Answer to comments by reviewer #1

The formation of deep and bottom waters on the continental shelf in the Weddell Sea is a key mechanism for sequestering carbon and exporting heat to the abyssal layer. This study by Nissen et al. explores the pathways of warm waters onto the shelf and dense waters flowing off the shelf under both historical and future conditions. They used output from the global ocean-sea ice model FESOM-1.4 to conduct Lagrangian experiments in the Weddell Sea in 1990-2009 (historical period) and in 2080-2099 under the high-emission scenario SSP5-8.5 (future period). The depth where particles reach the Filchner Ice Shelf front and where they originated in the open ocean and crossed the shelf break is evaluated as well as the pathways. In the historical period, particles mostly reach the ice shelf front within the upper 200 m and originate from the upper open ocean, suggesting weak inflow of modified Circumpolar Deep Water into deeper parts of the ice shelf cavity. Under a high-emission scenario, more particles reach the ice shelf front by the end of the 21st century, originating from greater depths offshore and reaching the ice shelf front at greater depth compared to the historical period. This increased onshore transport has important implications for future ice shelf basal melt rates and deoxygenation. In the future period, the transit time from the shelf break to the ice shelf front decreases by 6 months and cross-shelf flow becomes more likely in winter. Particles leave the Filchner Ice Shelf front mostly below 600 m (that would be within the ice shelf cavity), flow down the western shelf break of the Weddell Sea and enter the open ocean as dense waters mostly below 800 m. In the future period, the particles trajectories are overall shallower and especially in the open ocean the depth reached by the particles is greatly reduced with only 60% below 500 m and none below 1500 m, but their horizontal distribution is similar. Most particles reside on the shelf for a year and leave the shelf in autumn and winter in the historical period, while in the future period the median residence time on the shelf is 21 months and spring is as important as winter for the export across the shelf.

This is an interesting study and important contribution regarding the cross-shelf transport in the Weddell Sea using Lagrangian methods for the first time. The manuscript is very well structured and written with the figures illustrating the results and supporting the conclusions. I have a few minor suggestions which might help to further improve the manuscript.

As a paper should be self-contained, more details should be given when referring to results from your previous papers (Nissen et al., 2022, 2023) which are fundamental for understanding the conclusions. Especially the mechanisms for the changing pathways in the future period are not discussed in much detail and this leaves readers with open questions when they are not fully aware of these previous studies. Overall, I think that this manuscript is a valuable contribution to the community and should be published in Ocean Science after some minor revisions detailed below.

We thank the reviewer for the positive feedback on our study. We have revised the manuscript according to the reviewer’s comments and suggestions. Please see below for more detail.

Specific comments:

ll. 6-11: Rearranging these sentences (and potentially including additional results) would clarify the results and the conclusions made. The results should be described more clearly by e.g., referring to depth changes in meters as well. In addition, the implications could directly follow individual results and not be stated a few sentences afterwards.

We have modified this part of the abstract as suggested, and it now reads:

“We show that particles reaching the ice-shelf front from the open ocean originate from 173% greater depths by 2100 (median; 776 m as compared to 284 m for the present-day), while waters leaving the cavity towards the open ocean end up at 35% shallower depths (550 m as compared to 850 m for the present-day). Pathways of water leaving the continental shelf increasingly occur in the upper ocean, while the on-shelf flow of waters that might reach the ice shelf cavity, i.e., at deeper layers, becomes more important by 2100. Simultaneously, median transit times between the Filchner Ice Shelf front and the continental shelf break decrease (increase) by 6 (9.5) months in the backward (forward) experiments. In conclusion, our study demonstrates the sensitivity of regional circulation patterns in the southern Weddell Sea to on-going climate change, with direct implications for ice-shelf basal melt rates and local ecosystems.“

ll. 84-85: A few sentences should be added on what has been evaluated in Nissen et al. (2022, 2023) and what biases were found to make the paper more self-contained.

We have added a sentence summarizing the outcomes of earlier evaluations of the model simulation:

“Acknowledging that the strength of the Weddell Gyre in the FESOM1.4 simulation is biased low compared to estimates based on Argo floats (Reeve et al., 2019), water-mass distributions and water-mass transformations were shown to overall agree well with observations. In the context of this study, we note the high-density bias of the WDW core in the open ocean, which possibly makes the southern Weddell Sea continental shelf too susceptible for an on-shelf flow of WDW during the 21st century.”

ll 174-176: Be more specific about the mechanisms detected in Nissen et al. (2022, 2023), e.g., increasing on-shelf heat transport with negative cross-shelf break density gradient in future period.

