#R.Marsh Referee

The authors present improved representation of iceberg melting in the ORCA025 configuration of the NEMO ocean model. Improvements are specifically developed in the melting associated with three processes: wave erosion; basal melting; sidewall melting. Key improvements are in the vertical distribution of meltwater, in relation to upper ocean stratification and the mixed layer in particular. The experiments are clearly designed and the analysis is revealing of the meltwater partitioning – and hydrographic impacts – above/below the mixed layer depth, and between offshore waters and the continental shelf. The shift away from wave erosion to lateral melt is particularly striking. Clear logic is evident throughout and the useful conclusion is that surface-confined meltwater is a good approximation, with some local exceptions, subject also to better observations of iceberg melting.

Regarding experimental details, 15 years is not long for bottom T and S differences to be established far from Antarctica. The authors explain that **'After the spin-up period, the 5 simulations are run for 25 years to allow the new melting parameterisations to equilibrate, and the annual and monthly climatologies are computed by averaging the final 15 years of this run'**. While it is clear in Fig. 3 that total ice volume stabilizes around 2015-20 (run years 15-20), the slow advective timescales around Antarctica imply a longer adjustment timescale for the deeper circulation and hydrography. Are deeper T and S significantly trending after 25 years? Can the authors comment on this caveat, in both results and discussion?

We thank the reviewer for raising this important point. We have first clarified and better justified our choice of the adjustment and averaging periods (Lines 209 and 212). The iceberg freshwater flux has already reached a quasi-steady state during the spin-up period, as can be seen in Olivé Abelló et al. (2025). After modifying the melting parameterisations and meltwater distribution, we allow an additional 10 years for the associated surface ocean-sea-ice system to adjust before computing the 15-year climatologies. This timescale is consistent with the 5-10-year adjustment of Antarctic sea ice following changes in freshwater forcing reported by Pauling et al. (2016).

In the revised Discussion (Lines 430–437), we explicitly address the incomplete deep-ocean equilibration as a caveat and examine the evolution of bottom temperature and salinity over the simulations (new Figure S7). Both variables continue to evolve in the abyssal Ross and Weddell gyres (not shown). However, over the Antarctic continental shelf, the Amundsen Sea, the western Ross Sea and western Weddell Sea tend towards stabilization, especially in the last 15 years. As these trends are largely shared across experiments, we expect incomplete equilibration to have a limited impact on our bottom properties distribution.

