Response to Review Comments

We thank the editor and reviewers for their efforts in making constructive remarks and suggestions, which have significantly improved the quality of our manuscript. Below you can find point-by-point replies to the major and minor comments (*font in Italic*) and the corresponding revisions to the manuscript. In the revised manuscript, revisions are highlighted by light-blue color. We hope that all the editor's and reviewers' concerns have been addressed adequately.

Reviewer #1:

General comments:

This study investigated the reproducibility of the sea-ice conditions (sea-ice concentration and production) and oceanic conditions in the Ross Sea using a high-resolution ocean-sea ice-ice shelf model for the Amundsen and Ross Seas, named RAISE v1.0. Additionally, the authors examined the impact of meltwater from the ice shelves in the Amundsen Sea on the water properties in the Ross Sea. Understanding the changes in the coastal water masses around Antarctica is very important due to its significant influence on deep water formation and, subsequently, global thermohaline ocean circulation. However, while reviewing this manuscript, I noticed a significant overlap with the content of the authors' previous publication in JGR-Oceans (Xie et al. 2024, doi:10.1029/2024JC020919). Although there is a slight difference in the model integration period, it is evident that the model used is the same as that in Xie et al. (2024). Moreover, the sensitivity experiments regarding increased meltwater from the Amundsen Sea ice shelves are very similar to each other. Even the description of the model, while arranged differently, appears to be nearly the same. If my understanding is correct, this could be considered a case of duplicate publication. However, if I have misunderstood the extent of the overlap or the novelty of the current work, I would appreciate a clear rebuttal or clarification from the authors. At the very least, it is necessary to properly cite the previous work and clearly highlight the differences.

We are sorry for giving the reviewer an impression that the model mentioned in this study is the same as that in Xie et al. (2024), which is actually not. Please find our clarifications below.

First, the model developed in this manuscript is an updated version of the one used in Xie et al. (JGR: Oceans, 2024, and also in Zhang et al. (2024) which was published in September of this year). The difference is that surface temperature and salinity are nudged to a monthly mean climatology provided by the World Ocean Atlas 2018 in this model, while Xie et al. (2024) did not apply any nudging. The two versions are developed at the same time. We actually compared the simulations from the two models, and found that the version employing nudging performs better in sea ice production assessed against satellite estimates (Fig. R1 shown below). Additionally, it better captures the interannual variation of DSW compared with CTD data (Fig. R2). In the manuscript, we did not mention Xie et al. (2024) or Zhang et al. (2024) as they were still under review at the time we submitted this manuscript, and we think it might be inappropriate to cite it without a DOI assigned. In the revised manuscript, we have added such comparisons and emphasized the difference of this model from the one in Xie et al. (2024) and Zhang et al. (2024). In addition, Xie et al. (2024) is focused on scientific problems relevant to the influence of enhanced ice shelf melting in the Amundsen Sea on the Ross Sea water properties, rather than model development and validations. They provided 4 figures for model validation (in the main text and supplementary materials), and while the 3 figures for validating sea ice production, hydrographic variables along the Ross Sea cross-shelf transect and spatial distributions of sea ice concentration are plotted in the same way as those in this manuscript, as mentioned above, these results are based on different model versions and are not duplicate results.

