We thank the Editor and the Referees for their time and their positive and constructive feedback of the manuscript. In response to these reviews, we have edited the text to clarify our arguments and the results of the study. In particular, we have added text to the introduction that contextualizes the motivation of our study for a broader audience. Further, we have addressed all minor revisions suggested by the Referees. We believe that the revised manuscript is improved relative to the original.

In the following, we address each of the comments raised in the reviews and provide a detailed listing of the associated revisions to the text. We intersperse the reviewers' comments (black font) with our responses (blue font).

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The authors investigate how glacial isostatic adjustment (GIA) has influenced zones of potential grounding line stability in the Ross Sea Embayment since the Last Glacial Maximum (LGM). They use a high-resolution bathymetry model combined with a simple grounding line stability framework to assess how GIA-induced changes in bathymetry affect ice sheet retreat and stabilization. Their analysis incorporates three different ice sheet histories and several Earth models to account for uncertainties in past ice loading and mantle viscosity.

The results show that during the LGM, grounding line stability was concentrated near the continental shelf edge, but as isostatic rebound progressed, stability zones migrated upstream, aligning with the present-day grounding line. They also find that coarse-resolution bathymetry underestimates grounding line stability, emphasizing the importance of high-resolution models. The authors conclude that GIA plays a crucial role in stabilizing ice sheets over long timescales and that bathymetric resolution significantly impacts the accuracy of grounding line predictions.

General remarks

This study presents an insightful analysis of the role of glacial isostatic adjustment (GIA) in grounding line stability within the Ross Sea Embayment. The authors effectively apply a high-resolution bathymetry model and an ensemble of simple grounding line stability calculations to assess how GIA-induced bathymetric changes influence grounding line migration. The results contribute valuable knowledge on the spatial and temporal evolution of stability zones, and the study convincingly demonstrates the importance of bathymetric resolution in capturing these effects. The paper is well-structured, with clear research objectives and a logical progression of results.
We thank the referee for this positive appraisal.

However, the introduction is quite brief and lacks sufficient discussion on how this study builds upon and differentiates itself from prior research on GIA and ice sheet stability. Providing more context on the relevance of grounding line stability zones and linking this work more explicitly to previous studies would strengthen the framing.

Thank you for this suggestion. We have added additional discussion within the introduction to provide background and frame the motivation of our study, which we highlight in the line-by-line comments below.

The methods section, while detailed, could benefit from additional clarification in several places, particularly regarding the ice sheet histories, Earth models, and parameter choices. Please see the line-by-line comments for the details.
We now provide more detail within our methods section, which is addressed in the line-by-line comments below.

Line-by-line comments

L53-58: The connection between the paragraphs can be more informative. Lines 53-56 explain that the retreat have been found to be reduced due to GIA and that the models cannot explore a large parameter space at high resolution, but it is not stated explicitly why one needs to explore the full parameter space and which remaining research questions are still open.
This comment is addressed with the comment for L59-61 below.

L59-61: Place your research in context here. Discuss other research that have been conducted in Antarctica to study how GIA modulates bathymetric features. Why do you not need coupled ice sheet – GIA to study the effect of bathymetry on grounding line migration? What is the method to obtain your ensemble of simple grounding line stability calculations? Have this method been applied in literature, maybe to other regions? Have the ensemble of simple grounding line stability calculations been used in other studies? Are there other regions, or other studies for the Ross Sea Embayment, where the effect of GIA on bathymetry have been studied using high resolution models?
The general feedback raised in these two comments are now addressed in an additional paragraph added to the introduction.

We add text explaining the benefit of ensembles (L 59-61):

> "As a result, ensemble runs of ice sheet or coupled GIA-ice sheet models that can encompass uncertainties in climate and glaciologic conditions are run at relatively coarse resolution …"

We specify the open research question we are addressing (L 62-70):

> "…and are unable to resolve smaller scale bathymetric features, such as pinning points (≤5 km; e.g., McKenzie et al., 2023), that may influence grounding line evolution. …Therefore, exploring the impact of high-resolution bathymetry on grounding evolution in the Ross Sea Embayment since the LGM is still a computational challenge."

We provide broader context regarding coupled GIA-ice sheet models to highlight the benefits of using a simpler modeling approach that allows for high resolution bathymetry (L 58-64).

