Response to RC1

Author responses are in blue.

Summary:

This manuscript investigates the sensitivity of ice loss in the Amundsen Sea Embayment (ASE), West Antarctica, to prescribed calving front retreat rates using the Úa ice-flow model. The authors systematically apply constant retreat rates from 0.1 to 1 km/year along the calving fronts of major glaciers, including Pine Island, Thwaites and Crosson/Dotson. They quantify the additional sea-level rise (SLR) contributions caused by these retreat rates, comparing their impact with that of ocean-induced melt variability from ISMIP6 ocean forcing scenarios. They find that calving processes have an impact comparable to ocean forcing, highlighting the necessity of better representation of calving in future ice sheet models.

This manuscript addresses a crucial gap in understanding the dynamics of Antarctic ice shelves, specifically the sensitivity of future ice loss projections to calving front retreat. The study is timely and of high relevance, given the uncertainties associated with calving dynamics and their impact on global sea-level rise. However, parts of the results and discussion lacks clarity. This overall issue is address in more detail in the specific comments below. Several aspects would benefit from additional clarifications and expansions to enhance the robustness and readability of the paper.

Thank you for your review, and your positive comments on the study along with constructive criticism on the clarity of presentation. In the revised manuscript, efforts have been made to improve clarity in all instances you have pointed out, in order to make the results and discussion easier for a reader to follow and present our work in the best possible way.

Specific comments:

L17-18: Please add references.

References added to Depoorter et al. (2013) and Pattyn et al., (2017).

L21: Does this mean that it is easier to implement continuous calving rate rather than modelling small-scale individual calving events? Please clarify.

We have reworded this to "it is often easier and more practical to implement calving in long-term simulations via a continuous calving rate, rather than modelling individual calving events as they occur naturally."

L31: "...reproducing observed grounding lines consistently..." => reproducing observed calving front

Fixed. Thanks!

L32: More numerical models now include calving capability, as mentioned in the Discussion section. Therefore, it may be more appropriate to specify “for real glacier simulations?”. Also please add some supporting references.

Updated to specify “for predictive simulations”, and added a reference to ISMIP6 as an example: “For example, in the recent model intercomparison project ISMIP6 (Seroussi et al., 2020), only three of the ten participating models implement a more complex calving scheme. One applies an approach based on strain rates (Levermann et al., 2012), while two other models use the calving law of Pollard et al. (2015).”

L47: “raise sea levels by over a metre.” : Please add references.

Reference added: Rignot et al. (2002).

L62-69: This should move to the Methods section.

This has been moved as suggested.

L67: What ocean domain is referred to here? I assume it means the surface area of the entire global ocean — please clarify.

We have clarified this is global.

L76: Why was it necessary to lower the bed topography when forcing the retreat? By how much was it lowered? How does the model behavior differ if this step is included?

Information on this, plus a figure showing the difference between out topography and BedMachine, has been added to a new appendix.

L107: “The repeated forcing… between 2100 and 2300.”: Could you clarify this? Was the forcing from 2080–2100 repeated uniformly across the 2100–2300 period?

This has been clarified: “…sampled randomly between 2100 and 2300 to avoid repeating the same forcing pattern.”

L103-108: It would be helpful to include a table summarizing the experiments described here or in Section 2.3. For the ocean forcing scenarios, please clarify which models provide extension to 2300 and which provide data only for a partial period and should be extended with repeated forcing.

A table has been included to summarise this.

L114: ‘Ocean_RR#’ this format is not used later in the text, which make it difficult to follow the experiment descriptions in the Results and Discussion sections.

This was an oversight, and we have edited throughout to stick to this format where possible.

L128: "… at various points during the simulation": … at various points in time during the simulation.

Added

L141: a significantly different compared to Control_RR0?

Clarified

L142: until later: Please specify the year or time range.

Added

L146: "as contact is lost with pinning points": Please specify the year after which contact is lost with pinning points.

This whole section has been improved by adding references to panels in the figure as well as specifying years.