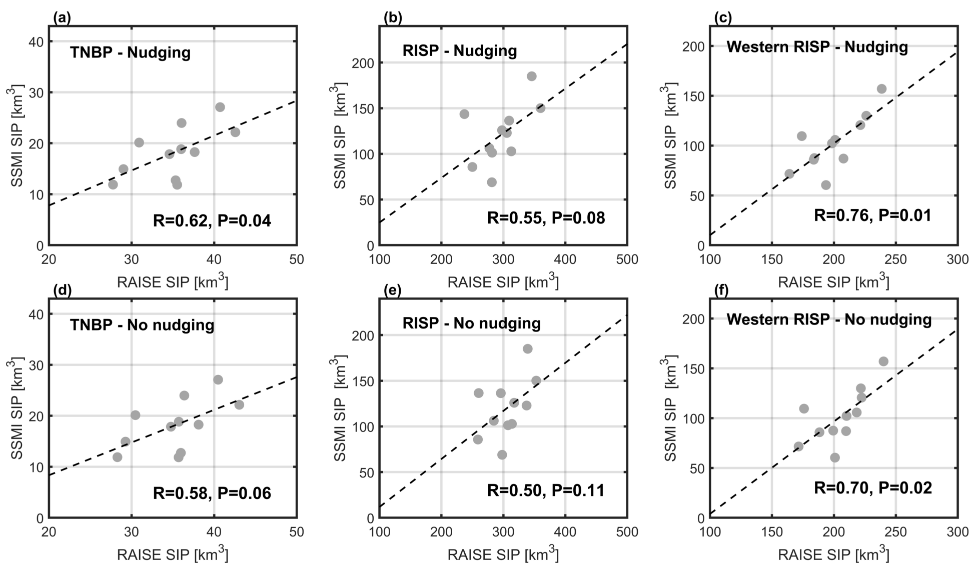

Fig. R1. Scatter plots of modelled winter sea ice production versus satellite-estimated winter sea ice production from simulations (a–c) with nudging and (b–d) without nudging for (a and d) the Terra Nova Bay polynya (TNBP), (b and e) the Ross Ice Shelf polynya (RISP), and (c and f) the western RISP.

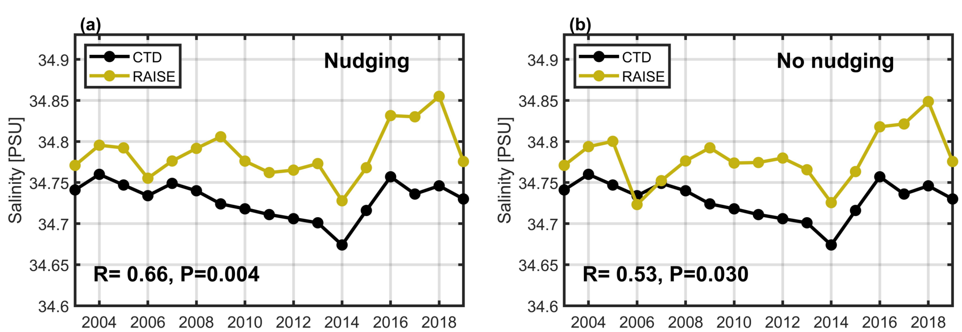

Fig. R2. (a) Time series of summer bottom water salinity near the Ross Island from the model simulation with nudging (i.e. the model version used in this study) and CTD observations (from Jacobs et al. (2022)) during 2003–2019. (b) Time series of summer bottom water salinity near the Ross Island from the model simulation without nudging (the model version used in Xie et al. (2024)) and CTD observations.

Second, as for the sensitivity experiments regarding increased meltwater from the Amundsen Sea ice shelves, the scientific motivations and configurations in Xie et al. (2024) and this work are quite different. Xie et al. (2024) is focused on the impacts of accelerated ice shelf basal melting in the future on DSW formation and CDW intrusion in the Ross Sea, and they increased the melting rates based on future projections of ice shelf melting in the Amundsen Sea from CMIP6 scenarios. In this work, we designed ice shelf sensitivity experiments to address the missing and underrepresented ice shelf melting processes in the model. This adjustment aims to mitigate the overestimation of DSW salinity observed in the model compared to mooring observations. We conducted these experiments by artificially increasing the ice shelf melting rates to match the values estimated from satellite data.

In the revised manuscript, we clarified the differences between the model used in this study and the one used in Xie et al. (2024) and Zhang et al. (2024) (Lines 120–122 and Lines 147–152), and hope in this way we can prevent any potential confusion regarding the originality of our research.

Specific comments:

Figs. 3g, 10, 11

I believe it is misleading to claim that the model accurately reproduces the observations simply because the correlation coefficient is significant when seasonal variability is included. Seasonal variability has a strong cyclic pattern, which can lead to a high correlation between the model and observations, even if the model does not truly capture the underlying processes. Evaluating the model's performance without removing the seasonal component can overestimate the model's skill. For a more accurate assessment, the seasonal signal should be removed before calculating the correlation, or the analysis should separately address seasonal and non-seasonal/interannual variability.

In fact, throughout the manuscript, we avoided using "accurately" to describe the performance of the model, and we mostly used "well" or "reasonably well" for the descriptions. The reviewer is correct that including seasonal cycles normally leads to high correlations between the temporal variability of modelled and observed variables. In Fig. 3g of the revised manuscript, we removed the seasonal cycle for sea ice concentration (SIC) by subtracting the multi-year climatology from the original SIC values, and the variation of modelled SIC (which is now the anomaly value) is still significantly correlated with the satellite estimate, although the correlation coefficient is reduced (now R=0.68 and P<0.0001).