> "Although coupled GIA-ice sheet models provide valuable insight into ice sheet-solid Earth interactions across Antarctica, they are computationally expensive. As a result, ensemble runs of ice sheet or coupled GIA-ice sheet models that can encompass uncertainties in climate and glaciologic conditions are run at relatively coarse resolution (16-40 km; Albrecht et al., 2020, 2024; van Calcar et al., 2023; Gomez et al., 2018; Pollard et al., 2017), and are unable to resolve smaller scale

bathymetric features, such as pinning points (≤5 km; e.g., McKenzie et al., 2023), which influences grounding line evolution.

And note recent high resolution, coupled GIA-ice sheet models in other regions of Antarctica (L 64-68):

> "Recent coupled GIA-ice sheet modeling showed that increasing bathymetric resolution (from 2 km to 1 km) slowed predictions of grounding line retreat by up to ~20% in the Amundsen Sea (Houriez et al., 2025); however such high-resolution modeling is more appropriate for smaller regions (the Ross Sea Embayment is ~4x their model domain size) and for timescales of centuries…"

L58: How large is the ensemble?

We now specify (L 71): "Here we use an ensemble ($n=9x10^5$)"

L63-65: Explain why you made the choice to predict zones of potential grounding line stability and not reconstruct the exact history.

Our choice to model zones of potential grounding line persistence, rather than the exact history of grounding evolution, is driven by the opportunity to (1) sample a wide parameter space glaciologic conditions, and (2) understand the role of glacial isostatic adjustment on grounding stability across a broad topographic region (an entire flowline across the Ross Sea) regardless of the exact configuration of the past ice sheet. It is challenging to reconstruct the history of grounding line evolution over the last deglaciation in the Ross Sea; indeed, much of this history is unknown, leading to uncertainty in ice sheet reconstructions and associated glacial isostatic adjustment predictions. Our approach allows us to focus on a subset of the many controls on deglaciation, namely assessing the stability of possible grounding line locations across the entire Ross Sea for a range of glacial isostatic adjustment scenarios. The advantage of this approach is that we can identify multiple possible persistent grounding line locations, rather than being tied to a single specific grounding line evolution history.

We now explain (L 75-81):

> "Rather than reconstructing an exact history of grounding-line evolution, we predict zones where a potential grounding line could persist at 20 ka and present day. This choice allows us to produce a probability distribution of locations where past ice stream grounding lines were likely to persist, which we term "zones of potential persistence", across the entire Ross Sea Embayment. We explore the contribution of GIA to grounding line persistence at present-day and 20 ka grounding line locations, quantifying the impact of GIA on zones of potential persistence across the deglaciation."

We also note (L 202-206):

> "However, linear stability analysis provides a useful guide to identify locations where grounding lines were likely to have persisted or slowed down retreat for prolonged time periods without information about where the ice margin existed geologically at any time, since information about the age and location of past grounding lines is uncertain."

We also want to highlight a broad terminology change in the manuscript. In the original submission we included text to make distinctions between mathematical steady states and how our analysis provides locations at which grounding lines were likely to have persisted or slow down retreat for prolonged time periods. To further make this distinction clear we now use the term "zones of potential persistence" instead of "zones of potential stability".

L65-68: Explain in more detail the relevance of the identification of locations.
Identifying these locations, and how they change across the deglaciation provides examples of locations within the Ross Sea that might be of interest for future modeling efforts such as coupled models with mesh grids that can achieve locally high resolution at these areas of interest. For locations where drill campaigns have already occurred identifying these locations provides more context to view the geologic records from the drill campaigns.

L68: In the introduction, there is no mention of the contribution of GIA to grounding line stability at present-day. Please include a section in the introduction about ongoing GIA in the Ross Sea Embayment, how is it measured, how strong is the signal.
Since our study focuses on the GIA signal across the deglaciation and not the ongoing GIA signal, we choose to not discuss present-day observations, to limit potential confusion.

L75: Which version of Bedmachine?
We now specify in the main text (L 84-85).

> "To reconstruct Ross Sea Embayment 20 ka paleobathymetry we modify present-day BedMachine v1.38 bathymetry (500 m horizontal resolution; Morlighem et al., 2020)"

L94-104: Please provide more information on the ice thickness histories. How have these three histories been selected? Is the output of the Gol14 and Gom18 models constrained by observations? For example, how well does bedrock change at present-day from Gom18 match with GPS observations? What is the uncertainty of the benthic d18O records? Furthermore, why do the models vary in Antarctic ice sheet volume change? What is the spatial and temporal resolution of the output of all three models? How do the ice sheet histories exactly differ from each other and is one more realistic than the other? Why have W12 and Gom18 a sharp transition in ice thickness upstream and downstream of the grounding line, respectively. Might this effect your results?
Instead of providing a detailed review of each ice history, we refer the readers to the original papers, however we do now provide more information (**underlined in bold**) within our summaries of each model to contextualize the choice of ice histories (L 103-118)