We have added a sentence to explain the mechanisms at play:

“The overall enhanced future on-shelf transport is facilitated by a reversal of the cross shelf-break density gradient by the end of the 21st century (Nissen et al., 2023).”

Figures 2 and 6: These figures illustrate the results really well, but they could be improved. The thickness of the arrows doesn’t seem to be “scaled with the relative importance of different depth intervals for the origin of these waters before the crossing and their fate after the crossing, respectively”, as stated in the figure caption. For example, in Fig. 2a the thick blue and yellow arrows representing flow from the open ocean on to the shelf in the upper layer should represent about 80% of the particles but this is not represented by their combined thickness. Can you depict the changes in the vertical distribution offshore better by changing the position of the arrow at the right axis of panel a and e? For example, in Fig. 6e the red arrow should point at a shallower depth offshore (approximately 600-700m) compared to panel a. In my opinion the size of the figure is too small, especially the text in panel a and e is hard to read, and the lower panels should be enlarged. This could be achieved by having the panels corresponding to the historical and future simulations in separate rows instead of columns.

We appreciate the reviewer’s feedback and suggestions. We have revised the Figure by making better use of white spaces and by increasing font sizes in all panels (see Fig. 1 & 2 below). We note that there was a misunderstanding in how the arrow thickness is scaled in this figure. The scaling corresponds to the relative contributions within each color, i.e., within each depth interval at the shelf-break crossing. This means that the scaling of the blue and yellow arrow in the upper layer cited by the reviewer are scaled relative to their contribution to particles crossing the shelf in the upper (blue) and middle (yellow) layer, respectively. Their thickness thus indicates that the vast majority of the particles crossing the shelf break in the upper and middle layer originate from the uppermost layer in the open ocean. We have revised the figure caption to enhance clarity. The respective sentence in the Figure captions of the revised Fig. 2 & 6 in the manuscript reads:

“The arrows are colored depending on the depth level at the shelf-break crossing, and for each color, their line thickness is scaled with the relative importance of different depth intervals for the origin of these waters before the crossing and their fate after the crossing, respectively.“

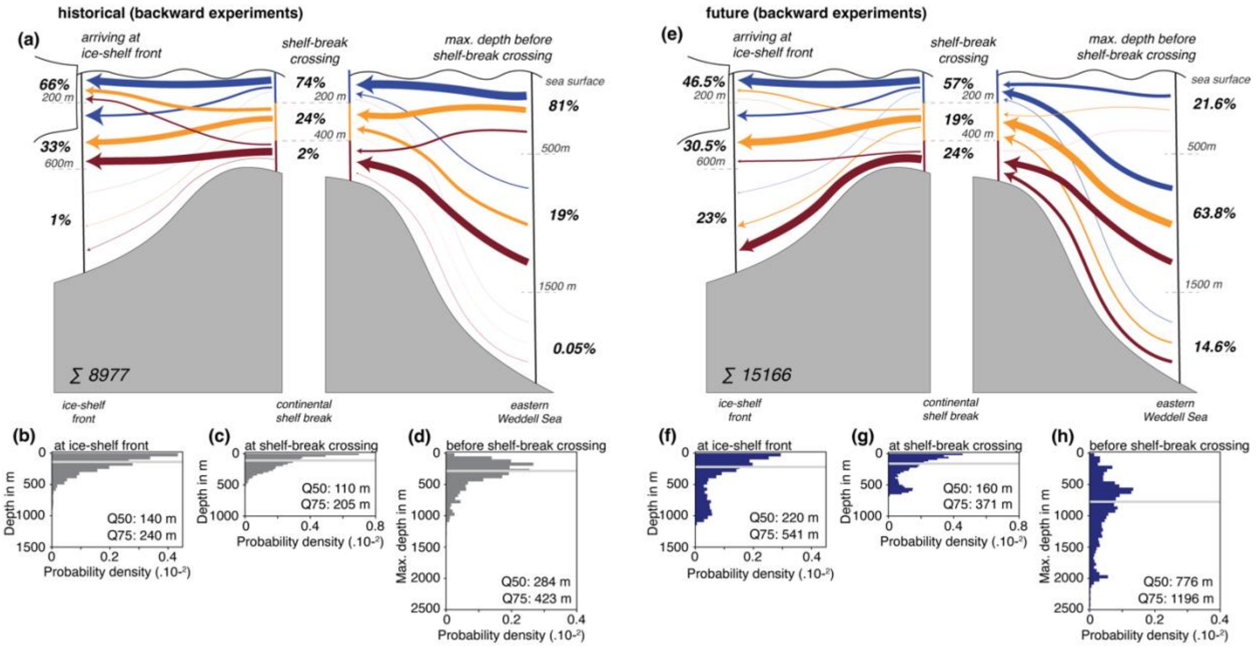

Fig. 1: Revised Fig. 2 of the manuscript.

