

Reply to reviewer 2

The manuscript by Lambert and colleagues uses output from Earth system models, ice sheet models, and observations to estimate the impact of an ocean-ice feedback on sea level projections. The majority of Earth system models do not yet include coupled ice sheets and ice shelves, and thus ice-ocean feedbacks are not currently included in sea level projections. Additional meltwater from Antarctica increases stratification, causing surface cooling and subsurface warming at the depth of ice shelf basal melting, which has the potential to accelerate melting. Making use of existing model output, the authors calculate linear response functions to estimate the impact of this feedback on sea level projections. They find at first pass, that this feedback could increase sea level projections for 2100 by 80%, which is a substantial effect. However, they also note that the basal melt parameter for this estimation has not been calibrated on observed historical melt rates. When accounting for calibration, they revise their estimate to suggest that the feedback could increase sea level projections for 2100 by 5%.

The findings of this manuscript will be useful to the scientific community working towards coupling dynamic ice sheets and shelves into Earth system models. The manuscript is well written, and the methodology is clearly described. I have several minor comments specified below, which I expect will be straightforward to address.

Thank you for your positive and constructive review. Please find our point-by-point replies below in blue.

I also have one major comment, regarding bias / potential bias in the Earth system model ocean component that will influence the ocean response function and results – sensitivity to this should be investigated and presented – currently, it is not clear how dependent the results are on possible ocean-model bias in both the mean state and trends. I thus recommend major revisions for this manuscript.

We agree that ESM biases provide a significant uncertainty in our results. This comes in two forms: 1) in the ORFs derived from EC-Earth3, and 2) in the historical and future warming from a suite of ESMs.

Point 1 was also raised by the other reviewer, who acknowledged that an explicit sensitivity analysis would require an intercomparison study; this is the very purpose of the SOFIA initiative and hence beyond the scope of this study. To address this point, we will elaborate on the biases in EC-Earth3 with respect to other ESMs; we will discuss in more depth the response to increased meltwater forcing in contrast to other ESMs; and we will add a clear disclaimer that our results are dependent on a single ESM, including in the abstract.

Point 2 will be addressed with a quantitative inter-model assessment as described below where this point is raised explicitly. We hope that these proposed modifications satisfy the reviewer's concerns.

Specific comments

Abstract line 10-14: The three sentences with reported percentages read a bit as unconnected listed items, and this has the effect of making the percentages seem unrelated. Rewording the calibration methodology and revised sea level enhanced projection sentences would help here.

We agree and will rephrase to better highlight these results.

Line 40: “SOFIAMIP project” would be better described as “Southern Ocean Freshwater Input from Antarctica (SOFIA) Imitative”.

Agreed, we will implement this

Line 40-42: Can you add citations for these modelling studies in the last sentence – as it is currently written, this seems like it is referring to the SOFIA model output from Swart et al. (2023), which is not the case.

Yes, we will add these

Line 50-51: Do any of models or the multimodel mean agree with the observations?

Individual ensembles of individual models do, but not the multimodel mean. Because there is an intense debate in the ice sheet community (and the design of ISMIP7) on this topic, we'd prefer to stay away from this in the present study. Hence, we will not elaborate on this further.

Line 89: Suggest “redistributed” here.

Agreed, will implement

Line 99-102: It is implicit here that the Antarctic runoff generated in the CMIP6 version of the model is no longer generated in this version, but it would be helpful to describe this explicitly, so that it is clear you aren't double counting this runoff plus your more realistic representation of meltwater release.

Good point, we will state this explicitly.

Line 142: Does “bias correct” mean bias correct the mean state, or to bias correct the trends, i.e. de-drift? I think it means the latter. How is this bias correction / de-drifting done? E.g. have you removed linear grid point trends from the piControl in the corresponding historical and SSP scenarios?

Yes, this point was unclear. We refer here to detrending rather than bias correcting. We will rephrase this to clarify.

Further, the historical CMIP6 ocean trends around the Antarctic margins themselves are biased (Purich and England 2021) – have you corrected for this? For example, multimodel mean historical trends around the margins show more warming than observed in most regions, except the Amundsen Sea, over 1975-2012. The historical ocean trends will presumably exert a strong influence on your projections and gamma calibration. Sensitivity to model bias in both the mean-state and trends should be investigated and reported in the manuscript.

We agree that the aspect of model bias deserves more attention in our study. A bias correction to historical trends is unfeasible due to the large uncertainties in observations (Schmidtko et al., 2014). However, Purich and England (2021) indeed reveal an important positive relationship between historical biases and future trends. To investigate the relationship between

ESM bias, future warming, gamma calibration, and sea-level contribution, we will include either a table or a figure with inter-model correlations in the Appendix.

Purich, A., & England, M. H. (2021). Historical and future projected warming of Antarctic Shelf Bottom Water in CMIP6 models. *Geophysical Research Letters*, 48, e2021GL092752. <https://doi.org/10.1029/2021GL092752>

Line 169: Computation.

Thank you, will correct.

Line 204-207: It would be useful if you list the ice sheet models and ESMs used in this study in a table.

We agree and will list these in a table in the appendix.

Line 220-222: It would be useful here to specify that you are using the observed historical ice mass loss, and the modelled ocean warming. What is the uncertainty in the historical ice mass loss? What is the uncertainty in the ocean warming?

We will elaborate on this.

Line 232-235: What does it mean that some model pairs require a negative gamma to reproduce the positive sea level contribution? Is the model representation of ocean temperature around the Antarctic margins suitable for this use?

No they are not and are therefore excluded. We will explain this in more detail.

Fig. 4 caption: Capitalisation should be “western Peninsula” and “eastern Peninsula”

Thank you, we will correct.

Line 275: In this section it would be useful here to comment on this subsurface warming relative to other studies (particular in the Amundsen Sea), and comment on the resolution of this model / limitations to representation of high-resolution processes that may affect the response to meltwater.

We agree and will expand on this here.

Line 293-295: This saturation effect has been reported previously, e.g. in Schloesser et al. (2019).

Thank you for pointing this out, we will cite this study accordingly.

Schloesser, F., T. Friedrich, A. Timmermann, R. M. DeConto, and D. Pollard, 2019: Antarctic iceberg impacts on future Southern Hemisphere climate. *Nat. Climate Change*, 9, 672– 677, <https://doi.org/10.1038/s41558-019-0546-1>.

Line 296-298: The upper limit seems reasonable. Did you experiment with other (non-linear) fits?

Yes, we have explored a non-linear fit. However, the sensitivity of the final results to this choice was small and did not validate the introduction of a more complex mathematical description. We will briefly mention this in the text.

Line 319: Specify “subsurface” warming.

Agreed, will do

Line 353-354: Specify “the last decades of our projections”, so it is clear that you are not referring to the last decades of the observations. Also, here and elsewhere, the date that you are presenting projections for (i.e. 2100) should be specified.

Agreed, we will specify this.

Line 363: Specify “surface” cooling.

Agreed, will do

Line 364-365: Can you elaborate on why it could lead to an overestimation of sea-level projections?

Yes, we will elaborate on this

Line 375-377: Have you shown the warming around Antarctica in EC-Earth3, compared to other models? Can you support this statement with references?

The references are included in the following sentences. We will reorganise this paragraph to avoid confusion.

Line 380: “Contrast”

Thank you, will correct

Conclusions: Some of the conclusions text seems like it is written in brief draft format. I recommend revising the text.

We agree. A similar comment was made by the other reviewer. To address this, we will move the last paragraph of the Discussion to the Conclusions and expand the Conclusions overall.