> "To represent these uncertainties, we use three different ice-sheet histories that span a plausible range of LGM ice-sheet thickness reconstructions. The first ice history Golledge et al. (2014; henceforth Gol14) contains a deglacial Antarctic Ice Sheet volume change of ~10.5 m global mean sea level equivalent (GMSLE), **and was run at 14 km resolution and 100 year timesteps** . Gol14 was created from the median of an ensemble of Parallel Ice Sheet Model runs (Bueler and Brown, 2009) forced by an Earth system model and uniform sea-level changes, **and constrained**

**by geologic observations such as ice-core derived changes in regional ice thickness**. The second ice history Whitehouse et al., (2012; henceforth W12) contains a deglacial Antarctic Ice Sheet volume change of ~8 meters GMSLE and was created by running the GLIMMER ice sheet model (Rutt et al., 2009) for discrete time intervals (20, 15, 10, and 5 ka) **with a 20 km resolution, and is constrained by glaciologic, geologic, and Antarctic relative sea-level records**. The third ice history Gomez et al. (2018; henceforth Gom18) has a deglacial Antarctic Ice Sheet volume change of ~6 m GMSLE. The Gom18 model **is a single model run** of a coupled, gravitationally consistent GIA-dynamic ice sheet model that incorporates 3-D earth structure and was forced by climate via benthic $\delta^{18}O$ records. **The ice sheet model was run with 20 km resolution and 200 year timesteps.**"

Regarding the sharp transition in ice thickness upstream and downstream of the grounding line for W12 and Gom18, we do not know the exact origin of the difference, although it is likely due to differences in modeling approach and attempts to reproduce present-day conditions. However, given the long-wavelength signal of GIA, and given that the W12 and Gom18 output produce similar patterns of zones of potential stability offshore the Siple Coast (main text Figure 3), it is unlikely that this ice thickness transition impacts our analysis.

L109-110: Explain briefly how Whitehouse et al. (2012) determined the best fit 1D model.
We now explain (L 123-125):

> "…similar to the best fit 1-D Earth model used in Whitehouse et al. (2012), which was determined by inverting for the solid Earth rheology that best fit Antarctic deglacial sea-level data"

L111-114: To improve readability, move this sentence to line 110 to discuss it right after you mention the 1D model. Also, explain the VM5a Earth model and include a reference for the representative Earth model for West Antarctica.
We move the sentence and now include the reference for the representative Earth model (Pollard et al., 2017) and include the lithosphere thickness and upper and lower mantle viscosity values for VM5a (L 127-129).

> "VM5a Earth model which has a lithosphere thickness of 96 km, average upper mantle viscosity of 0.5 x $10^{21}$ and average lower mantle viscosity of 1.6 x $10^{21}$ (Peltier et al., 2015)"

Pollard, David, Natalya Gomez, and Robert M. Deconto. "Variations of the Antarctic Ice Sheet in a Coupled Ice Sheet-Earth-Sea Level Model: Sensitivity to Viscoelastic Earth Properties." *Journal of Geophysical Research: Earth Surface* 122, no. 11 (2017): 2124–38. https://doi.org/10.1002/2017JF004371.

L114-115: The sensitivity analysis compares the 3D model to a 1D model, but a more comprehensive exploration of uncertainty would require varying the 3D Earth model itself, as it inherently contains uncertainties. Since mantle viscosity and lithospheric thickness cannot be measured directly, the 3D model is subject to assumptions and potential biases. Currently, the discussion does not acknowledge the uncertainties within the 3D model, which may affect the

results. It would be valuable to include a discussion on this limitation and its potential impact on the findings.
Instead of exploring uncertainty within the 3-D Earth model of Gom18, which arises from choice of lithospheric thickness as well as the method used to map seismic velocity maps to mantle viscosity (e.g., Austermann et al., 2013, 2021; Gomez et al., 2018), we compare GIA output from Gom18 to GIA output that utilizes a 1-D reference Earth model (Gomez et al., 2018). Although we are not exploring uncertainty within the 3-D Earth model of Gom18, comparing the 3-D and 1-D GIA output of Gom18 provides context for how incorporating 3-D Earth structure may affect the GIA output of Gol14 and W12.

L119-120: Explain in more detail how LGM ice stream flowlines are defined based on both the reconstructions and the present-day ice flow.
We now specify (L 136-139):

> "From the ice divide to the present-day grounding line, ice flowlines are based on observed ice surface velocities (Rignot et al., 2011), and from the present-day grounding line to the edge of the continental shelf, ice flowlines follows reconstructions of paleo-ice flow reconstructed of Anderson et al., (2014)."

