

Reply to Reviewer #2

We thank reviewer #2 for the positive and insightful comments. We have followed each of the comments, presented in black font below, to carefully revise our manuscript. Our point-by-point responses are given in blue.

This manuscript presents a valuable new circum-Antarctic coupled ocean–sea ice–ice shelf configuration based on MITgcm and documents it through an extensive evaluation against a wide range of observational and reanalysis products. The configuration itself is a substantial technical achievement, combining relatively fine horizontal resolution, explicit ice-shelf cavities, and a long hindcast forced by ERA5 over 1979–2022. I also appreciate the authors’ transparency in discussing remaining biases and limitations. Overall, I see this work as a strong contribution that will likely be of broad interest to the Southern Ocean and Antarctic modeling communities.

In my view, the manuscript is already in good shape scientifically, but it would benefit from a to help clarify the model’s novelty, better contextualize some of the remaining biases, and strengthen the discussion of where the configuration is especially robust versus where caution is still warranted.

I want to emphasize that one of the best features of the manuscript is its transparency. The authors do not oversell the model and openly discuss important remaining issues such as the warm abyssal drift, sea-ice seasonal bias, and underestimated total ice-shelf melt. That gives the paper credibility.

We thank reviewer #2 for the recognition of our work!

We fully agree with the reviewer that we should strengthen the discussion.

Rather than changing the underlying results, I think the manuscript would benefit mainly from reorganizing some of this discussion so that readers can more easily distinguish:

- 1) where the model performs particularly well,
- 2) where biases are moderate but acceptable for many applications,

3) where caution is needed.

A summary figure or table listing strengths, limitations, likely causes, and implications for model use would be extremely helpful.

We thank the reviewer for this helpful suggestion.

Following the advice of the reviewer, we have added a table (Table R1) to categorize the strengths, biases, likely causes, and implications of SOSIM across its main components, including the open ocean, continental shelf, continental slope, sea ice, and ice shelves as follows (see lines 1381-1386 in the revised manuscript):

Table R1. A summary of the performance of SOSIM.

Component/ Process	Key strengths	Main biases	Likely causes	Implications for usage
Open oceans	1) Large-scale θ and S structures 2) Frontal positions 3) Spatial patterns of surface MKE and EKE	1) Underestimated ACC transport 2) Warm and fresh drift in abyssal waters 3) Weakened AABW	1) Northern boundary proximity to ACC 2) Insufficient dense water formation/mixing 3) Open boundary conditions	Robust: subpolar gyre structure; frontal dynamics. Caution: ACC transport studies; abyssal trend analyses.
Continental shelf	1) Bottom water mass properties 2) Meridionally averaged θ and S structures 3) large-scale CDW/MCDW intrusion patterns	Regional biases in CDW intrusion	1) Biases in open-ocean source waters 2) Overestimated ASC strength	Robust: regional process studies; water mass transformation. Caution: quantitative heat transport in specific sectors.
Continental slope	1) Three typical ASC/ASF regimes 2) Good θ and S correlations with observations	1) Overestimated ASC strength 2) Absent Dense SW overflow	1) Local wind biases 2) No tides	Robust: Three typical ASC dynamics. Caution: quantitative along-slope velocities; AABW production
Sea ice	1) Winter SIC and SIE distribution 2) Interannual	1) Exaggerated seasonal cycle 2) Overestimated coastal SIP	1) Zero-layer thermodynamics 2) Overestimated air-ice stress	Robust: winter sea ice state; interannual

	variability 3) SIP spatial pattern	3) Regional SIT biases	3) Neglect of ice tongue barriers	variability. Caution: summer sea ice projections; quantitative SIP in polynyas.
Ice shelves	Spatial pattern of high melting rates in West Antarctica	1) Underestimated total mass loss 2) Absence of basal freezing in large ice shelves	1) No tides 2) Coarse vertical resolution near ice-ocean interface 3) No frazil ice	Robust: regional patterns of basal melting. Caution: quantitative basal mass balance of ice shelves.

‘To provide a concise summary of the performance of SOSIM, we synthesize our evaluation in Table 1. By outlining the primary strengths, major biases, the likely causes of these biases, and the practical implications for future applications, this summary is intended to clearly show the regimes and processes that are robust in SOSIM, as well as those where caution is warranted or further development is still necessary.’

Moreover, the use of repeated 1979 forcing for spin-up is a reasonable practical choice, especially given the desire to begin the hindcast consistently in 1979. At the same time, the manuscript shows that some domain-integrated drifts remain, especially in deeper waters and in the early evolution of kinetic energy. I do not see this as undermining the value of the model, but I do think the paper would benefit from a slightly fuller discussion of what this means for interpretation. In particular, it would help readers if the authors could state more explicitly that:

- 1) the deep ocean remains less equilibrated than the shelf regions,
- 2) some large-scale integral diagnostics should be interpreted cautiously,
- 3) shelf-focused applications may be more robust than basin-scale abyssal trend analyses.

That would strengthen the manuscript considerably.

We thank the reviewer for this constructive comment. Following the suggestion of the reviewer, we have added two paragraphs to state these points more explicitly.