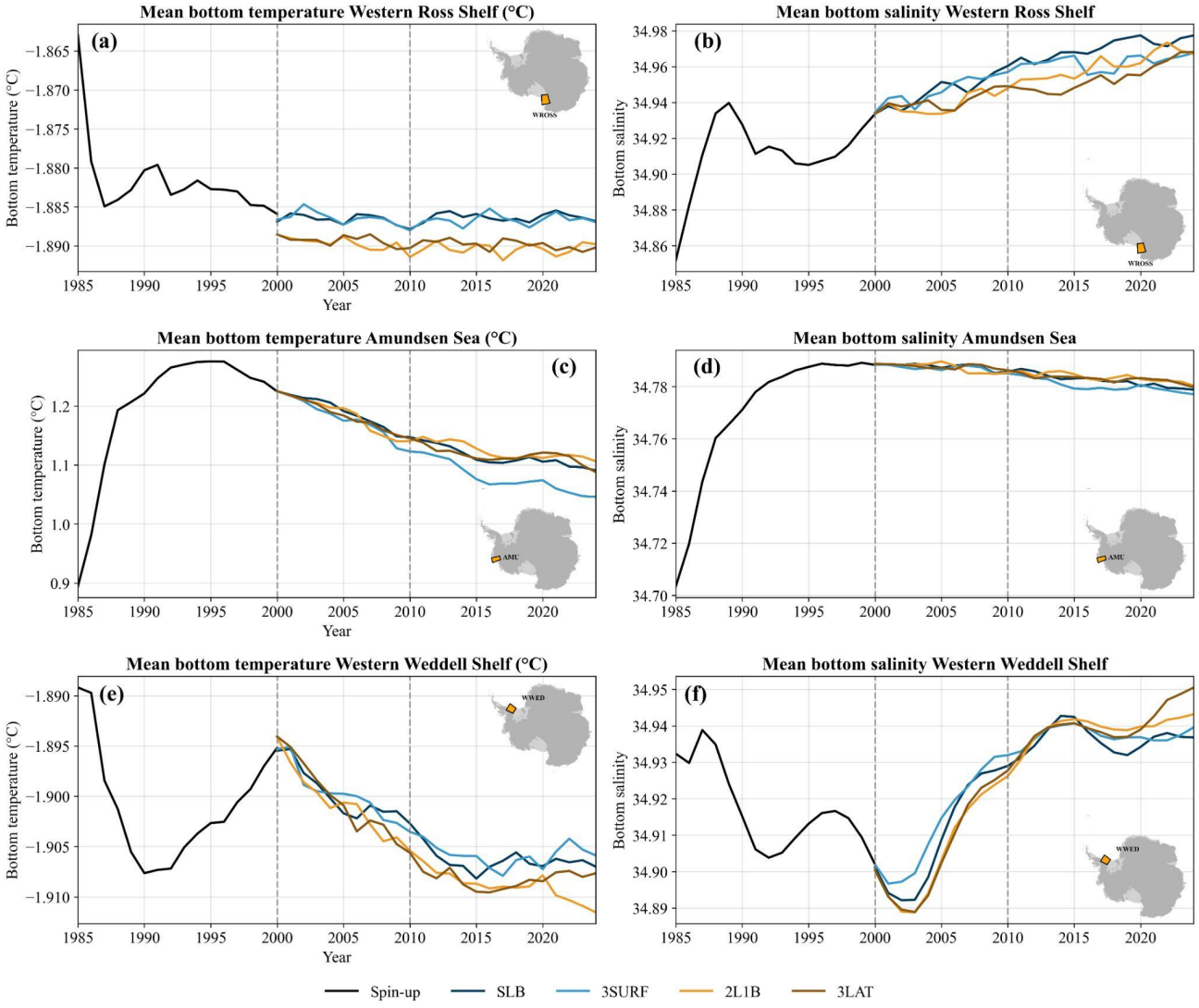


Figure S7. Mean bottom temperature and salinity evolution in the (a, b) western Ross Sea, (c, d) Amundsen Sea and (e, f) western Weddell Sea. The black line shows the 15-year spin-up simulation (1985–2000), while the coloured lines show the four sensitivity experiments (SLB, 3SURF, 2L1B, and 3LAT) over the subsequent 25-year simulations (2000–2024). The vertical dashed lines indicate the start of the sensitivity experiments (2000) and the beginning of the 15-year period used to compute the climatologies (2010).

A further thought regards the small hydrographic impacts around Antarctica: 'slight cooling and freshening of bottom waters in East Antarctica and the western Ross Sea, and slight warming and salinification of shelf bottom waters in the Amundsen Sea'. Given the similarly small trends and anomalies reported in deeper and abyssal waters over recent years (see Gunn et al. 2023 and references therein; notably AABW freshening in the Ross Sea sector, attributing to 'increasing glacial meltwater'), can the authors comment on the relative size of differences between T and S between their experiments? The question is whether changes in iceberg melting (due to changes in calving, draft, wave influence, etc.) might account for some of the observed changes?