L121: Explain interglacial endmembers.
We now clarify in the text (L 140):

> "LGM and interglacial (i.e. present-day) endmembers."

L130-131: Explain why the understanding of solid Earth-ice sheet interactions would not be possible with traditional ice-sheet modelling methods.
Our ensemble approach with a simple linear stability analysis allows us to assess the stability of all potential grounding line locations across the entire Ross Sea for a range of glacial isostatic adjustment predictions. Traditional ice sheet modeling would require simulating ice sheet evolution over time, which would only predict a single history of grounding line evolution. Given the uncertainty on ice extent over the last deglaciation, our approach allows us to predict a range of GIA-corrected bathymetries, and then assess the stability of possible grounding line locations for all flowlines across the Ross Sea. This approach permits exploration of various scenarios of glacial isostatic adjustment for many possible grounded ice extents.

L136: Why is it spaced at 1 km if the resolution of the ice thickness is lower. How does it improve results to use a 1 km resolution along the flow line?
The 1 km spacing was an error in the text. All high-resolution stability analysis is run at 500 m resolution, and this text has been updated to reflect that (L 155).

> "…to test for stability along each ice stream flowline at 500 m-spaced nodes"

While the resolution of the ice thickness histories is much lower than 500 m (14-20 km), our glacial isostatic adjustment predictions are sensitive to the broader (hundred kilometer scale) loading history, and produce changes in topography with smooth signals that can be interpolated onto higher resolution topography. Indeed, ice sheet loads on a spatial scale smaller than the effective lithospheric thickness will not cause crustal deformation. Therefore, even though our ice history input and our glacial isostatic adjustment model have coarse spatial resolution, it is possible to produce high spatial resolution bathymetric reconstructions using interpolated maps of our glacial isostatic adjustment predictions. We have explained this concept in the main text (L 98-99):

"The resulting GIA output varies smoothly across spatial scales much broader than the spatial scales of Ross Sea Embayment bathymetric changes."

L136-138: Could you clarify the sample size used for each parameter? Are the values evenly spaced within the given range? Additionally, for clarity, it may be helpful to remove variables from Table 1 that do not have specified values.

We now specify the sample size used for each parameter in Table 1. We choose to keep all parameters within Table 1 to provide the user an easy location to view all parameters, however we do group parameters with specified values together for easier reading.

We also specify our sampling (L 155-159):

"We consider different combinations of accumulation, basal friction, and ice-shelf buttressing parameters (Table 1) by uniformly sampling the range of basal friction and ice-shelf buttressing and sampling the range of accumulation rates with a non-linear spacing, since they range over an order of magnitude…"

L145: Variable b is not defined.

We now define (L 170-171):

"b is bathymetric depth at the grounding line"

L149: Insert "and" instead of comma before "ice-shelf buttressing".

Corrected.

L174-176: It is not entirely clear how a zone itself is defined and how the zones are defined as stable or unstable.

In the original text we distinguished between mathematical steady states and how our analysis provides locations at which grounding lines were likely to have persisted or slow down retreat for prolonged time periods. To further make this distinction clear we now use the term "zones of potential persistence" instead of "zones of potential stability".

This is a key concept in our manuscript, and in response to this comment, we have edited the text to provide more detailed descriptions defining our zones of potential persistence. Zones are defined as a 50 km reach along a flowline representing in ice stream transect (Figure 2), or 20 km x 20 km grid cell within the Ross Sea Embayment (Figure 3). A zone is considered mathematically stable if our linear stability analysis produces a "stable steady state" within the zone. A zone is considered a zone of potential persistence based on the number of "stable steady states" it contains, with more "stable steady states" increasing the potential for persistence.

We now provide a more explicit definition of "zone of potential persistence" and explain how we determine whether a zone is considered stable (L 270-273):

"Zones along the transect with higher counts of potential stable grounding line locations are stable across a wider range of input parameter combinations and therefore have a relatively higher likelihood of persisting at that location regardless of parameter uncertainty and are referred to as "zones of potential persistence"

L179: The parameter space has been explored by ice sheet models as well, for example Albrecht et al. (2020) performed hundreds of simulations for which they systematically varied the parameters using full-factorial parameter sampling. Do you mean here that sampling a wide range of parameter space is not feasible with ice-sheet models on a relatively high resolution? Please clarify.

