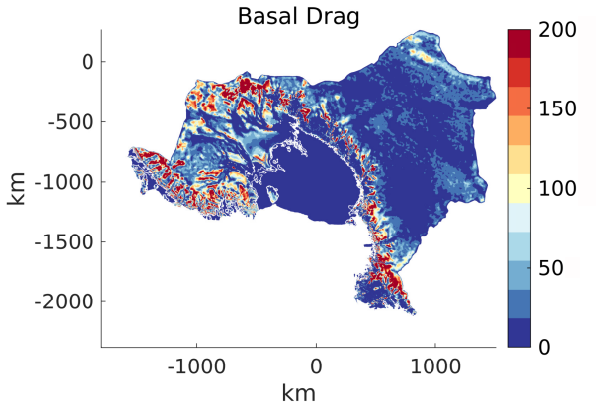

Figure 1: Inverted basal drag (kPa).

2 Reviewer #2

2.1 Specific Comments

- You ran additional simulations with a Weertman Friction law but you did not mention what exponent (m) you used in the law, I suppose that m is not 1, since the goal was to introduce a non-linear relationship between the velocity and the basal drag. If the exponent is m = 1 (which I doubt), then I think that the extra results might not be that useful to the manuscript and that a non-linear friction law should be used instead. Could you mention the exponent you use and maybe add the equation in the Appendix? A proper reference to Weertman is also missing.

The Weertman Friction law used exponent of m = 3 for these additional simulations. This has now been clarified throughout the manuscript in the methodology and limitations sections. A proper reference to Weertman has also now been included *Weertman* [1957]. And the equation for the Weertman Friction law has been included in the limitations section.

- I am sorry if I mention this idea only now but I think that some numbering such as "Figure Xa,b,c,..." and associated references in the text would really help navigating between the text and the figures. Keeping the name is fine but additional "lettering" would nice. For example, line 218 could write: "Our results show that Bindschadler Ice Stream has the highest sensitivity to changes in ice rigidity at the margins (Fig. 4e), while MacAyeal Ice Stream has a higher sensitivity in the main ice trunk (Fig. 4f)."

This has been edited throughout the manuscript to help the reader more easily navigate between the text and figures. Thank you for this suggestion!

- Line 198: the basal friction within the main trunk is more important than what? More important than in the shear margins? I think this statement is really clear for Binschadler Ice Stream but not that much for MacAyeal Ice Stream. At least this is what I see when comparing Figure 4b and 4c

This has now been rephrased and the word 'more' has been removed. We still think that this statement fits in with the MacAyeal Ice Stream as we can see that there is high sensitivity within the main ice trunk.

- line 220: I think I did not catch this one during my first review. "Meyer and Minchew (2018) show that Bindschadler Stream has temperate zones of ice within its shear margins and thus changes in ice rigidity here would influence the ice stream discharge as shown by our results." Could you explain why a change in temperate zones is any different to a change in a cold zone? I think that what matters is the intensity of the change in rigidity, not the absolute value of the rigidity.

This line has been rephrased to explain the importance of the temperate ice in influencing changes in ice rigidity more clearly: "*Meyer and Minchew* [2018] show that Bindschadler Ice Stream has temperate zones of ice within its shear margins, with these zones being at melting temperature and controlling the rate at which the ice stream flows by softening the ice rigidity. Therefore, changes in the ice rigidity of the Bindschalder Ice Stream margins would influence the ice stream discharge as shown by our results."

- 4.4 Limitations: Can you add a unit for the basal drag coefficient (and maybe specify that this coefficient is the one for Budd law you used during the inversion)?

The unit has been added in the limitations section and clarification that the Budd linear sliding law was used during inversion has been added in the caption of Figure A1.

- You use alternatively "yr" (e.g., fig A1) and 'a' for years (e.g., Fig 2 or Fig A3). Could you use one or the other only? You give the units for sensitivity maps (Fig 2 and 5) but not for the grounding-line and along-flow profiles (Fig 3 and 4). Could you add those?

"yr" was removed from Figure A1 and replaced with 'a' to keep it consistent throughout the manuscript. The units for the grounding line and along-flow profiles (Figures 3, 4 and 6) were included in the figure captions. We did not include these units on the y axis labels as it resulted in the figure panels becoming overcrowded and less readable.

2.2 Technical Comments and Typos

- Line 50: Thank you for the edition of this sentence. Please, just add some punctuations to the sentence, e.g., "(Dinniman et al., 2018), which will highly likely increase ice-shelf basal melting and, subsequently, the future stability of the RIS (Stewart et al., 2019)."

Done.

- Line 62: I am not sure I understand the correction, i.e., keeping only "[...] which changes in external forcings and internal material properties of the ice effect the overall mass balance [...]". Do you mean "affect" instead of "effect"?

Yes, this has been changed from 'effect' to 'affect'.

- Line 79: I'd suggest to rewrite "(i.e. Sub-element Parameterization 1 in Seroussi et al., 2014)"

Done.

- Line 149: I still think that passive ice should be introduced in the text and not only in Figure 5.

This has been included in lines 163-164.

- Line 188: leading to "leading to an thickening"

Done.

- Line 193: delete the last part, since basal friction is always at the bed, i.e., "by the basal friction conditions at the bed."

Done.

- Line 205: "Our results show that Whillans Ice Stream is highly sensitive to changes in basal friction at its shear margins, suggesting that changes in lubrication conditions here influences the flow and discharge rates of the ice stream."

Done.

- Line 212: To me, this sentence is almost a repetition of the previous paragraph, I don't understand why you introduce a new paragraph here.

A new paragraph has been introduced here as we are discussing a different region of the model domain, Byrd Glacier, while the paragraphs above were discussing the Siple Coast Ice Streams.

- Line 240: "[...] and this makes it highly sensitive to changes in ice rigidity, which is also shown by our results."

Done.

- Line 324: I'd change "but the sensitivity patterns remain qualitatively similar" since the "quantity" doubles when you double the simulation period.

Done.

- Figure A3: "Top row of the figure"

Done.

References

Meyer, C. R., and B. M. Minchew, Temperate ice in the shear margins of the Antarctic Ice Sheet: Controlling processes and preliminary locations, *Earth and Planetary Science Letters*, *498*, 17–26, doi:10.1016/j.epsl.2018.06.028, 2018.

Weertman, J., On the sliding of glaciers, *Journal of Glaciology*, *3*(21), 33–38, doi:10.3189/S0022143000024709, 1957.