Response to reviewer comments of egusphere-2024-3905 "On the seasonal variability of ocean heat transport and ice shelf melt around Antarctica" by Fabio Boeira Dias et al.

REFEREE #1:

Dear anonymous reviewer,

We thank you for the valuable and constructive feedback. Please find below our responses. In the following, reviewer's comments are shown in **bold font**, our response in regular text, and verbatim changes to the manuscript are indicated with *italic font*.

General comments

In this study the authors produce a pan-Antarctic heat budget using 4km ocean-ice shelf model. They focus on seasonality of this heat transport, with their main results being that ice-shelves in East Antarctica are subject to high seasonality, in contrast to those in West Antarctica. Overall I found this study interesting and easy to follow with clear enough conclusions. While I don't have any particularly major comments, I do have a number of more minor, which I think require addressing before the manuscript be published.

Specific comments

1. After equation 1, I suggest reminding readers that Q_sfc includes latent heat from imposed sea-ice melt/formation. Further, it was never quite clear to me if this also includes heat fluxes associated with ice-shelf melting. Stating whether or not this is case would be appreciated.

Thanks for your suggestion. The *Q_sfc* (SHF) includes the latent heat from sea-ice melt and formation and also includes the heat fluxes associated with ice shelf melting. We have included this in the methods (now Lines 124-125):

"SHF accounts for both the heat fluxes from sea-ice melt and formation (Tamura et al., 2011) outside of the ice shelf cavities and from the ice shelf melting within the cavities."

I would suggest including, potentially just as a figure in the appendix, confirmation that the heat budget is closed/accurate. For the ice-shelf cavities, this would require the latent heat flux from the melting of ice shelves. Has this been diagnosed in these simulations (from my comment 1, I wasn't certain it's part of Q_sfc)? Subtracting this from the timeseries in Fig. 1c will lead to a measure of the temporal change in the heat content in the cavities, which can be used as a useful verification of the heat budget itself. If the latent heat flux from ice-shelf melting hasn't been diagnosed, it could be estimated from the ice-shelf melting itself, but this would have small errors since this is also dependent on the local temperature field.

Thanks for your suggestion. We have included in Figure A1 the annual average heat budget closure, by summing up all RHS terms of Eqn. 1 (DIFF + ADV + SHF, dotted magenta line) and comparing with the

NET term (solid black line). As mentioned in our response to comment #1 above, the net surface heat flux term (SHF) includes the heat flux from ice shelf melting. In agreement with the reviewer suggestion, the black line in Fig. A1 (NET) represents the temporal change in the heat content within the ice shelf cavities (Fig. A1a) and the whole continental shelf (Fig. A1b), and the perfect match between the dotted magenta and solid black lines (in both panels) confirms the heat budget is closed.

2. L140: "The heat transport term integrated meridionally over the continental shelf describes the effect from the cross-slope heat transport". There's also a contribution coming from heat going into/out of the ice shelf cavities.

Thanks for your comment, but in this case where we integrated the heat transport over the whole continental shelf (including the ice shelf cavities), the horizontal advective and diffusive component shown in Fig. 1d accounts for the cross-slope and zonal convergence only (but not the cross-calving front), accordingly with the boundaries of each longitudinal bin. The cross-calving front and zonal convergence within adjacent ice shelves (when lacking meridional obstruction) are included in the heat transport term in Fig. 1c.

To further clarify this in the manuscript, we opted to change the labels in Fig. 1d, 2b and A1b from "Continental shelf" to "Continental Shelf (incl. ice shelf)". In addition, we added to Fig. A1b the difference between the integral over the whole continental shelf (including ice shelf cavities) and the integral over the ice shelf cavities only in dashed lines; this is denoted in the legend as, e.g. "NET (excl. ice shelf)". We now mention this figure in lines 161-162:

"This impact of the air-sea fluxes on the heat convergence is substantial, given the differences in magnitude of the heat transport convergence in the continental shelf and within the ice shelf cavities (Figure 1c,d and A1b)."

3. L147. "The correlation between the annual mean heat convergence integrated meridionally over the continental shelf and within the ice shelf cavities is indeed low". Is this the correlation between the black lines in Figs 1c,d? I would imagine advective timescales cause this correlation to be low. I would also imagine that considering lagged correlations wouldn't help much since the lag would be location-dependent. I suggest adding a sentence describing such potential reasons for the low correlation, and how it doesn't necessarily such a weak physical relationship between the timeseries.

Thank you very much for your suggestion. Yes, you're correct, this correlation refers to the black lines in Fig. 1c,d. We agree with these potential sources of degrading the correlation, and have amended the sentences in lines 163-166:

"The correlation between the annual mean heat convergence integrated meridionally over the continental shelf and within the ice shelf cavities (black lines in Figure 1c,d) is indeed low (r^2 = 0.12). We note that this

low correlation could be caused by differences in advective timescales not represented in the time-mean, which does not necessarily imply a weak physical relationship."

