**Response to Reviewer 1 for "Southern Ocean polynyas and dense water formation in a high-resolution, coupled Earth System Model" by Jeong et al.**

We thank the reviewer for the additional comments. Please find our responses below (the reviewer's comments are noted in italics and our reference to manuscript line numbers refers to the revised version of the manuscript).

*I thank the authors for thoroughly addressing each comment from my previous review. I only have very few minor comments aimed to further improve the manuscript. I recommend accepting the manuscript for publication after the minor comments have been addressed.*

***Minor comments:***

*L51-57: Solodoch et al. 2022 analyze simulated AABW formation in a global ocean-sea ice model. The study should be mentioned in the introduction.*

We thank the reviewer for introducing this reference. We have added it (line 65).

*L223: Please elaborate on the comparison between the model and Pellichero et al. 2018: Do the results 'compare well' in magnitude, pattern or both?*

We thank the reviewer for this suggestion. We have clarified this on line 220.

*L279: Please use ASF acronym.*

Done.

*Section 2.1 and discussion (L325): Regarding the horizontal resolution of E3SM-HR and resolving the mesoscale. Multiple modelling studies have shown that a resolution of 1-2 km is required to adequately simulate mesoscale eddy activity over the Antarctic continental shelf and slope (e.g., Nost et al. 2011, Dinniman et al. 2012, St-Laurent et al. 2013, Hattermann et al. 2014, Stewart and Thompson 2015). E3SM-HR is with 8 km far from eddy-resolving at this part of the ocean. Please incorporate a sentence or two on the fact E3SM-HR might be 'high-resolution' in terms of Earth System models, but not in terms of resolving the mesoscale in the high latitudes.*

Thank you for noting this. We have first of all corrected a typo in Section 2.1 (line 99: the MPAS resolution varies from 18 km at the equator to 6 km at the poles). We have also added a statement about needing much higher resolution on the continental shelf in order to fully resolve mesoscale eddies on lines 306-309.

**Response to Reviewer 2 for "Southern Ocean polynyas and dense water formation in a high-resolution, coupled Earth System Model" by Jeong et al.**

We thank the reviewer for their helpful and constructive comments. Please find our responses below (the reviewer's comments are noted in italics and our reference to manuscript line numbers refers to the revised version of the manuscript).

*This manuscript is a re-submitted second version of the work. The authors explore dense water formation in coastal and open ocean polynyas around Antarctica using both a low-resolution and a high-resolution version of the fully coupled Energy Exascale Earth System Model (E3SM) forced with 1950 conditions. The work is an important contribution to the modeling society, providing insights into improvements and remaining challenges regarding dense water formation in GCMs. The manuscript is well-written and includes high-quality figures to support the main results. The methodology is sound and builds on state-of-the-art coupled Earth System Model (ESM) development. The manuscript improved much from the first version but will benefit from further revision. Below is a summary of major and minor comments.*

***Main comments:***

*1. The paper will benefit from rewording/restructuring to tell the story more compellingly. For example, a long discussion of what the model cannot do is not appealing to the reader. In the present version, many paragraphs start with what the model cannot do. Then, key findings are given at the end, drowning in all the information about what does not work. Throughout the paper, it would be much more interesting for the reader to focus on what works well, or at least what*

*works better than previous modeling attempts. Then you could briefly overview the remaining challenges and causes/solutions to these challenges.*

We thank the reviewer for this suggestion. We agree that the narrative would benefit from a streamlining of the results presentation. We have followed the specific suggestions mentioned in the minor comments below and also made other minor revisions to the text wherever necessary. Please see, for example, text in blue on lines 148-163, a more streamlined version of the first part of section 3.2, as well as a new version of section 4.2.

*2. The introduction (from line 48) needs restructuring. It would help the reader to give an overview of the current status concerning resolution and the current versions of GCMs. What is currently problematic due to resolution? -And then give more information about why you hope to improve with the HR version of the E3SM-HR. The added information in the discussion from line 325 would be good to give here to set better premises for what you hope to achieve in this paper. The information is partly there, but it could have been more clear.*

We thank the reviewer for this suggestion. Indeed, some reorganization was necessary to pull the relevant information together. We have moved the referenced text out of the Discussion and into the new version of the Introduction. We have also followed one of the reviewer's minor suggestions below to move a paragraph out of Results and into the introduction. Finally, we have pulled together the information about the difficulties that GCM's have in reproducing Southern Ocean processes. Please see the new version of the Introduction section (especially the text in blue), lines 37-77.

*3. The result section on why the winds are too strong and the implications of this is unnecessarily long. You convince me early on, and then you keep arguing for this. You could easily cut parts of this section to keep the reader interested.*

We have reduced section 4.2 a bit to make it more concise (see blue text on lines 247-256). Another reviewer felt strongly about providing more quantitative evidence for the implications of strong winds on the ASC and the cross-shelf stratification, and for this reason, we included the analysis that is summarized in Fig. 8.

***Minor comments:***

*Line 23: Points i and ii combined are key dense shelf water formation mechanisms. You also mention the processes that lead to AABW but only include the more direct process. For example, DSW could also interact with ice shelves or water masses within the ice shelf cavities as part of the AABW formation process.*

We have now added the word 'direct' to line 23. Other indirect mechanisms that impact DSW formation are mentioned in the Discussion section.