For Figs. 10 and 11, on the one hand we kept the original plots in the revised version, as if we remove the seasonal cycles, the plots can only show the time series of DSW density anomalies, and in this case we cannot show the effects of improved simulation of the absolute value of DSW density in the Melt+ experiment. On the other hand, we provided plots with seasonal cycles removed (Fig. 10c,d and Fig. 11c,d), and the results show that the temporal variations of modelled and observed DSW neutral density are still significantly correlated. The revised texts are provided in Lines 384–386 and Lines 401–402.

Fig. 7

Regarding the spatial correlation as well, there may still be residual effects from the initial conditions. Even if the model shows a good correlation with observations, it does not necessarily mean that the model accurately reproduces the underlying processes. The initial conditions can strongly influence the spatial patterns, leading to high correlations that may not truly reflect the model's capability to simulate the key dynamics. One could imagine that the spatial correlation between the initial conditions and the observations might yield a similar correlation coefficient. It is important to demonstrate that the higher correlation is due to the high-resolution model resolving fine-scale structures that were not present in the initial conditions, rather than simply reflecting initial condition influence.

The initial conditions for the model developed in this study come from the simulations produced by a coupled ocean-sea ice-ice shelf model for the Southern Ocean (Dinniman et al., 2015). To verify if the model simulations are strongly affected by the initial conditions, we conducted an additional experiment in which the initial conditions are replaced with the World Ocean Atlas 2018 climatology, and all the other configurations are the same as those in the CTRL simulation. From Figs. R3 and R4 shown below, it can be seen that there are large differences in temperature and salinity between the two initial fields used. Due to computational costs, we only integrated the model in the sensitivity experiment for 5 years from 1998 to 2003, i.e., the spin-up period for the CTRL simulation, and the results show that after 5 years the simulated spatial distributions of temperature and salinity in the sensitivity experiment are very similar to those in CTRL for both the bottom and middle layers (i.e. the DSW and CDW layers, Figs. R5 and R6). These results demonstrate the high spatial correlations between the modelled and observed temperature/salinity in our study are not a result of initial conditions. In the revised version we mentioned that

"Alternative initial conditions from the World Ocean Atlas 2018 (WOA18) are also employed for this model, and we found that after a 5-year spin up period, these conditions yield quite similar model simulations to those initialized by the model results from Dinniman et al. (2015)." (Lines 131–134).

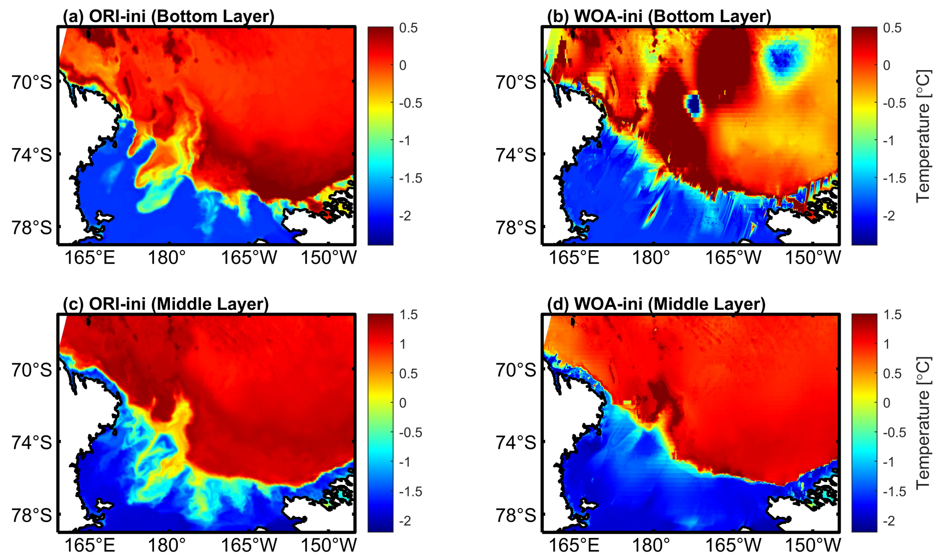

Fig. R3. Spatial distributions of temperature from the model simulations using (a and c) original initial conditions and (b and d) the WAO18 data as initial conditions in the (a and b) bottom layer and (c and d) middle layer of the Ross Sea.