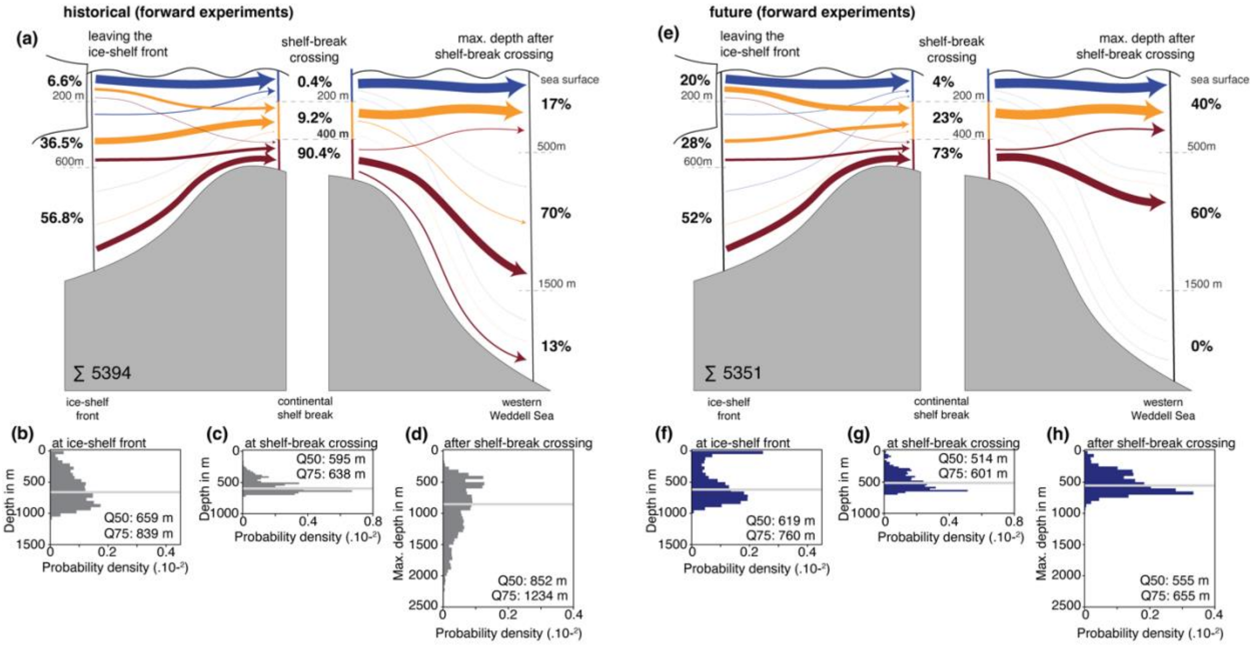

Fig. 2: Revised Fig. 6 of the manuscript.

ll 271-273: Be more specific about what changes were detected in Nissen et al. (2022), e.g., reduced ventilation rate along the slope, reduced surface water mass transformation and decline in density in future period.

We have added a sentence to explain the mechanisms at play:

“The reduced density of newly formed dense waters is mainly caused by the freshening of waters on the continental shelf as a result of reduced sea-ice formation and enhanced ice-shelf basal melt and results in reduced ventilation of bottom waters along the Weddell Sea continental slope (Nissen et al., 2022).”

Technical comments:

caption of Fig. 1: Include description of black and grey contours in the figure caption.

Changed as suggested, and the respective part of the new caption reads:

“Blue colors display the bottom topography in the area (based on RTopo-2; Schaffer et al., 2016), while the black and grey lines denote the 700 m isobath and the ice-shelf front, respectively.”

ll 309: Be more specific, what percentage of particles is referred to as “sizeable”?

We rephrased this sentence to now read:

“Specifically, the maximum depth that particles reach after leaving the continental shelf in our forward experiment exceeds 3000 m, and ~13% of particles reach a depth >1500 m for the historical period.”