4. L154,155. Can it be clarified what this "spatial correlation" is referring to? My thinking is that it refers to the correlation between instantaneous maps of heat flux convergence in the ice-shelf cavity and ice-shelf melting, which is then averaged over time. Is this correct?

Thank you for your comment. This refers to the correlation between the time-mean basal melting (Fig. 1b, black line) and the time-mean heat convergence due to total transport (Fig. 1c, black line). Because we're again looking for the relationship between time-mean variables, we referred to this as spatial correlation. To avoid confusion, we rephrase this sentence (now at lines 171-172), which now reads:

"High basal melt and heat transport convergence within the ice shelf cavities, however, are closely related, exhibiting a high time-mean correlation (black lines in Figure 1b,c; r^2 = 0.90)."

5. L196. It's stated that the grey sections in Fig 1b are based on high basal melt rates, but some areas with high basal melt are not included (e.g., near -20), and some grey regions have low basal melt (e.g., 1st and 8th grey section). Can the authors explain the reasoning for this?

Thank you for your question. We agree with this suggestion that some areas with high basal melt rates are not included. Although we aimed to include all regions with significant basal melt, our choice was focused on major, well-known ice shelves. Thus we have changed the reason for the chosen sub-regions as they are related with major ice shelves (lines 221-222):

"... we integrate the ocean heat budget terms over eleven selected major ice shelves (grey shadings in Figure 1b)".

In addition, we have modified the Fimbul sub-region to include the region around longitude -20°, encompassing the Brunt and Riiser-Larsen Ice Shelves. This expanded sub-region was renamed to "Brunt-Fimbul", as the Brunt, Riiser-Larsen and Fimbul Ice Shelves are all classified under a steady melting regime. We also extended the Amery Ice Shelf sub-region (8th grey section) to include the West Ice Shelf; this updated sub-region is now referred to as "Amery-West". Regarding the 1st grey region, it corresponds to the eastern side of the Ross Ice Shelf and remains included in the Ross sub-region. It is interconnected with the bin/grey area in the right corner of Fig. 1b. No change has been made to this region.

6. In section 4 there is some discussion surrounding the use of just one year of model data and associated limitations. I would suggest adding more discussion of how this can also limit confidence in the diagnosed seasonality.

Thanks for your suggestion. We have expanded the analyses for subsequent years beyond the simulated year 10 shown in the main manuscript. The comparison of the individual annual average ocean heat budget processes (advection/ADV, diffusion/DIFF and surface heat flux/SHF) is shown in Figure R1, which highlights very minor changes considering the 3 years (after the model spin-up). The advective component (Fig. 2c,d) has slightly larger changes than the diffusive and surface flux terms, but it is still virtually the same across the years analysed. Given that the overall picture is very similar, this indicates that the results analysed in the main manuscript are approximately in a steady state. We have replaced all the figures in the main manuscript and in the Supplemental Material with the averaged over the last three simulated years (years 10 to 12).

We include these results in lines 81-87:

"The WAOM simulation at 10 km resolution was initialised using hydrographic data from the ECCO2 reanalysis (Dee et al., 2011) and spun up for 10 years under a repeat year forcing (RYF), with 2007 selected as a representative year of the present-day state (Richter et al., 2022a). The 4 km resolution WAOM simulation was then initialised from the year 10 of the 10 km run and further spun up for another 12 years using the same RYF. The results presented here are averaged over the final three years of the 4 km simulation (years 10 to 12). A comparison across these three years shows virtually no differences (not shown), indicating that the model had reached a quasi-steady state by the time of analysis."