We further examined how freshwater injection at depth changes bottom temperature and salinity between SLB and 3SURF, the two experiments with the strongest anomalies in the Australian–Ross Sea sector, where the AABW cascading signal is most apparent. Over the continental shelf, the mean bottom-salinity difference is only +0.003 g kg^{-1}, although local anomalies can reach 0.11 g kg^{-1} in the

southwestern Ross Sea. Despite these locally significant changes, the net export of DSW (Dense Shelf Water, a precursor of AABW) across the 1020-km section along the Ross Sea continental shelf break increases by only 0.075 Sv (4.3%) relative to 3SURF (Figure S8 below). For comparison, Gunn et al. (2023) associated Australian–Ross Sea AABW salinity changes of 0.04 g kg^{-1} during 1992–2011 and 0.03 g kg^{-1} during 2011–2018 with substantial changes in AABW volume and transport, including a decrease of ~4.4 Sv during the first period and a recovery of 2.2 Sv during the second. Changes in the depth of iceberg meltwater injection can locally modify shelf-sea floor properties, but in our experiments these small anomalies do not translate into a comparably strong DSW export response. We have added this discussion to the revised manuscript (Lines 450 and 456) and included an additional figure in the Supplementary Material (Figure S8) showing the bottom-salinity changes and the section used to quantify DSW export.

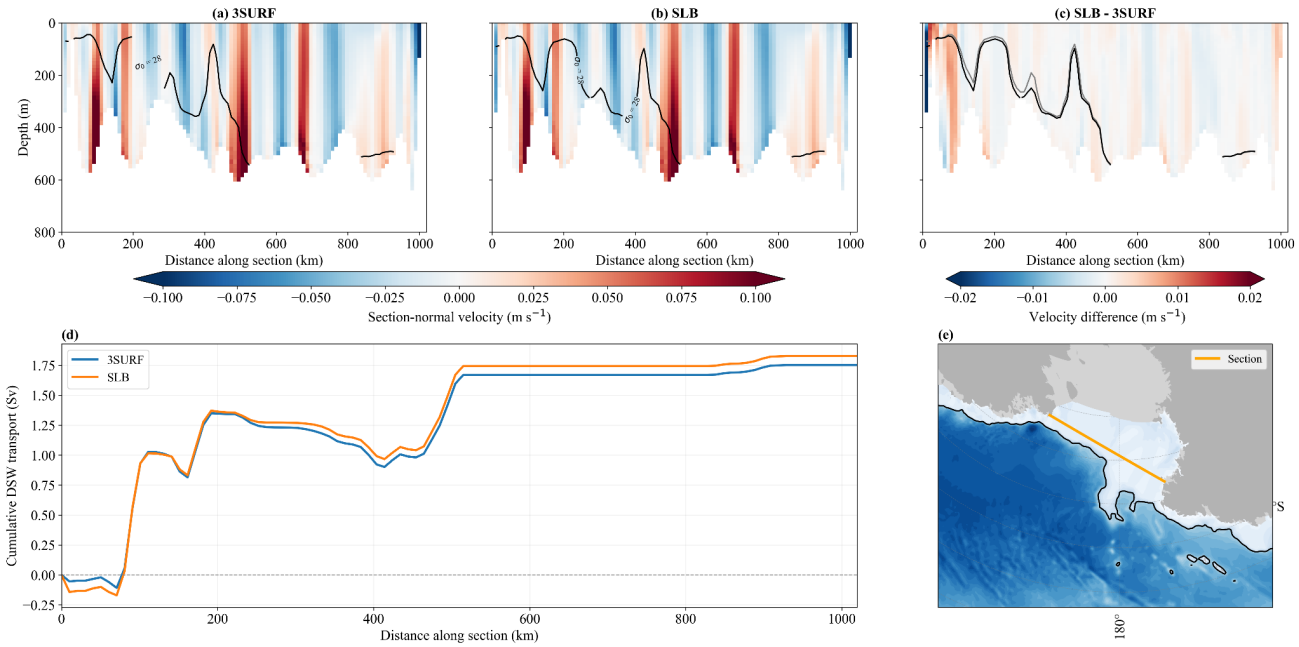


Figure S8. Section-normal velocity for (a) 3SURF and (b) SLB, and and (c) their difference (SLB − 3SURF), along the 1020-km section parallel to the Ross Sea continental shelf break. Black contours indicate the σ_0 = 28 kg m^{-3} isopycnal used to identify DSW (grey contours in panel c show its position in 3SURF for comparison). (d) Cumulative DSW transport along the section for 3SURF and SLB. (e) Location of the section across the Ross Sea continental shelf break. Positive velocities and transport represent offshore DSW export.

