RESPONSES TO REVIEWERS FOR
Brief Communication: Sensitivity of Antarctic ice-shelf melting to ocean warming across basal melt models
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Author response to reviewer #1

The manuscript of Lambert and Burgard analyzes the sensitivity of five different basal ice shelf melting parameterizations to an idealized warming of 1°C. The five analyzed basal melting parameterizations are widely used or discussed and differ in complexity. The parameterizations range from point-dependent approaches (quadratic function of the temperature difference between the ocean and local freezing point temperature) to horizontal extensions of models representing different aspects of the ice shelf pump overturning circulation (PICO and Plume model), vertically integrated models solving the Navier-Stokes equation in the upper mixed layer within the ice shelf cavities, to a neural network trained by model output form the cavity-resolving simulations with the NEMO ocean model.

The authors drive these parameterizations with an observational-inspired hydrographical distribution of ocean temperature and salinity, which replicate the main hydrographic conditions for different regions and their ice shelf types (warm vs. cold water ice shelves, for instance), and they retune these parameterizations to reproduce contemporary observational basal melting distributions – except for the neural network due to the limit data base. Afterward, the authors applied a temperature increase of 1°C to analyze how the melting rates change under such a warming. The control run and the warming are analyzed regarding the changes in the overall basal melting rate averages and how melting increases in deeper (ocean depth) parts compared to the overall and shallower ice shelf areas.

In addition to the distinct differences in terms of basal melting amplification due to the warming and the related spatial signatures, all parameterizations show the highest melting amplifications for the warm-water ice shelves located in the Amundsen Sea Embayment, intermediate sensitivities for some ice shelf groups, and a weak reaction to the warming for large cold-water ice shelves (e.g., FRIS, RIS).

It was a pleasure to read the well-structured and prepared manuscript. The figures are of high quality, necessary, and informative.

Various groups are working on the future evolution of the Antarctic Ice Sheet (AIS), where ocean-driven mass loss predominates, and basal melting of floating ice shelves accounts for about 40–66% of the ocean-driven ice mass loss (Rignot et al. 2013; Depoorter et al. 2013; Liu et al. 2015; Davison et al. 2023). Hence, this study is an important contribution to understanding how different basal melting parameterizations drive future mass loss. Therefore, this work is also highly relevant for studies addressing Antarctica's sea level contribution in the coming centuries. Since the ocean-driven basal melting is central to the health of Antarctica, this work

is also intriguing for the ice sheet modeling community and the coming Ice Sheet Modelling Intercomparison Project (ISMIP).

I recommend the publication of the manuscript after minor corrections.

Thank you very much for the very positive feedback and for your constructive comments on how to further improve our manuscript. We agree with most suggestions and will incorporate these in the revision of our manuscript. In the following, we provide a point-by-point response.

General comments

The manuscript is well organized and written.

Thank you, we appreciate this positive feedback.

Your manuscript addresses the basal melting enhancement for increased ocean temperatures. Since it is often discussed whether a particular parameterization shows a linear or quadratic behavior for increased temperatures, I wish you could perform an analysis for a temperature rise greater than 1°C, such as 0.5°C or 2°C, add the related results, and indicate if those different parameterizations have a linear or quadratic behavior.

We agree on the added value of an additional scenario to assess the melt sensitivities. We will therefore include a +2 degree experiment as a third data point. In addition, based on your comments, those of the other reviewer, and our own assessment, we have concluded that a quadratic sensitivity is ambiguous and may invite different interpretations. Therefore, we propose to complement the linear sensitivity with a quantification of the nonlinearity instead. This nonlinearity is defined as the second-order derivative of the relation between melt and temperature, derived from the three data points (reference, +1 degree and +2 degrees). The benefit of this approach is that the metric can still be compared to quadratic sensitivities and additionally functions as an assessment of how valid the application of a linear sensitivity is to larger temperature perturbations. We hope that this solution satisfies the concerns of the reviewer.

Have you considered including a linear parameterization in addition to the Quadratic parameterization? How would it behave compared to the other parameterizations listed in Section 2.2, Basal melt models (page 3)?

Yes, we did consider the inclusion of the linear parameterisation. However, in the interest of space, we decided to restrict ourselves to a subset of the most widely used parameterisations and chose to exclude the linear parameterisation. Also, in Burgard et al. (2022), which assessed a range of parameterisations, the linear parameterisation performed worst.

When it comes to the reference of the basal melting rate of (Paolo et al. 2023), I wish you could compare your reference with other estimates and how large the spread is because it would relate the found sensitivities of the analyzed parameterization to the uncertainty of current basal melting estimates, such as (Rignot et al. 2013; Depoorter et al. 2013; Liu et al. 2015; Davison et al. 2023).

We have considered this suggestion. However, we think that a comprehensive discussion of the relationship between observational uncertainties and melt sensitivities is beyond the scope of this study, particularly in the context of the compact format of a brief communication. As we do agree that these uncertainties are relevant and significant, we will mention the spread in the total Antarctic melt between Paolo et al. 2015 and alternative datasets and briefly discuss the implications.

You may recheck whether you use British or American English. I recognize mostly British English, but you use "e.g.," an American syntax. Please correct it.

Thank you for pointing out this stylistic error. We will correct this in the manuscript.

Specific comments
Main document

Line 9/L 9: You may add: "... loss is mainly driven by amplified ocean-induced melting ... ."
We will clarify this sentence by adding "increased" in front of ocean-induced melting.

L 13: I'm unsure that "best" is meaningful here. You may rephrase it, e.g., " to as basal melt, is consistently simulated ... ."
We will reformulate.