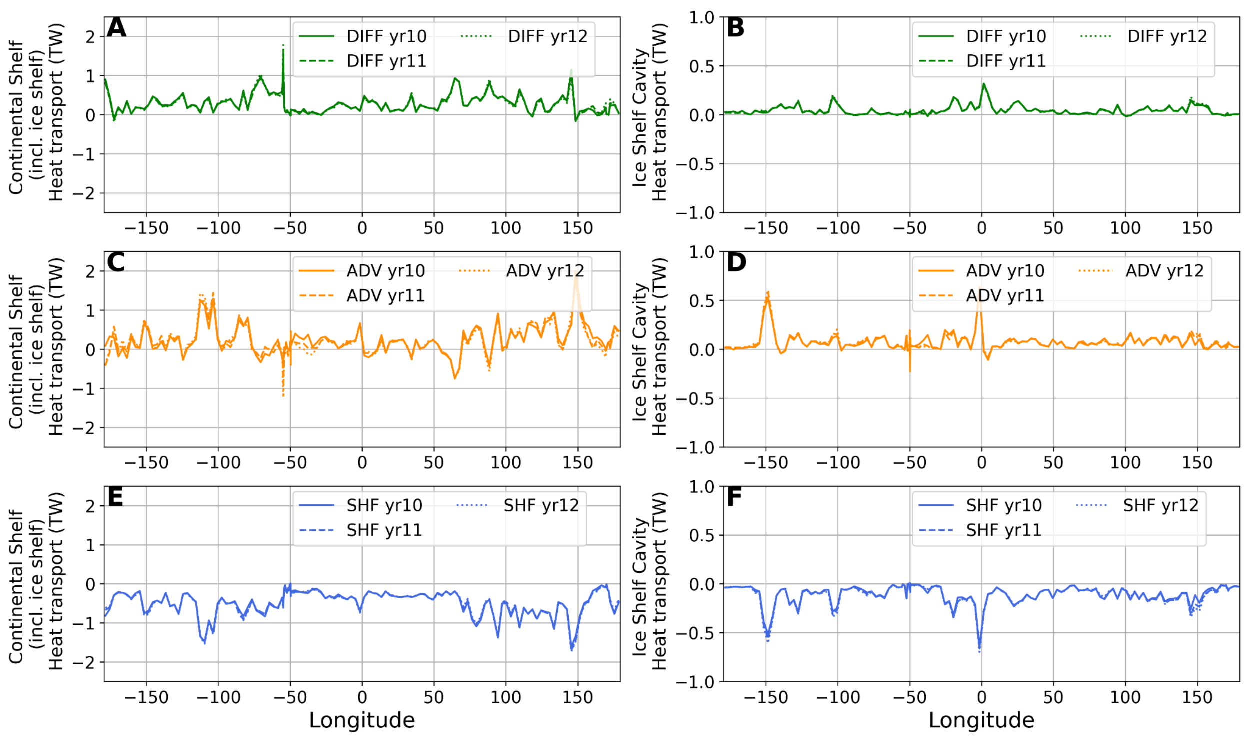

Figure R1: Ocean heat budget (OHB) processes (a,b: diffusion/DIFF; c,d: advection/ADV; e,f: surface flux/SHF) integrated vertically (full-depth) and horizontally over the longitudinal bins for the year 10 (solid lines), 11 (dashed lines) and 12 (dotted lines). OHB horizontally-integrated over the whole continental shelf (a,c,e) and over the ice shelf cavities only (b,d,f). This analysis shows that by Year 10, the model has converged to near steady-state.

Technical corrections

"Antarctic Ice Sheet" is capitalised in places, but not everywhere.

Thanks, it has now been fixed.

The phrase "ice-shelf" is hyphenated in instances of "ocean–ice-shelf", but not elsewhere. I suggest sticking with a consistent choice.

Corrected.

L18. Change "impede" to "impedes".

Corrected.

L23. Change "climate models outputs" to "climate model output".

Corrected.

L30. Change ";neither some" to ", nor are some".

Corrected.

L51. This paragraph repeats much the previous paragraph, e.g., that warm water ice shelves have mode 2 melting etc. This bit of the text could be made a bit briefer.

Thanks for your suggestion. We agree with the reviewer's comment, and we have removed the specific description of modes of melting in this paragraph to avoid repetition.

L79. Specify that these are ice-shelf thermodynamic interactions.

Thanks, it is now added to the sentence.

L101. Check the wording of this sentence.

Thanks, we have amended these sentences, which now reads:

"The ocean heat budget analyses were performed for the entire circumpolar Antarctic continental shelf (including the sub-ice shelf cavities). For ease of analysis, the circumpolar domain was divided into bins of 3° longitude (latitudinal bins on the east side of the Antarctic Peninsula due to the shape of Antarctica, Figure 1a)."

L128. 'Whereas…" This is not a full sentence.

Thanks for noticing this typo. This sentence now reads:

“In contrast, the majority of melting in the West Antarctic sector exhibits relatively stable melt rates throughout the year.”

Fig. 3e,f. Add to the caption the meaning of “<300m” and “>300m” in the legend.

Corrected, thanks for the suggestion.

Figs. 4,5. Can either panels b,e (or c,f) be edited to show basal melt anomaly in each season?

We have modified panels c,f to show the basal melt anomaly from the annual melting, and added this information in the figures' captions (4, 5, A7, A8, A9, A10, A11, A12, A13, A14, A15).

L280. Typo: “Totten ice Shelf”.

Corrected.

L289. Typo: “excerce”.

Thanks for catching this. Following also a comment from Reviewer 2, we have amended this passage, which now reads:

“Although the Totten or Moscow University region has historically been under-sampled, previous modeling studies have highlighted the role of coastal polynyas—such as the Dalton Polynya—in modulating basal melt variability (Gwyther et al., 2014; Khazendar et al., 2013; Kusahara et al., 2024). More recently, the influence of subglacial meltwater (Gwyther et al., 2023) and intrinsic ocean variability (Gwyther et al., 2018) has also been recognised as potentially important contributors. Additionally, winds may influence at longer, inter-annual timescales (Greene et al., 2017).”

Kind regards,
Fabio Boeira Dias and co-authors