Reference:

Gunn, K.L., Rintoul, S.R., England, M.H., et al. Recent reduced abyssal overturning and ventilation in the Australian Antarctic Basin. Nat. Clim. Change, **13**, 537–544 (2023). https://doi.org/10.1038/s41558-023-01667-8

#Anonymous Referee
General Comments

This study investigates the importance of vertically distributing iceberg meltwater in an ocean model that represents icebergs as Lagrangian particles. The authors introduce a new, more realistic parameterization and, using a suite of sensitivity experiments, assess its effects in terms of spatial distribution and temporal variability, appropriately discussing the relative importance of each component. The effects on the ocean, sea ice, and ice shelves are also examined. Based on these analyses, the authors conclude that, for Southern Ocean–scale responses, modelling studies to date that release iceberg meltwater at the surface can still provide reliable estimates.

Overall, the analyses needed to support the paper's claims appear to have largely been carried out. The Methods section is well written, with appropriate comparisons to previous studies, and the improvements to the iceberg-melt parameterization are presented clearly. I have two main suggestions below, along with a number of minor comments. I believe that incorporating these revisions would further strengthen the manuscript and enhance its overall clarity and impact.

Major Comments
(1) Model fidelity relative to observations

It would be useful to clarify whether the model reproduces the observed water-mass distributions. For example, previous observational studies have reported warm-water intrusions onto the continental shelf in the Amundsen and Bellingshausen Seas, and off Totten and Denman ice shelves. Are these features reproduced in this model?
It might be helpful to show, for instance, a horizontal map of temperature and salinity at 500 m depth over the entire Southern Ocean, together with temperature, salinity, and density sections for each of the regions defined in Figure 1, compared against observations.
Even where the model does not perfectly match the observations, presenting the water-mass distribution reproduced by NEMO would help to substantiate, for example, why lateral melting is larger in the Amundsen Sea and in parts of East Antarctica, and would add further depth to the discussion of the iceberg-meltwater results.
We agree. For that, we have added a new figure, Figure 1, comparing potential temperature, salinity, and potential density at 500 m depth between the baseline NEMO simulation and the World Ocean Atlas 2023 (WOA23) climatology (2015–2022). The corresponding description and assessment appear in Lines 88-100.
In the new Figure 1, it is clear that, despite regional biases, the model broadly reproduces the observed large-scale water-mass distribution at this depth, with a general tendency toward slightly saltier and denser waters. In particular, the temperature and salinity distributions reproduce the presence of relatively warm CDW waters around the Antarctic continental margin, including the Amundsen and Bellingshausen Seas and sectors of East Antarctica associated with the Totten and Denman ice shelves. Additionally, we examined the more recent regional climatology provided by Zhou et al. (2026) and found broadly similar salinity and temperature distributions to WOA23 at 500 m depth. We also note that WOA23 shows considerably colder waters in parts of the Amundsen Sea than both the model and previously reported local in situ observations, as observational climatologies are also subject to biases (e.g., Jourdain et al., 2020).

References:

- Jourdain, N. C., Asay-Davis, X., Hattermann, T., Straneo, F., Seroussi, H., Little, C. M., and Nowicki, S.: A protocol for calculating basal melt rates in the ISMIP6 Antarctic ice sheet projections, The Cryosphere, 14, 3111–3134, https://doi.org/10.5194/tc-14-3111-2020, 2020.

- Zhou Shenjie, Dutrieux Pierre, Giulivi Claudia, Lee Won Sang, Kim Tae-Wan, Hattermann Tore, Janout Markus (2026). Southern Ocean (90°S-45°S) conservative temperature and absolute salinity profiles compilation (OCEAN ICE D1.1). SEANOE. https://doi.org/10.17882/99787.