First, at the end of subsection 3.2 (Model spin-up and drift), we state that the deep ocean remains less equilibrated than the shelf and slope regions, and that large-scale integral diagnostics should be interpreted cautiously as follows (see lines 558-562 in the revised manuscript):

‘Overall, the model equilibration varies substantially across different regions of the model domain (Figs. 6-7). The continental shelf and slope regions reach a quasi-equilibrium state much more rapidly than the deep ocean, with no statistically significant trends over the last two decades of the simulation. In contrast, there are persistent, albeit slow, drifts in the deep ocean throughout the integration period. Therefore, large-scale integral diagnostics should be interpreted with caution, particularly for the abyssal circulation or long-term climate variability.’

Second, in subsection 4.1 (The simulated oceanic biases), we note that shelf-focused applications are likely to be more robust than basin-scale abyssal trend analyses as follows (see lines 1298-1299 in the revised manuscript):

‘Given the persistent drifts in the abyssal ocean (Fig. 7), shelf-focused applications are likely to be more robust than basin-scale abyssal trend analyses.’

A third point is the topography workflow. The geometry preparation appears to have required careful expert judgment, especially in handling remapping artifacts and problematic isolated cells. That is completely understandable in a configuration of this complexity. Still, because this paper will likely serve as a reference for future users, it would be valuable to document these steps a bit more fully, perhaps in the supplement. A brief workflow description, a mask of edited cells, or a short note on the scale of the edits would likely be enough. This would make an already useful paper even more reusable by others.

We thank the reviewer for this constructive comment.

Following the suggestion of the reviewer, we have added a brief description of the

topography construction workflow in the Supplement as follows (see lines 66-91 in the revised Supplement):

‘Text S1. Topography construction workflow

The topography datasets for SOSIM were derived from the Refined Topography dataset version 2 (RTopo-2), which provides consistent topography of bedrock, elevation, and ice draft on a spherical grid. The workflow for constructing the model topography is as follows.

1) The RTopo-2 data south of 35°S (43201 × 6601 cells, 30 arcsec resolution) is interpolated onto the SOSIM orthogonal curvilinear grid (1800 × 1800 cells, ~5 km resolution) using a nearest neighbour scheme. This approach preserves the original values without smoothing but can introduce artifacts in regions with complex coastlines or steep topographic gradients.

2) After remapping, a thorough inspection of the resulting topography fields is performed to identify problematic isolated wet cells that were disconnected from the main ocean domain (e.g., enclosed by dry land or ice shelves with no flow pathway). Since the model applies additional constraints during initialization, such as minimum water column thickness requirements and partial-cell adjustments, the model modifies the actual distribution of wet cells relative to the raw input topography. Therefore, the identification of isolated cells should be based on the mask file generated by the model (e.g., the ‘hFac’ file) rather than on the theoretical water column thickness (ice draft minus bedrock depth). The mask file can be generated by running the model for one time step without additional components (e.g., sea ice, atmospheric forcing, and open boundary forcing).

3) Problematic cells are corrected through a manual editing process. The edits of the bedrock depth and ice draft mainly focus on removing isolated wet cells by converting them to dry cells. The manual edits are concentrated in regions with complex coastal geometry, particularly around the Antarctic Peninsula, the sub-Antarctic islands (e.g., South Shetland Islands and South Orkney Islands), and the margins of large ice shelves (e.g., the Ross Ice Shelf and Filchner-Ronne Ice Shelf). The revised topography is then used to generate an updated mask file by running the model for a single time step.

4) The updated mask file is visually inspected again to ensure that the manual edits have not introduced unrealistic features or new isolated wet cells. If problematic cells are identified again, further modifications to the bedrock depth or ice draft are necessary, and the process of model re-runs and re-inspection is repeated. This iterative loop continues until all problematic cells are resolved in the final generated mask file. In total, ~0.15% of grid cells are manually adjusted in SOSIM v1.0.'

We have also added a reference to this supplement description in the revised manuscript (lines 257-258).

A final comment concerns the underestimated ice-shelf melt. The manuscript's treatment of ice-shelf melt is appropriately cautious, and the underestimation relative to observational products is clearly shown, with the omission of tides identified as one likely explanation. I would encourage the authors to frame this more explicitly as a priority avenue for future model development. This would leave readers with a clearer sense not only of the current model performance, but also of the most promising next steps.

We thank the reviewer for this insightful suggestion.

We have added the description to more explicitly identify the inclusion of tidal forcing as a primary and priority direction for future development as follows (see lines 1410-1411 in the revised manuscript):

'We therefore highlight the inclusion of tidal forcing as a priority avenue for future development of SOSIM.'

Overall, I consider this manuscript to be a strong and worthwhile contribution. The configuration is impressive, the evaluation is extensive, and the manuscript is strengthened by the authors' transparent discussion of remaining biases. The revisions I suggest are primarily aimed at sharpening the interpretation and improving the utility of the paper as a reference for the wider community.

We fully agree with the reviewer that these revisions can substantially strengthen the manuscript. We thank the reviewer again for these insightful and supportive comments,

which have helped us improve the clarity and impact of our work!