We thank the Editor Claudia Timmreck and the two reviewers for their second attentive evaluation of the manuscript. We hope that the clarifications we provide in this second review will fully address the comments and questions raised by the reviewers. To ensure clarity, the reviewer's comments are written in black and our responses in light blue.

## Reviewer #1

**General comments:**

This manuscript is a revision of an initial submission, in response to comments from three reviewers. The authors describe research based on modeling experiments, with the goal of characterizing projection uncertainty related to internal climate variability of the atmosphere and the ocean. First, they choose a set of three CMIP6 model ensembles, forced by the SSP2-4.5 scenario. Then they characterize the internal climate variability for each. Finally, the authors force a continental model of the Antarctic Ice Sheet with a representative subset of ensemble members in order to determine how internal climate variability in the atmosphere and the ocean affects Antarctica sea-level contribution over the coming century. The authors conclude that internal climate variability affects sea-level contribution by 45-93%, and this spread is dictated most strongly by the atmospheric forcing in most regions. Based on their results, CMIP models significantly vary in their representation of internal climate variability. Therefore, they suggest that that ice sheet model projection efforts should consider how well a CMIP model represents decadal-scale variability when choosing a future atmosphere and ocean forcing. They also recommend a longer reference period be used (greater than the standard 20 years) to calculate climate anomalies. Finally, they propose that multiple ensemble members be run to better capture internal climate variability in ice sheet model projections.

In response to suggestions by the reviewers, the authors have made a significant number of revisions to the manuscript, including a valuable reorganization effort. I find that they have improved the presentation of their results and the overall clarity of the manuscript's story. In addition, the authors have included a comprehensive response to all the reviewer comments and have adequately explained their modification/lack of modification stemming from each comment. Consequentially, I believe this work represents a novel contribution to the field, and I support the acceptance of this revised manuscript. I only have a few additional questions/comments about phrasing that I think may confuse the reader. I note these below.

**Specific comments:**

Line 102: Please specify here the spatial fidelity of this correction (i.e. per glacier I think). Temperature correction is performed by region (the 19 regions defined in Reese et al. 2018 mentioned in the previous sentence in the main text). Nevertheless, we have verified that this basin-scale correction results in melting in agreement with Adusumilli's observational estimates on a local ice-shelf scale (Fig. 1).

We have replaced *"A correction of temperature, ranging from -1.8°C to 0.6°C with respect to the ocean climatology, is added to match the 1994-2018 melt rates estimates from Adusumilli et al. (2020) (see Fig. 1)."* by *"A correction of temperature, ranging from -1.8°C to 0.6°C with*

*respect to the ocean climatology, is added to match the 1994-2018 observational melt estimates from Adusumilli et al. (2020) for each of the 19 regions. This regional correction resulted in improved estimates of local ice-shelf melting, except for Totten and Thwaites ice shelves (see Fig. 1).” (L101-104)*

Line 108: Please include more details about the steps of the friction tuning process. For instance, what years are considered for the mass change? You minimize RMSE of total ice sheet mass change in all of West Antarctica during that period, using which observations? If I understand correctly, this results in an estimation of 10%, and then you apply this reduction in friction to the entire ice sheet?

For clarity, we have added more details about the friction tuning process. We have also realized that bias is more appropriate than RMSE as there is a single value. We have therefore replaced *“For this, we minimise the RMSE between the modelled and the observed ice-sheet mass change for West Antarctica.”* by *“For this, we minimise the model bias in West Antarctic grounded ice mass loss with respect to the 1995-2014 observational estimate of the IMBIE Team (2018). West Antarctica is chosen to tune the basal friction coefficients as the ice dynamics is known to strongly explain mass loss in this sector. We then apply the resulting 10% correction to the friction coefficients of the entire ice sheet.” (L110-113)*

To avoid any confusion about the period over which the calibration is performed, we have also indicated IMBIE values for the period 1995-2014 (instead of 1992-2017) in Table 1.

Line 122: Please indicate that the SMB is cumulative “over time”.

We have reorganised the paragraph following the comment hereafter and the term *cumulative* no longer appears.

Lines 122-124: These sentences are awkward and a bit confusing. Please clearly rephrase them to describe what was done. For instance, it sounds like only 3 different SMBs were used for forcing (one per CMIP model), but all the ocean forcing was run. It is clear that the dynamics and SMB can reconstruct the mass balance in this way, but can you explain why only the first member SMB is used? Is there a computational constraint that prompted this decision?

Due to the number of comments received on section 2.3, we have reorganised the section to improve clarity. Section 2.3 is now divided into 4 paragraphs:

- paragraph 1: a general paragraph explaining that Antarctic contribution to sea-level rise can be seen as the sum of the SMB contribution and the dynamical contribution. We have also added a general sentence that explains how we calculate each of these contributions in our study, i.e., through emulation of a regional climate model driven by the atmosphere of the selected CMIP6 models for SMB contribution and through simulation of ice-sheet model driven by the ocean of the selected CMIP6 models for dynamical contribution.

- paragraph 2: a paragraph explaining the choice of scenario used for the projections (scenario SSP2-4.5).
- paragraph 3: a paragraph explaining in greater detail the method used for the SMB contribution.
- paragraph 4: a paragraph explaining in greater detail the method used to estimate the dynamical contribution.