(2) Structure of the Discussion

The Discussion covers genuinely interesting material—for example, the contrasts with the Arctic and the parameterization uncertainty. However, several distinct topics are currently combined within a single Discussion section that runs to more than two pages, which makes it somewhat difficult to follow. I would suggest condensing the content and organizing it into thematic subsections. Once the Discussion has been restructured, it would also be helpful to revisit the Conclusion and confirm that it maps clearly onto the reorganized points.

We have condensed and reorganized the Discussion into thematic subsections, which has improved its clarity and readability. Following this restructuring, we have also revised the Conclusion to ensure that it clearly reflects and aligns with the main points of the reorganized Discussion.

Specific comments

L22–24: Naughten et al. 2022, Moorman et al., 2026 inject iceberg meltwater in the vertical. It may be need rephrasing this sentence accordingly. Naughten et al. 2022 and Moorman et al., 2026.

Thank you for pointing this out. We were not aware of these studies. Following Naughten et al. (2022), iceberg meltwater is applied as a steady three-dimensional source of mass. Horizontally, the meltwater flux follows the spatial distribution of Merino et al. (2016), while vertically it is evenly distributed throughout the upper 350 m of the water column, which improves the properties of the Winter Water layer without producing excessive stratification. Moorman et al. (2026) adopt the same approach as Naughten et al. (2022). We have therefore rephrased the corresponding sentence to clarify that most ocean models still do not inject iceberg freshwater flux at depth.

L34: If this value is intended to represent an observational or satellite-derived estimate, a reference such as Dowdeswell and Bamber (2007) may be more appropriate.
(https://doi.org/10.1016/j.margeo.2007.04.008)

Thank you for this comment. Dowdeswell and Bamber (2007) highlight the three typical ranges of Antarctic iceberg keel depth distribution. These ranges are also reported in Olivé Abelló et al. (2025) from BedMachine version 3 (Morlighem et al., 2020). Our original sentence was intended to emphasise the substantial depth at which iceberg freshwater can be released, rather than adding only at the ocean surface. We were particularly surprised by the maximum keel depth of 678 m found for the eastern Getz Ice Shelf, implying a total iceberg thickness exceeding 700 m once the freeboard is included. We have therefore revised the sentence and added the corresponding reference.

L57: The text states that "Amaral Wasielesky (2025) made the first attempt in numerical ocean models to release the total iceberg melt," but Naughten et al. (2022) also appears relevant. Could you please verify this and revise the sentence if necessary? We clarified that Naughten et al. (2022) and Moorman

et al. (2026) also injected iceberg meltwater at depth over the first 350 m using the MITgcm ocean model. Then, we modified the previous sentence to clarify and specify that Amaral Wasielesky (2025) made the first attempt in the NEMO ocean model.

L201–209: The changes in the Weddell Sea are large and can be read off Figure 1, but the changes in the Amundsen Sea in particular are difficult to discern. Would it be possible to add a difference panel to Figure 1?
We agree that the differences between some sectors were hard to identify in the original panels. We have added the corresponding pie chart differences (panel c, 3SURF − PRE) to Figure 1, where the gains (orange) and losses (grey) in the three melting components can be appreciated, facilitating comparison between the two simulations.

L210–214: Could these values be tabulated in Table 2?
Sure, thank you for the suggestion. We have added the iceberg freshwater fluxes for all sectors separated into inshore and offshore contributions, including the difference between the alternative and pre-existing parameterizations to Table 2.

L218–220: This passage would benefit from a figure reference—presumably Figure 2g,h?
We have now added a direct reference to the corresponding panel (g) in Figure 2, making it clear exactly which panel's results are being described.