L170: … SLR for RR0 and RR0.5, respectively.

Added

L170: "Comparing these ranges to Figure 3(b)…" Consider rewriting this sentence to clarify what is being compared here. What's the range of RR0 to RR0.5 or RR0.7 to RR1?

This has been reworded, and additional values added in for the ranges.

L173-178: This paragraph is unclear. For example, "-DVAF_add follows a similar trajectory for each RR00.5 and each RR1 ocean forcing case." Does this mean "-DVAF_add of Control_RR1 falls within the upper bound of the RR0.5 ensemble across ocean forcings"? Please rephrase for clarity.

This has been reworded, and now references the relevant part of the figure as a visual aid to clarify the point. We have also changed the caption on the figure for clarity.

L181: "Our results show that for a given … without retreat.": Could you give a figure or table including -DVAF and -DVAF_add for each ocean forcing scenario to strengthen this statement?

We have added a clarification of the statement with reference to the figure to demonstrate our meaning.

L186: I think this sentence makes too strong a generalization. Perhaps, I suggest something like "While our findings demonstrate that prescribed calving front retreat rates drive comparable ice loss across a range of ISMIP6-2300 ocean forcings within the ASE, caution should be taken in generalizing these results to the entire Antarctic Ice Sheet."

We believe the potential of generalisation is an important possibility to point out, so have kept this in. We suggest it as an interesting subject for future work, rather than asserting it as fact. Further to the existing caveats in the paragraph, an extra clause has been added that care should of course be taken in making generalisations.

L204: Refer to Figure 2(c) and (d)

Added

L229: RR0.4

Corrected

L229: "However, the curve for..": can you comment more on this?

An additional comment has been added, suggesting that competing signals from various sources could mask the particular threshold signal we are looking for.

L229-L240: Consider moving this part to the Results section.

We have left this in place, but updated the paragraph to strengthen its link to the rest of the discussion in this section.

L241: Can you comment more on "some interactions"?

We have rewritten this sentence to highlight that the sum of the three individual experiments does not differ from our main experiments until around ~2100, and speculate that it is due to our boundary definitions.

L246-L247 "In our case, the additional VAF loss when retreating..." Please quantify the additional VAF until 2050 or 2100 (early stages).

This has been added for 2050.

L255: Could the post 2100 results be influenced by the repeated ocean forcing scenarios? If so, it may be worth discussing this.

The UKESM repeated forcing certainly produces different results to the non-repeating forcing, as can be seen in Fig.3(a). However, this is only one of the range of forcings we use, and this particular difference is not important for our results beyond being part of demonstrating that the retreat rates are largely independent of the chosen forcing.

<u>References</u>

Depoorter, M. A., Bamber, J. L., Griggs, J. A., Lenaerts, J. T., Ligtenberg, S. R., van den Broeke, M. R., and Moholdt, G.: Calving fluxes and basal melt rates of Antarctic ice shelves, Nature, 502, 89–92, 2013.

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Pattyn, F., Favier, L., Sun, S., and Durand, G.: Progress in numerical modeling of Antarctic ice-sheet dynamics, Current climate change reports, 3, 174–184, 2017.

Pollard, D., DeConto, R. M., and Alley, R. B.: Potential Antarctic Ice Sheet retreat driven by hydrofracturing and ice cliff failure, Earth and Planetary Science Letters, 412, 112–121, 2015.

Rignot, E., Vaughan, D. G., Schmeltz, M., Dupont, T., and MacAyeal, D.: Acceleration of Pine island and Thwaites glaciers, west Antarctica, Annals of Glaciology, 34, 189–194, 2002.

Seroussi, H., Nowicki, S., Payne, A. J., Goelzer, H., Lipscomb, W. H., Abe-Ouchi, A., Agosta, C., Albrecht, T., Asay-Davis, X., Barthel, A., et al.: ISMIP6 Antarctica: a multi-model ensemble of the Antarctic ice sheet evolution over the 21st century, The Cryosphere, 14, 3033–3070, 2020.