We hope that the addition of the general sentence in the first paragraph helps the reader to understand the method more clearly: *"In this study, variations in SMB are evaluated through the emulation of a regional climate model driven by the atmosphere of the selected CMIP6 models, while the dynamical mass losses are calculated using the ice-sheet model Elmer/Ice driven by the ocean of the selected CMIP6 models." (L125-127)*

Lastly, we explained the lack of impact of the choice of member 1 for the SMB within the Elmer/Ice simulations at the beginning of paragraph 4: *"For each selected CMIP6 model, the contribution of ice dynamics to sea level is estimated through Elmer/Ice simulations driven by the SMB of the first member (as SMB changes have little impact on the Antarctic dynamical contribution to sea level over a century, the choice of SMB member does not matter) and the ocean of several members. We then remove the SMB contribution of the first member to isolate the dynamical contribution of each member." (L150-153)*

Small SMB variations between each member have little impact on the dynamics (Seroussi et al, 2023). However, the total absence of SMB during the simulation could have impacts on the dynamics, which is why we kept atmospheric forcing for the Elmer/Ice simulation. Note that we could also have forced the Elmer/Ice model by the same member for the atmosphere and the ocean, rather than only member 1 for the atmosphere, even though, taking the same member for the atmosphere theoretically gives a better estimate of the internal variability purely related to the ocean.

Line 126: This statement is not clear. Please rephrase and specify what is meant by word "seems". Is it that this scenario is the best match to present-day warming in Antarctica?

'seems' is not appropriate. We wanted to indicate that we chose the SSP2-4.5 scenario because it is considered as one of the most plausible scenarios (at global scale) based on the current effort and policies (Hausfather and Peters, 2020) whereas SSP5-8.5 is considered unlikely (Huard et al, 2022). We have not verified whether this scenario is the one that most closely matches current warming in Antarctica, as the ice-sheet simulations carried out for ISMIP6-Antarctica show that the choice of scenario for total mass change projections to 2100 has little impact, and as both SMB and ocean-induced melt rates are influenced by the scenario only after ~2050 (Jourdain et al., 2024; Naughten et al., 2023).

We have removed the word *'seems'* and the sentence is now *"We use the medium SSP2-4.5 scenario, which corresponds to a global warming of 1.4 to 3.0°C from 1995-2014 to 2081-2100*

*(90% confidence interval, Lee et al., 2021) and considered plausible in view of current efforts to tackle climate change (Hausfather and Peters, 2020).” (L128-130)*

Line 129: To prevent confusion, maybe you could explicitly list somewhere the various subsets of runs and forcing used for your analysis: i.e., those used for characterization of variability, those for deducing dynamics, and those used for 2100 ice sheet model simulations. This could be in a diagram or table of some sort, or maybe a few sentences in the methods where the number of simulations and the forcings for each analysis are described.

We think that this is a very good idea, so we have added a table in the appendix describing the number of members used and the method used for each analysis (see Appendix C).

For the projections, we have also added for each of the contributions (dynamical or SMB) the number of members used for each of the three selected CMIP6 models in the main text, as well as a reference to the table in Appendix C.

Line 130: For clarity, please specify in these sentences that this is for the selection of CMIP model ensemble members used for the ice sheet model runs.

See response to comment on Line 129.

Line 214: supposed => “expected” ?

Yes, the manuscript has been corrected accordingly. (L222)

Line 229: Please clarify that this is for all the members chosen, i.e. a subset of members (instead of using "all")

We have added the word *‘selected’* in the sentence *“In our ice-sheet projections, Antarctica gains mass over the century for all selected members of the three CMIP models…” (L237)*

Figure 4, caption: Please clarify what is meant by the “MAR-based” reconstructions here.

We have replaced *“standard deviation of the 1995-2014 mean SMB across the ensemble relative to the multi-member mean, from the MAR-based reconstructions”* by *“standard deviation of the 1995-2014 mean SMB across the ensemble relative to the multi-member mean. The SMB shown is not a direct CMIP6 output but is derived from emulated behaviour of the regional climate model MAR driven by selected CMIP6 models.”*

Figure 5, caption: Just a note that the caption goes beyond the page, so it was not possible to read it all.

We have reduced the size of the figure to ensure that the last line of the caption appears.

Line 367: Please specify that this result pertains to your chosen medium-range scenario over ~ 1 century time scale.

We have added *'for medium-range scenario'* in the sentence *"In this study, we show that internal climate variability affects the Antarctic contribution to changes in sea level until 2100, for medium-range scenario, by 45%-93%." (L369-370)*

Line 398: seat => "sit"?

Yes, the manuscript has been corrected accordingly. (L406)

Line 457: Extra ")" included at the end of the sentence.

Yes, the manuscript has been corrected accordingly. (L478)

**References:**

Huard, D., Fyke, J., Capellán-Pérez, I., Matthews, H. D., & Partanen, A. I. (2022). Estimating the likelihood of GHG concentration scenarios from probabilistic Integrated Assessment Model simulations. *Earth's Future*, *10*(10), e2022EF002715.

Naughten, K. A., Holland, P. R., & De Rydt, J. (2023). Unavoidable future increase in West Antarctic ice-shelf melting over the twenty-first century. *Nature Climate Change*, *13*(11), 1222-1228.