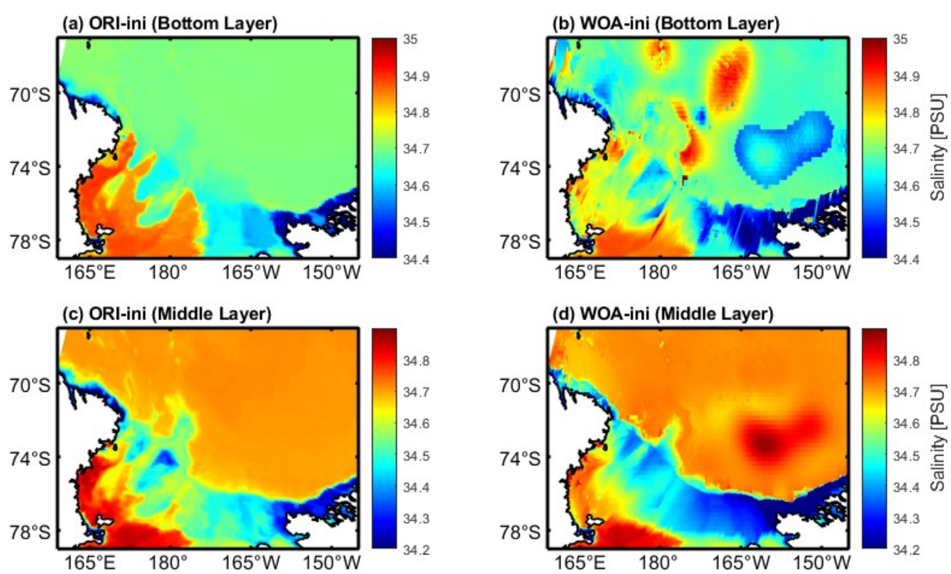

Fig. R4. Spatial distributions of salinity from the model simulations using (a and c) original initial conditions and (b and d) the WAO18 data as initial conditions in the (a and b) bottom layer and (c and d) middle layer of the Ross Sea.

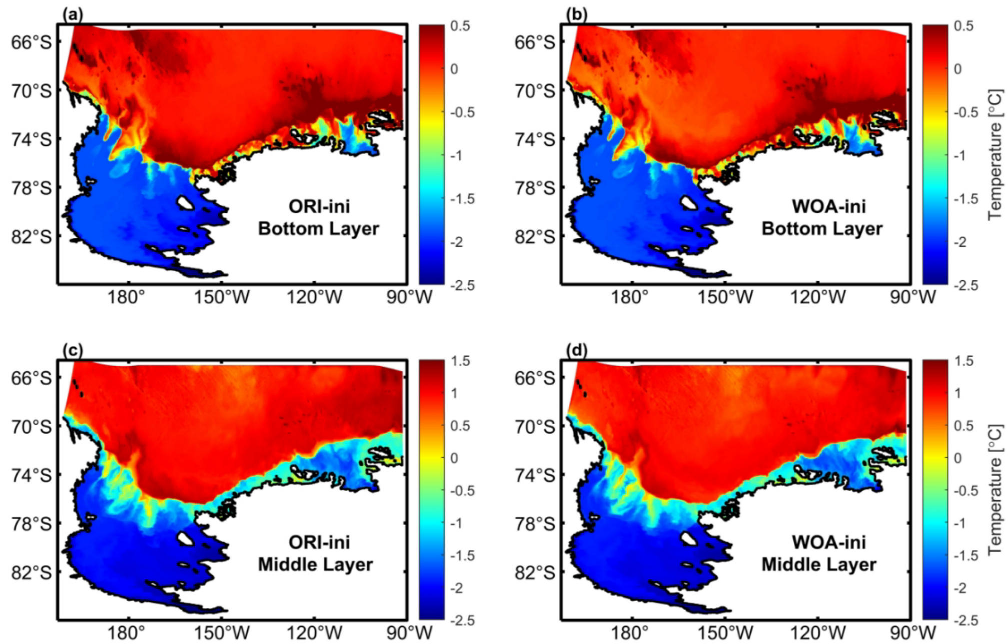

Fig. R5. Spatial distributions of temperature after 5-year spin up period of the model using (a and c) original initial conditions and (b and d) the WAO18 data as initial conditions in the (a and b) bottom layer and (c and d) middle layer of the Ross Sea.