L218–220: In Figure 2d, wave-induced ablation appears to increase in some locations and decrease in others. It might be informative to plot panels like Figure 2g,h separately for each of the regions shown in Figure 1. From Figure 1 and Table 2, the effect of wave-induced ablation appears to decrease overall in 3SURF, but the seasonal variability may well differ between regions.
We have added a Figure in the Supplementary Information, named Figure S2, representing wave-induced ablation for each region. Generally, the alternative parameterization preserves the seasonal evolution observed in PRE across all sectors, with maxima during the austral summer months and minima in winter. Over the Weddell sector, the iceberg wave-induced ablation input dominates, whereas the Australian and Indian sectors show the largest differences between experiments. The remaining Ross, Amundsen, and Bellingshausen sectors contribute comparatively little and exhibit a shorter ablation season.

L220–224: Using Figure 2g,h to explain the difference between PRE and 3SURF is a little hard to follow because the two cases are shown separately. It would help to provide a plot directly comparing PRE and 3SURF—for example, a line plot of wave erosion with both experiments shown together—even if only in the supplementary material.
The first panel of the new Figure S2 in the Supplementary Information corresponds to the total freshwater flux from wave-induced ablation for 3SURF and PRE as recommended.

L220–224: In Figure 2g,h, making the colours for wave erosion, basal melt, and lateral melt more consistent, or adding common markers, would clarify the correspondence and improve readability.
Done. We have added common markers in the panels to improve the readability.

L227–228: It would help to indicate the relevant location(s) in the figure with an arrow.
Done.

L271–273: Can the values of 143 Gt yr^{-1} and 102 Gt yr^{-1} be read off Figure 5g,h,i?
The total values above and below the mMLD have been added below each pie chart to help the reader estimate where these values came from.

L278–279: Mizobata et al. (2025) may also be relevant in this context. The authors may wish to consider whether this study should be cited here.
Thanks for the recommendation. As the suggested manuscript mainly focuses on the oceanic response to positive SAM conditions in East Antarctica and does not discuss effects on mixed-layer depth, we have chosen not to cite it, as this could confuse the reader.

L286–288: Why do the temperature and salinity of AABW increase (warming and salinification)? I would have expected that, if AABW formation weakened as a result of reduced sea-ice production, both temperature and salinity would decrease. Could you clarify?
Our analysis does not allow us to affirm whether AABW formation weakens, as we assess SLB-3SURF changes in bottom temperature and salinity rather than transport anomalies or AABW formation rates. In fact, Figure 8a shows increased sea-ice production in the East Ross sector, which is consistent with enhanced brine rejection and could therefore explain the slight increase in salinity.

L296–299: Focusing on 60°E–180°W, why does the warming relative to 3SURF follow the order SLB > 2L1B > 3LAT? Some explanation would be helpful.
In the 60°E–180°W sector, although SLB shows the smallest fraction of meltwater injection at depth compared to 2L1B and 3LAT, it produces the strongest warm and saline bottom anomaly offshore (relative to 3SURF). Looking at the depth-integrated freshwater input in the region (Figure below), the differences between 2L1B and 3LAT relative to SLB seem to arise from the considerable amount of additional freshwater released in the western Ross Sea. This tends to freshen the relatively warm and saline dense-shelf water (DSW) on the Ross continental shelf, also inside the cavity, thereby reducing its density and weakening its cascading off-shelf. A possible explanation is that when subsurface freshwater injection is limited (SLB), HSSW production is slightly enhanced, maintaining saltier waters within the cavities and promoting DSW cascading. In contrast, when more freshwater is injected, also at depth, it can reduce HSSW production and maintain fresher and colder conditions near the seafloor. However, given the complexity of these interacting processes, we prefer not to provide a specific mechanistic interpretation in the manuscript.