L 15: You may add: "... currently remain rare and computationally too expensive to run ... ."
Thank you for the suggestion. We will incorporate it.

L 62: You may expend the sentence: "that mimics the overturning circulation in the cavity; known as ice-shelf pump (Lewis and Perkin 1986)".
We will expand as suggested.

L 72: Do you think the three-equation model is linear with respect to the temperature forcing? If so, please consider modifying the sentence "commonly adopted 'thre-equations parameterization,' which is linear in the temperature forcing, and the overturning ... ."
The three-equations parameterisation, in our formulation, is not linear in temperature forcing. Temperature (and its gradients) impacts the horizontal velocities and thereby the friction velocity that appears in the turbulent exchange coefficients of both heat and salt. As we consider this discussion to be too detailed for the brief model description in the current manuscript, we will not elaborate on this further.

L 84: You may add some information about CDW to address a wider audience, e.g., "… a warm layer of Circumpolar Deep Water (CDW), which a temperature of ≥0°C."
Thank you for pointing this out. We will add this information.

L 87: You may modify "The subsurface warm water mass … ."
We will modify it.

L 88: Please delete "where possible"
Deleting "where possible" would be inconsistent, as not all values are directly inferred from observations. This is explained in the next paragraph. Hence, we will keep this sentence as is.

L 90–91: I do not fully agree with the description of the water masses since the lowest temperature of HSSW corresponds to ocean water's surface freezing point temperature (about -1.87°C). In contrast, the water mass that is supercooled in relation to the surface freezing point temperature is Ice Shelf Water (ISW). The interaction of the HSSW with the ice shelf base transforms it into ISW. Please clarify this point.
Thank you for pointing out this imprecision. We will rectify this.

L 94: You may delete: "the exact values of"
We will delete it.

L 95: I am unsure, but should it be "… division of the ice shelves between Cold and Cool, … ."
You are right, this should be "between". We will correct this.

L 94–95: Since you create and use idealized ocean forcing, you may want to drop "cannot be sufficiently constrained by observations" since the idealization of observations is not necessarily identical. You may describe it like this: "Several experimental choices are made, such as … Cold and Cool case. Considering the idealized forcing, the value selection has a subjective component."
Thank you for the suggestion. We will reformulate accordingly.

L 99: You may replace the verb: "… ice shelf, we restrict CDW intrusion into … ."
Thank you for the suggestion, we will replace it.

L 109–112: Long sentence. You may consider splitting and rearranging it with the following sentence. For instance: "As changes … higher than ice-shelf averages (e.g., Jourdain et al., 2020). Hence, we additionally define the 'deep amplification,' where the nondimensional metric … ice-shelf average."
We will follow your suggestion and restructure these sentences.

L 122–124: It is unclear how the effective turbulent temperature exchange velocity is determined. Please clarify.
Thank you for pointing this out, we will clarify.

L 140 and L 141–142: Intriguing that the spreading factor is 100 = O(10 m yr-1)/O(0.1 m yr-1) in the first case and only 10 =O(5 m yr-1)/O(0.5 m yr-1) for the Plume Model and Neural Network.
We agree that some differences in behaviour between the parameterisations are intriguing. As we could not discover a question or request in this comment, we will not adjust the manuscript in response to it.

L 162–164: You speculate that the selected minimum layer thickness may overestimate the heat transport. Would a thicker or thinner layer thickness reduce the heat transport?
This is not a trivial question and is beyond the scope of this paper to discuss. A thicker minimum thickness enhances entrainment and thus heat transport, a thinner layer thickness allows for a more efficient heat transfer to the ice shelf base. We will reformulate this sentence to provide some more insight.

L 187 and 189: First, I was confused about what "linear sensitivities" and "quadradic sensitivities" mean. I guess you may something line "(T_cold – T_warm)/ Delta T" and "(T_cold – T warm)2/Delta T ", or? Please clarify it.**
Thank you for pointing out that this was unclear. Partly in response to this comment, we have decided to redefine the sensitivities. In the revised manuscript, we will explicitly define the different metrics that appear in Fig 3.

L 228: I am afraid I have to disagree that we can not avoid it, but it could be essential. Furthermore, some models/parameterizations may only be fit for some purposes. Therefore, reducing the intermodel spread might be misleading. Instead, knowing the limitations of the models and coming to a generalized description might be more critical.
We note the concern and will reformulate accordingly.

L 232: I am unsure about the style guide of Copernicus journals, but should each quantity have its own units so that it comes to "67% to 240%"?
This is something we will double-check.

L 197: You may be more implicit with your message: "... by the quadratic sensitivities (Fig. 3c), having on average the highest sensitivity, with values ... ."
This appears to be an incorrect interpretation by the reviewer. The consensus relates to a weak sensitivity as mentioned in the previous sentence. We will therefore not adopt this suggestion.

L 240: I am unsure if you would like to extend the sentence: "... melt enhancement in the deeper regions and none towards lowest depths: PICO ... ."
We will reformulate as suggested.

Figure
Figures 1 b—g) and 2 a—e): Great figures and a very smart way to use the available space to plot the ice shelf regions around Antarctica. Since your color bars have a "whitish" color around zero (0), it is not always clear what values are along the ice

shelf edge facing the ocean. Would it help to color the ocean (e.g., gray) and, therefore, mark the ice shelf edge?

Thank you for pointing this difficulty out. Filling the ocean is not trivial with the way we constructed these figures. Hence, to address this issue, we will explore ways to highlight the grounding line and/or calving front.

Bibliography

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