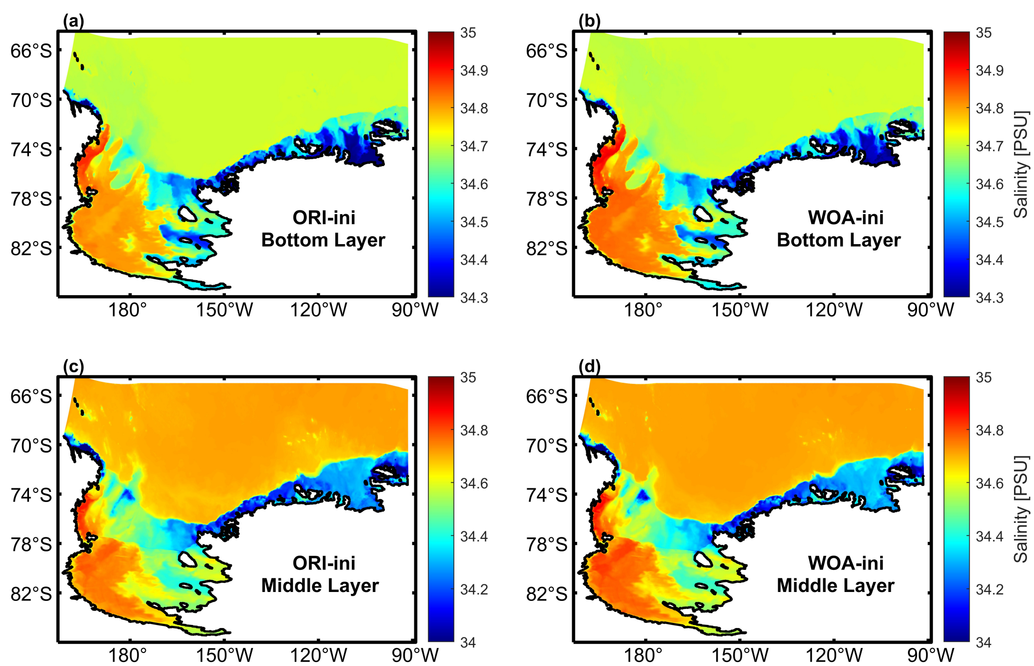

Fig. R6. Spatial distributions of salinity after 5-year spin up period of the model using (a and c) original initial conditions and (b and d) the WAO18 data as initial conditions in the (a and b) bottom layer and (c and d) middle layer of the Ross Sea.

Fig. 4

The interannual variability of sea ice production in the Ross polynya, which accounts for a large portion of sea-ice production in the model domain, does not reach the 95% significance level. Therefore, I do not believe the model can accurately reproduce the observed interannual variation in sea-ice production.

We admit that if we consider the entire Ross Ice Shelf polynya (RISP), the interannual variability of sea ice production from the model is not quite strongly correlated with that from the satellite estimate, which only reaches the 90% confidence level. However, it is demonstrated that DSW primarily exists in the western portion of the RISP and not in the eastern portion (Orsi and Wiederwhol, 2009; Wang et al., 2021), which can also be seen in Fig. 9b. This is because there is more ice shelf meltwater from the Amundsen Sea transported to the eastern portion, and also there is more local meltwater from the Ross Ice Shelf in the eastern portion as the eastern Ross Sea shelf is narrower that facilitates the intrusion of warm CDW to the ice shelf. So sea ice production in the western portion of the RISP contributes most to the DSW production in the RISP. We compared the interannual variability of modelled sea ice production in the western RISP (west of 186°E) to that from the satellite estimate, and the correlation is notably improved (R=0.76, P=0.01). In the revised Fig. 4 both the plots for sea ice production in the entire RISP and the western RISP are provided, and descriptions for ice production in the western RISP are provided in Lines 268–275.

References

Orsi, A. H., and Wiederwohl, C. L.: A recount of Ross Sea water, Deep-Sea Research Part II, 56(13), 778–795, https://doi.org/10.1016/j.dsr2.2008.10.033, 2009.

Wang, X., Zhang, Z., Dinniman, M. S., Uotila, P., Li, X., and Zhou, M.: The response of sea ice and high-salinity shelf water in the Ross Ice Shelf Polynya to cyclonic atmosphere circulations. The Cryosphere, 17, 1107–1126, The Cryosphere, 17, 1107–1126, https://doi.org/10.5194/tc-17-1107-2023, 2023.

It would be beneficial to include not only a comparison of the water mass properties but also quantitative estimates regarding DSW and AABW formation/production rate in the model.

While it is important to validate the modelled DSW and AABW production rates, it is difficult to obtain an accurate estimate of these rates from observations, since temporally continuous observations of DSW/AABW for calculating the rates are only available from mooring measurements, which are very sparce in space. Also, hydrographic sensors on these moorings are only installed at limited depth levels. This makes it difficult to accurately estimate the volume of the DSW and AABW using the mooring observations, and thus difficult to provide a good reference for evaluating the model simulations of the production rates (in unit of $m^3\ s^{-1}$).