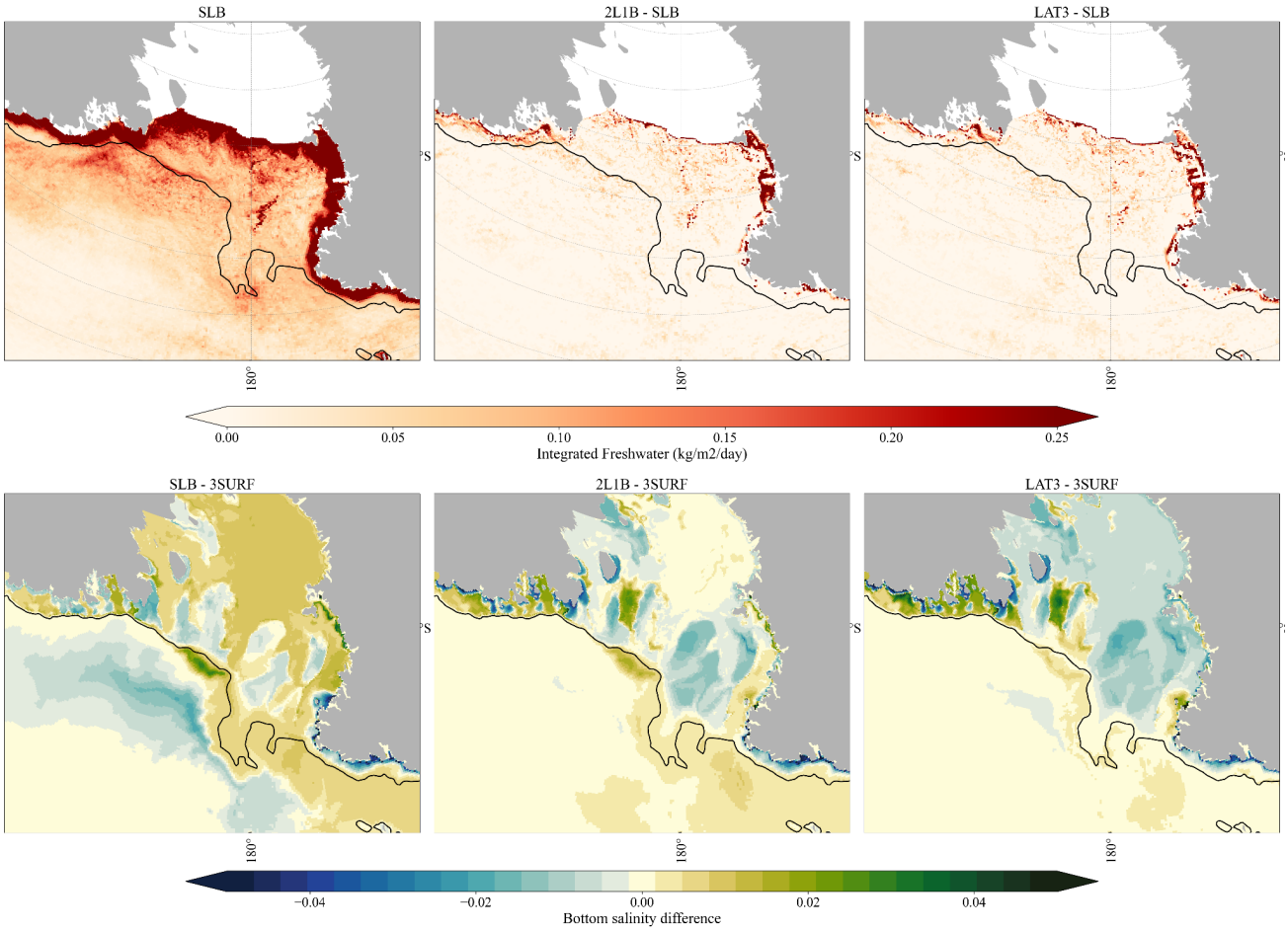


Figure. Spatial distribution of iceberg-derived freshwater input and its impact on bottom salinity over the Ross Sea sector. Top row: vertically integrated iceberg freshwater flux (kg m^{-2} day^{-1}) for SLB (left), and differences between 2L1B and SLB (middle) and 3LAT and SLB (right). Bottom row: bottom-salinity differences relative to 3SURF for SLB (left), 2L1B (middle), and 3LAT (right). The black contour indicates the continental shelf break.