Yes, indeed. We clarify that we are able to explore a large parameter space while maintaining a relatively high resolution bathymetry, as opposed to Albrecht which utilized a resolution of 16 km (L 59-64):

> "As a result, ensemble runs of ice sheet or coupled GIA-ice sheet models that can encompass uncertainties in climate and glaciologic conditions are run at relatively coarse resolution (16-40 km; Albrecht et al., 2020, 2024; van Calcar et al., 2023; Gomez et al., 2018; Pollard et al., 2017), and are unable to resolve smaller scale bathymetric features, such as pinning points (≤5 km; e.g., McKenzie et al., 2023), which influences grounding line evolution."

Albrecht, T., Winkelmann, R., and Levermann, A.: Glacial-cycle simulations of the Antarctic Ice Sheet with the Parallel Ice Sheet Model (PISM) – Part 2: Parameter ensemble analysis, The Cryosphere, 14, 633–656, https://doi.org/10.5194/tc-14-633-2020, 2020.

L204-206: This is not clear from figure S2, please be more specific on which location this can be seen.

In the Supplementary Material we now specify:

> "The simple grounding line stability model (main text) predicts grounding line stability for Gom18 paleo-bathymetry near the edge of the continental shelf (~1,600 km; Figure S2b) and near the present-day grounding line (~800 km; Figure S2b), and the ice stream flowline model produces the smallest grounding line retreat rates and grounding line discharges at these locations as well. A similar spatial pattern emerges with present-day bathymetry (black; Figure S2). The simple grounding line stability model also predicts a small number of potential stable grounding line zones for present-day bathymetry between 900–1,400 km downstream (Figure S2), but no potential stable grounding line zones over this reach for 20 ka paleo-bathymetries. Over the same reach, the flowline model produces grounding line retreat rates over present-day bathymetry that are ~5-10 times slower than those over 20 ka paleobathymetry."

L300-307: Also discuss how this effect the results of the Gom18 GIA output, since this sea level change does not include the effect of the northern hemisphere.

The Gom18 ice sheet history does include the effects of northern hemisphere ice sheets. Gomez et al. 2018 references Gomez et al., 2013 for methods of applying their sea-level model, which states:

> "In the coupled simulation, changes in the distribution of grounded ice in Antarctica are passed to the sea-level model by the ice-sheet model. However, sea level in the vicinity of the AIS is impacted by changes in ice loading both locally and globally. Thus, in the results presented here, we adopt the ICE5G model (Peltier, 2004) to prescribe the space–time geometry of ice complexes outside of the AIS over the last 40 ky." (Gomez et al., 2013)

L312: Not clear how this is analyzed, since grounding zones were only analyzed at 20 ka and present day.

We clarify how this metric is calculated in the supplementary material:

"We term, "emergent" zones of potential persistence as zones of potential persistence that are stable at present-day, but not stable at a specific previous time in the deglaciation (e.g. zones that are "emergent" at 15 ka are stable at present-day but not at 15 ka). For each time-step we calculate the number of "emergent" zones of potential persistence for that specific timestep. We then normalize all times by dividing by the maximum number of "emergent" zones of potential persistence at a given timestep, which occurs at 12.5 ka for Gol14 and Gom18, and at 10 ka for W12."

L330: Please define "grounding line depth" explicitly.

We define the grounding zone depth as (L 38-39):

"…where ice transitions from grounded to floating"

Figures

Fig. 2: Concerning panel b, please clarify which present day topography is shown, is it observed present day topography? Is the modelled present-day topography by Gomez et al. (2018) equal to the observed present day topography? Please indicate in the text how the difference in present day topography between modelled and observed topography might affect your results.

We now clarify in the figure caption:

"Present-day bathymetry of the Ross Sea Embayment (Morlighem et al., 2020)"

We believe that the ability or inability of the Gomez et al., (2018) model to reproduce observed present-day topography is outside of the scope of this manuscript. Running our persistence analysis over observed present-day bathymetry down sampled to 20 km may produce different spatial patterns than if we used the 20 km modeled present-day bathymetry of Gomez et al., (2018). However, the scope of our manuscript is to explore the use of high-resolution bathymetry and differences that arise with coarser-resolution bathymetry, and so we do not include a discussion on this so as to not distract from the main theme of the manuscript.

Fig. S1: Include in the caption which flow lines are shown and where they are taken from. Also include that the present-day grounding line is shown and explain where it is taken from or how it is computed.

We now clarify in the figure caption

"Flowlines are identical to in main text. Black contour represents present-day grounding line from MEaSUREs (Rignot et al., 2011)."

Fig. S2: Label of the x axis is missing.

Corrected.