*Line 39: What resolution is required to resolve the DSW export along the continental slope?*

The first baroclinic Rossby Radius is less than 20 km over the whole Southern Ocean (e.g., Chelton et al. 1998), with values going down to less than 10 km over parts of the Antarctic continental shelf. Hallberg (2013) suggests resolutions of at least 1-2 km on the shelf in order to be able to represent mesoscale eddies and cross-shore transport properly. The 6 km resolution in E3SM-HR polar regions is adequate, although it is still too low for very coastal regions. We have now added a statement discussing this on lines 306-309.

*Line 145: typo fluxes→flux*

Corrected.

*Line 147: Get to the interesting point right away: "There is more sea ice…"*

Thank you for this suggestion. Please see new sentence in blue on lines 148-150.

*Line 153: Move the general statement "E3SM-HR generally does well…" to the start of the paragraph to help your story flow.*

We have now revised section 3.1 to address this, the following two comments, and the general suggestion in main comment 1. Please see text in blue on lines 148-163.

*Line 157: Get straight to the point "The mean coastal…"*

Please see previous comment and text in blue on lines 148-163.

*Line 159: See major comment 1: The story will improve if you focus on what you do well and why and then compare other features. Start saying that the HR version does much better than the LR version, and tell us why some polynyas are closer than others (MBP, SP, VPB, MP, TNBP, BeP all do well in either/or volume and area)*

Please see text in blue on lines 148-163.

*Line 218: How does this differ if you show the mean over 5 OOP years vs 5 normal years? Since the variation in figure 4 is so large, it would be helpful with some considerations of this.*

We thank the reviewer for this question. To increase the robustness of our WMT results, we opted for considering the regional Weddell Sea WMT as a representation of OOPs effects onto the total

WMT, rather than slicing the model data in time. Please compare the pink and black lines in Fig. 5b as well as panels c and d of the same figure.

*Line 233: Can you comment on why the positive transformation rates occur at lighter densities over the shelf? Is the shelf water generally too light compared with observations, and if so, why?*

We discuss this at the end of Section 4.1 (lines 242-245) as motivation for Section 4.2.

*Line 239: Rewrite the text in the parenthesis.*

Changed to ”mostly because less cold” (see line 235).

*Line 250: Please rewrite the first statement in the paragraph to improve readability.*

We have now revised the beginning of section 4.2 (blue text on lines 247-254) substantially, also to follow the suggestions in main comment 3.

*Line 260-272. This is not results but information that belongs to the introduction.*

As mentioned in the reply to main comment 2 above, we have moved this information to the Introduction (see lines 37-54).

*Line 277: Could you start with some general comments before you go into each shelf type? In all shelf types, you find down-sloping isopycnals close to the continental slope. The fresh and dense shelf areas are similar, indicating little/no(?) dense water formation. On the warm shelf, you have upward-tilting isopycnals offshore, but the tilt does not extend onto the shelf.*

Please see text in blue on lines 259-260.

*Line 332: How will land-fast ice alter the dense water formation? Would you get more/less dense water?*

Landfast ice could enhance dense water formation due to the possibly increased divergent motion and associated larger coastal polynyas as mentioned on lines 165-168.

*Line 336: You say you want to include land-fast ice in the future, but how will you fix the too-strong wind problem?*

Thank for this suggestion. We have now added a sentence about this on lines 312-315.

*Figure 1c is hard to read. Could it be an idea to lower the longitudinal resolution of the production data to make it easier to compare the two data sets? If you, for instance, make longitude bins of 10 degrees, the figure would be less crowded. I guess the exact position of the individual polynyas varies from model to observation anyway, and a lower resolution would not be a problem.*

We thank the reviewer for this comment. We would prefer to leave Fig. 1c unchanged.

*Figure 2 would benefit from rescaling the axes on individual polynyas. I generally appreciate similar axes for inter-comparison, but given that RISP is so different, it would be beneficial to zoom in on the others and comment on the different aces for RISP. Panels n and o in figure 2 do not contribute much to the story. I guess RISP is the main contributor to the discrepancies(?) I think you could either give the total numbers or consider plotting stacked bar charts for volume/area for the individual polynyas to display the effect of each polynya on the sum.*

We agree with the reviewer's suggestion and have changed the limits of the y-axis for panels 2a-i and 2k-m to be 0-18, while leaving them unchanged in 2j (we have noted the different scale in the

figure caption). As a result, we think Fig. 2 is now more legible.

*Figure 3 caption: The last sentence seems to be the opposite of what is correct. SIC lower than 15% is masked out.*

Corrected. Thank you for catching this.

*Figure 3g-i: I do not think showing the sensible heat flux in polynya months is necessary. Rather comment on the increase in the polynya area, or say something about the overall contribution to heat loss.*

Thank you for this suggestion. As the reviewer suggested, we removed Fig. 3g-i and commented on the increase in the polynya area on lines 181-182.

*Figure 4: Is it possible to add numbers for dense water production for the various years?*

We believe that the number of simulated years is insufficient to compute the interannual variability of dense water production. For this reason, we decided to focus on the climatological results for this study.

*Figure 8: There is no dense water in either the strong or weak wind composites. I do not think it is necessary to show this figure, but you could add this to the supplementary instead.*

This figure and the description of the analysis behind it (lines 271-279) were added as a response to another reviewer comment that we should provide more evidence that the strong winds in E3SM-HR are impacting the ASC and cross-shelf stratification. We therefore prefer to leave this figure in the main body of the manuscript.