L334–338: The increase in open-water area would be worth showing in a figure. Comparing sea-ice concentration between experiments could be one possible approach.

We agree. We have added new panels in Figure 8 showing the sea-ice concentration between experiments. Generally, the areas with negative sea-ice concentration anomalies over the Antarctic continental shelf coincide with thinner and more productive regions, supporting our statement that increased freshwater release along the water column promotes enhanced vertical mixing, more heat loss to the atmosphere, and the maintenance of open-water areas free of ice.

L342: Throughout the paper, many specific regional and ice-shelf names appear (e.g., Drygalski, Prince Harald, and Larsen D ice shelves). To aid the reader, it would help to indicate their locations on a figure.

We have added the names we mention in the text to Figure 8e.

L342: Sea-ice production and sea-ice thickness do not always appear to coincide. Could the authors clarify the relationship between these two variables?

Sea-ice thickness is influenced by sea-ice production, since thermodynamic freezing increases sea-ice volume and therefore thickness. Indeed, in the NEMO SI³ manual it is specified: "Ice growth in open water section (ice_thd_do) converts negative heat available for freeze-up into a volume of new sea ice and assigns this new ice a thickness, an area, enthalpy, and salt concentration, and redistributes these into relevant ice categories." However, thickness is not determined by production alone because it is

also modified by ice transport, convergence/divergence and mechanical redistribution. Consequently, regions of high sea-ice production do not necessarily coincide with regions of thick sea ice. For example, coastal polynyas can sustain high thermodynamic ice production while remaining characterized by thin ice or open water because newly formed ice is continuously exported, whereas convergence and mechanical redistribution can produce thick ice in regions with relatively low local thermodynamic production. We have now clarified the relationship between sea-ice production and sea-ice thickness in Lines 363–365 of the revised manuscript.

L344–349: This sentence is rather long and could be made more concise. In addition, to support these statements, it would be helpful to clearly show the enhancement of sea-ice divergence and export in a figure.
We agree. We have divided the original sentence into two to improve readability. To further support this interpretation, we have added sea-ice divergence and sea-ice volume transport (ice volume per unit area × velocity) anomalies to the Supplementary Information (Figure S6), focusing on the coastal region south of the Drygalski Ice Tongue. The results show enhanced northward sea-ice volume transport along the coast as more meltwater is injected at subsurface levels, consistent with enhanced sea-ice export from the region. In contrast, sea-ice divergence anomalies are spatially heterogeneous and do not exhibit a clear spatial pattern. We have revised the corresponding results section accordingly (Lines 375 – 378).

L354–355: Would it be possible to include the locations of other ice shelves across Antarctica in the figure as well, to provide a broader geographical context?
To provide broader geographical context, we have added a small overview map of the Antarctic continent indicating the areas shown in the enlarged panels.

Figure 1: The text is too small in many places. This applies not only to Figure 1 but to the other figures as well—please adjust the font sizes appropriately (e.g., "(a)", "(b)", "PRE", "3SURF"). The legends also seem small. In addition, for the pie charts, removing "Gt yr^{-1}" and showing only the numerical values would improve readability.
We have adjusted the font sizes in the old Figure 1 and other figures and increased the legend size.

Figure 2: The orange dashed line appears to indicate the −1.8 °C isotherm, but it is shown as a solid line in the legend.
Done.

Figure 7: The temperature and salinity profiles for 3SURF are both shown as solid black lines, which makes them somewhat difficult to distinguish. Could the authors consider using different line styles or other visual adjustments to improve the clarity of the clarity?
We agree that some of the profiles can be difficult to distinguish, as the differences between experiments are small and the lines almost overlap. We explored alternative visual representations, including different colours and line styles, but found that these changes did not improve the figure's clarity and, in some cases, made the profiles even harder to distinguish. For these reasons, we have chosen to retain the current representation.

Technical corrections
L342: "Figure 8d,f,g" appears to be a typo.
Fixed.